48 Extension Note

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Ten-year Conifer and Vegetation Responses to Glyphosate Treatment in the SBSdw3

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Introduction

In forestry, vegetation management treatments are widely used to ensure establishment of young stands and achievement of free-growing requirements. In 1996/97, approximately 72 529 ha of Crown forest land received brushing treatments to ensure establishment and growth of young seedlings at a cost of $34.3 million (B.C. Ministry of Forests 1998a). During the past two decades, research on the silvicultural implications of vegetation management has focused on short-term information needs to support forest stand establishment operations. However, long-term growth and yield gains and economic returns are still unknown. The demand for long-term information in relation to key forest management issues (e.g., free-growing, green-up, growth and yield, biodiversity, stand dynamics, and stand structure) has also increased substantially due to recent changes in provincial forestry legislation and policy (B.C. Ministry of Forests 1995).

In the late 1980s, a region-wide network of operational herbicide monitoring sites was installed in the Prince George Forest Region to study the impacts of vegetation control treatments on trees and vegetation communities (Hays 1990). This extension note reports the 10-year post-treatment results of the study site near Tsilcoh River (Aspen Block) in the Fort St. James Forest District.

The purpose of measuring this trial in 1998 was:

- to assess the long-term effects of glyphosate treatment on growth of white spruce,
- to document the number of well-spaced and free-growing spruce 11 years after planting,
- to assess the impacts of glyphosate treatment on the development of the vegetation community, and
- to assess the impact of glyphosate treatment on mixed-stand timber yield.

Study Site

The study site is classified as the Stuart variant, Dry Warm subzone of the Sub-Boreal Spruce biogeoclimatic zone (SBSdw3) (DeLong et al. 1993). The site has medium to good productivity, mesic moisture regime, mesotropic nutrient regime, well- to moderately well-drained soils, elevation of 1075 m, and average slope of 10% facing east-southeast. The site association is SxwFd-Pinegrass (01 site series).

In 1971, a stand dominated with mature hybrid spruce was logged using a clearcut silvicultural system. Prior to planting, mechanical site preparation treatments (i.e., cable knockdown and winter shearing) were applied to clear the natural vegetation. In 1987, 1-year-old (1+0 PSB 313) white spruce (*Picea glauca*) seedlings were planted at a 2.9 m espacement.

Research Approach

At the study site, two 100 × 100 m (1 ha) treatment plots with a minimum 10 m buffer on all sides were established in July 1988. The herbicide glyphosate (Roundup®) was applied aerially at a rate of 2.14 kg a.i./ha in one of the treatment plots on August 15, 1988. Glyphosate was applied to control the primary target species, trembling aspen (*Populus tremloides*), Sitka alder (*Alnus viridis* spp. *sinuata*), and black twinberry (*Lonicera involucrata*).

Within each treatment plot, 100 white spruce seedlings were selected at a 10 × 10 m grid using a systematic selection technique. Seedlings were measured in years 0 (pre-treatment), 1, 2, 3, 4, 5, and 10. Measurements included total height, basal diameter, and crown diameter. Spruce seedlings were also assessed qualitatively for vigour. During the summer of 1998, four 3.99 m radius (0.005 ha) regeneration measurement plots (RMPs) were established in each treatment plot using EXPLORE methodology (Biring et al. 1998) to collect vegetation community data (species percent cover and modal height) and stand data (density and free-growing).

To project long-term treatment plot yield, the Mixedwood Growth Model (MGM) version 98E (Titus 1999) was used for yield simulations. MGM is a deterministic, distance-independent, individual-tree-based stand growth model developed to project yield of white spruce and aspen growing together in varying mixtures in boreal forests. Whether MGM is an appropriate model for yield simulations in the SBS zone is uncertain, because MGM has not been calibrated or validated for use in this zone. However, for conifer-broadleaf complex mixedwood stands in the SBS zone, no other quantitative models are currently available to explore the long-term yield.

Statistical analysis included a one-way analysis of variance (ANOVA), analysis of covariance (ANCOVA), and a chi-square (χ^2), which was calculated using SAS statistical software (SAS Institute Inc. 1990). Data from tagged spruce seedlings and four RMPs in each treatment area were considered an experimental unit and used as replicates (pseudo-replicates) to test for significant differences between treatment means. Analysis results based on pseudo-replication must be interpreted cautiously, since differences in vegetation and differences in site factors between plots confound treatment differences.

Results and Discussion

Results from this study site are discussed in relation to forest management objectives or key issues that are important for stand establishment and beyond, including free-growing, stand development, vegetation community response, and stand growth and yield.

