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Pinchi Lake Operational Herbicide Monitoring: 10-year Conifer and Vegetation Responses 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, 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. This extension note reports the 10-year post-treatment results of the study site near Pinchi Lake in the Fort St. James Forest District.

The purpose of remeasuring this trial was:

- to assess the long-term effects of a glyphosate treatment on growth of white spruce,
- to document the number of well-spaced and free-growing spruce 14 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 productivity, mesic moisture regime, mesotropic nutrient regime, predominantly sandy

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loam soils with an LFH of 5–20 cm, elevation of 1075 m, and average slope of 5% facing northwest. The site association is SxwFd-Pinegrass (01 site series).

In 1983, a mixed stand of mature hybrid spruce and interior lodgepole pine present at the site was logged using a clearcut silvicultural system. In May 1984, white spruce (*Picea glauca*) (1+0 PSB 211) and Douglas-fir (*Pseudotsuga menziesii*) (2+0 BR) were planted at a 2.7 m espacement. Four years after planting (1988), the site had a multi-storey canopy consisting of trembling aspen (*Populus tremloides*) and Sitka alder (*Alnus viridis* spp. *sinuata*) interspersed with willow (*Salix* spp.), balsam poplar (*Populus balsamifera* spp. *balsamifera*), prickly rose (*Rosa acicularis*), *Rubus* spp., grasses, and herbs.

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 broadcasted once at a rate of 1.8 kg a.i./ha using a backpack sprayer on August 15, 1988. Glyphosate was applied to control the primary target species, trembling aspen and Sitka alder.

Within each treatment plot, 100 white spruce seedlings were selected on 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 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 complex multi-species and/or 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) test, 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 treatment differences are confounded by differences in vegetation and differences in site factors between plots.

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

Starting 2 years after treatment (1990) until year 10 (1998), glyphosate treatment had a measurable effect on white spruce growth parameters. Basal diameter, height (except 1998), crown radius, and stem volume were significantly greater in the glyphosate-treated plot than in the untreated control plot (Table 1, Figures 1 and 2). Significant increase in basal diameter of white spruce after glyphosate application on this site is 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 other words, if a tree is competing for light it will allocate more carbon to the shoot system to reach for the light. However, when a tree is not competing for light it allocates more carbon to the main stem and increases diameter growth. In this study, glyphosate treatment significantly reduced the HDR of spruce seedlings (Table 1).

In 1998, 10 years after treatment, glyphosate improved white spruce vigour significantly. In the glyphosate-treated plot, 46% of white spruce seedlings exhibited good vigour compared to 12% in the untreated control plot. Most of the seedlings (67%) in the untreated control plot exhibited moderate vigour compared to 46% in the treated plot.

Establishment to Free-growing

White spruce survival 10 years post-treatment was high (>96%) in both treated and untreated control plots. Spruce density (total and well spaced) was not significantly different between the two treatments (Table 2). More than 1150 well-spaced spruce stems per hectare (sph) were tallied in both treatment plots, thus the plots are fully

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

Variable	Treatment	1988	1989	1990	1991	1992	1993	1998
Basal diameter (mm)	Glyphosate	11.7±0.3	17.4±0.5	24.5±0.6	27.4±0.7	31.5±0.8	39.8±1.0	84.7±3.7
	Control	10.4±0.4	13.1±0.5	18.2±0.7	19.0±0.7	22.7±0.8	28.2±0.9	62.2±3.2
	p-value[a]	*0.005*	*0.0001*	*0.0001*	*0.0001*	*0.0001*	*0.0001*	*0.0001*
Height (m)	Glyphosate	0.71±0.02	0.87±0.03	1.11±0.03	1.24±0.03	1.72±0.04	1.99±0.05	4.09±0.15
	Control	0.67±0.02	0.82±0.02	1.01±0.03	1.09±0.03	1.47±0.05	1.65±0.05	3.48±016
	p-value	*0.14*	*0.35*	*0.037*	*0.0004*	*0.0001*	*0.0001*	*0.054*
Height-to--diameter ratio	Glyphosate	62