White Spruce Growth Response

Ten years after treatment, glyphosate treatment had a measurable effect on white spruce diameter and height growth parameters (Table 1). The significant differences in basal diameter and height first appeared 1–2 years after treatment and continued thereafter. Crown radius and stem volume were also significantly greater in the glyphosate treated plot than in the untreated control plot (Table 1, Figures 1 and 2). These results suggest that increases in height and basal diameter of white spruce after glyphosate application are consistent with results reported in other studies (Sutton 1995; Harper et al. 1997; Biring et al. 1999).

Various studies indicate that increased vegetation competition reduces diameter growth more rapidly in relation to height growth, resulting in a higher height-to-diameter ratio (HDR). In this study, glyphosate treatment significantly reduced the HDR of spruce seedlings (Table 1).

Glyphosate treatment improved white spruce vigour. Ten years after treatment, 46% of white spruce seedlings in the glyphosate-treated plot exhibited moderate vigour compared to 29% in the untreated control plot. Most of the seedlings (52%) in the untreated control plot exhibited poor vigour compared to 28% in the treated plot.

Establishment to Free-growing

Ten years after treatment, white spruce survival for planted seedlings was high (>84%) in both treated and untreated control plots. Spruce density (total and well-spaced includes naturals and ingress) was not significantly different between the two treatments (Table 2). Both plots meet the minimum stocking (700 sph) requirements based on current free-growing stocking standards for the Prince George Forest Region (B.C. Ministry of Forests and BC Environment 1995) (Table 2). However, the herbicide treatment

TABLE 1 *Means and standard deviations for basal diameter, total height, height-to-diameter ratio, crown radius, and volume for white spruce*

Variable	Treatment	1988	1989	1990	1991	1992	1993	1998
Basal diameter (mm)	Glyphosate	4.9±0.7	6.5±1.5	8.8±2.9	11.1±3.1	13.6±4.2	17.0±5.3	36.9±15.2
	Control	4.6±1.0	5.6±1.2	7.1±2.0	8.4±2.3	8.8±2.8	11.0±4.1	21.2±11.8
	p-value[a]	0.022	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Height (m)	Glyphosate	0.29±0.06	0.34±0.09	0.47±0.14	0.54±0.15	0.66±0.18	0.80±0.25	1.88±0.72
	Control	0.29±0.07	0.34±0.09	0.43±0.11	0.47±0.13	0.53±0.17	0.63±0.23	1.33±0.7
	p-value	0.93	0.80	0.009	0.0001	0.0001	0.0001	0.0003
Height- to-diameter ratio	Glyphosate	59.8±10.4	51.8±11.4	55.3±13.0	49.6±9.7	49.3±8.6	47.7±10.4	52.8±10.5
	Control	64.2±14.4	61.2±13.1	63.6±18.4	56.7±13.1	61.7±14.0	61.6±46.5	63.3±15.3
	p-value	0.016	0.0001	0.004	0.0008	0.0001	0.018	0.0007
Crown radius (cm)	Glyphosate	no data	0.084±0.029	0.119±0.037	0.114±0.04	0.123±0.035	0.193±0.064	0.472±0.174
	Control	no data	0.083±0.025	0.095±0.03	0.077±0.031	0.093±0.034	0.154±0.051	0.339±0.174
	p-value	–	0.71	0.0001	0.0001	0.0001	0.0001	0.0004
Volume (m^3/ha)	Glyphosate	0.0023±0.001	0.0048±0.003	0.014±0.02	0.045±0.207	0.044±0.045	0.082±0.074	0.978±1.02
	Control	0.0021±0.0012	0.0037±0.0021	0.008±0.006	0.012±0.009	0.016±0.017	0.030±0.032	0.333±0.55
	p-value	0.31	0.0019	0.0035	0.14	0.0001	0.0001	0.0003

a 1988 p-values from ANOVA, 1989–1998 p-values from ANCOVA, and crown radius p-values (1988–1998) from ANOVA.

subsequently increased the number of free-growing white spruce. Eleven years after planting, 950 white spruce per hectare meets the minimum free-growing requirements (B.C. Ministry of Forests and BC Environment 1995) in the glyphosate-treated plot. Data from the untreated control plot indicate that the spruce stand is not free-growing (Table 2) and requires further treatment to meet the free-growing standard.

The proposed use of coniferous HDR and broadleaf stem density criteria to determine free-growing status in the Prince George Forest Region (B.C. Ministry of Forests 1998b) was also examined. Based on density and HDR criteria, 650 sph were free-growing in treated plots as compared to untreated, where trees were not free-growing due to high broadleaf density (>1000 sph) (Table 2).

Broadleaf Stand Development

Ten years after treatment, broadleaf density in the glyphosate-treated plot was significantly lower than in the untreated control plot (Table 2). Trembling aspen was the only broadleaf species found in both the untreated control and glyphosate-treated plots (Table 2).

The absence of vegetation control resulted in a two-storey mixed-wood stand with trembling aspen up to 8.4 m tall in the overstorey and 1.25 m tall suppressed white spruce in the understorey. If the management objective is to achieve an acceptable conifer-dominated stand at the end of the rotation, further treatments (e.g., brushing and spacing of broadleaf species) will be needed.

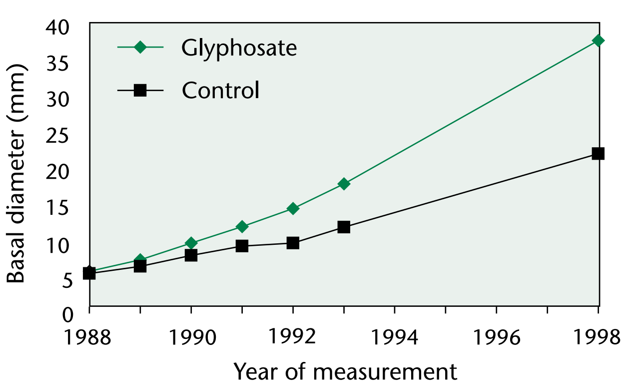

FIGURE 1 *Effects of treatment on basal diameter of white spruce, 1988–1998.*

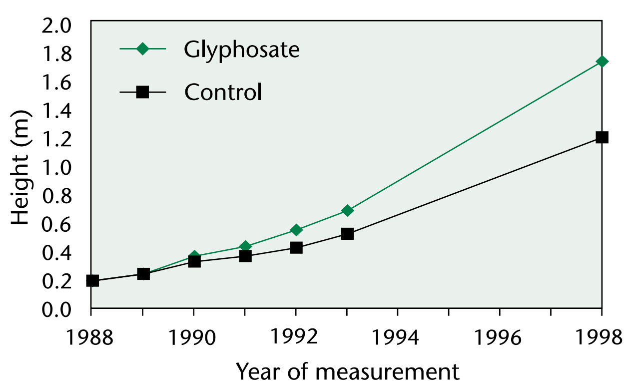

FIGURE 2 *Effects of treatment on height of white spruce, 1988–1998.*

TABLE 2 *Means and standard deviations for density: stand, conifers, trembling aspen, white spruce, other conifers, spruce well-spaced, spruce free-growing, and spruce free-growing based on (D+HDR) criteria, 11 years after planting*

Treatment	Stand (sph)	Conifers (sph)	Trembling aspen (sph)	White spruce (sph)	Other conifers (sph)	White spruce well-spaced (sph)	White spruce free-growing (sph)	White spruce free-growing (D+HDR)[a] (sph)
Glyphosate	3800±2525	2700±1291	1100±1311	1850±597	850±772	1150 ±443	950±473	650±854
Control	21600±7326	1400±566	20200±7888	1300±529	100±115	1200±163	0	0
p-value[b]	0.60	0.11	0.003	0.22	0.10	0.84	0.007	0.18

a Proposed Density (D) + Height-to-diameter ratio (HDR) criteria to determine free-growing.
b P-values from ANOVA.

Vegetation Community Responses

A count of vegetation species was used to determine species richness in each treatment plot. Species richness was similar in both plots. In total, 42 and 44 species were found in untreated control and treated plots, respectively (Table 3). Based on lifeform classes, the largest number of species was present in the herb layer. Non-vascular plants were not sampled thoroughly enough to provide reliable information on this lifeform. Rare species may also have been missed because of the relatively small sample area.

Both treatment plots had similar plant species composition. There were five shrubs that differ between the treatments: prickly rose (*Rosa acicularis*) was found only in the treated plot, whereas black currant (*Ribes laxiflorum*), red elderberry (*Sambucus racemosa*), soopolallie (*Shepherdia canadensis*), and birch-leaved spirea (*Spirea betulifolia*) were found in the control plot. While all of these species are perennial, all but red elderberry have the potential to affect the future development of the vegetation complex because they are not among the more common characteristic shrubs of this subzone (DeLong et al, 1993). These shrubs are, however, native to British Columbia.

Plant species abundance showed some distinct differences between the plant communities in the two treatments. The treated area had a lower percent cover of broadleaves and shrubs, and a higher cover of herbs and conifers than the control area (Table 3, Figures 3 and 4). Ten years after treatment, trembling aspen percent cover and density were significantly lower than in the untreated control plot. However, Sitka alder and fireweed (*Epilobium angustifolium*) were controlled for the first few years after treatment, but by age 10 they were more predominant in the treated plot than in the control plot (Figure 4). Assuming that the plant communities were the same before treatment, these results indicate that glyphosate shifted the plant community to herbs and conifers by reducing the cover of broadleaf trees.

Mixed-stand Timber Yield

Ten years after treatment application, the increases in spruce diameter and height growth have resulted in significantly larger spruce stem volume within the glyphosate-treated plot (Table 1). Yield projections based on MGM simulations suggest that glyphosate application can increase the conifer volume by up to 235% and reduce the rotation age by up to 30 years (at maximum mean annual increment) compared with the untreated control (Table 4). However, the glyphosate treatment also reduced broadleaf timber volume by up to 92% compared with the untreated control plot. If both stands are harvested using a two-pass harvesting system, the notable differences are shorter conifer rotation, more conifer volume, and less aspen and total volume in the treated plot compared to the untreated control plot (Table 4). In a two-pass system, 15% aspen density is retained during the first-pass harvesting (i.e., at 50 years) to maintain wind stability of the

TABLE 3 *Means and standard deviations for percent cover: total, conifers, trembling aspen, shrubs, and herbs, 10 years after treatment application in the summer of 1998*

	Total		Conifers		Trembling aspen		Shrubs		Herbs	
Treatment	% cover	No. of species[a]	% cover	No. of species	% cover	No. of species	% cover	No. of species	% cover	No. of species
Glyphosate	94.8±3.7	44	25.0±12.9	2	3.8±4.8	1	46.3±19.7	11	57.5±25.0	26
Control	90.8±7.9	42	9.3±4.3	2	46.3±17.0	1	53.8±18.8	14	28.8±14.4	22
p-value[b]	0.39	-	0.06	-	0.003	-	0.60	-	0.09	-

a Total number of species include lichens and mosses.
b P-values from ANOVA.

FIGURE 3 *A vegetation community in an untreated control plot (August 26, 1998).*

FIGURE 4 *A vegetation community in a glyphosate-treated plot (August 26, 1998).*

TABLE 4 *Stand yield projections derived from the Mixedwood Growth Model*

	Trembling aspen (first pass) (A)			Trembling aspen (second pass) (B)		Conifers[a] (second pass) (C)			Stand yield (A+B+C) (two passes)	Stand yield (one pass/clearcut @ 90 yr)			Stand yield @ 90 yr from VDYP[b]
Treatment	Vol. (m^3/ha)	MAI[c] (m^3/ha)	Age (yr)	Vol. (m^3/ha)	Max. MAI (m^3/ha)	Vol. (m^3/ha)	Max. MAI (m^3/ha)	Rotation (yr)	(m^3/ha)	Conifer (m^3/ha)	Broad-leaves (m^3/ha)	Total (m^3/ha)	Total (m^3/ha)
Glyphosate	38	1.0	50	5	0.1	356	5.1	70	399	384	24	408	438
Control	499	12.5	40	135	1.4	106	1.1	100	740	56	483	539	412

a Conifer species: white spruce; subalpine fir.
b VDYP = Variable Density Yield Prediction model.
c MAI = mean annual increment.

spruce, and then the aspen is harvested in the second pass along with the spruce. However, if both plots are clearcut at 90 years of stand age, the conifer yield is more and the aspen yield is less in the treated plot compared to the untreated control plot (Table 4). Since aspen is expected to occupy the site at least to maturity, it is logical to include broadleaf volume in the total yield analysis. However, the stand at this stage is very dynamic, and various changes (e.g., reduction in aspen density) will have yield implications in the future.

Conclusions

The results from 10-year measurements suggest that:

- controlling competing vegetation using glyphosate 1 year after planting increased white spruce height and basal diameter, reduced height-to-diameter ratio, and improved vigour,
- glyphosate treatment significantly improved white spruce height and the number of free-growing spruce per hectare 11 years after planting,
- glyphosate treatment significantly reduced broadleaf percent cover and density,
- glyphosate treatment did not affect species richness or total number of species, and
- glyphosate treatment applied to control trembling aspen and shrubs has the potential to increase conifer yield, and to reduce conifer rotation age.

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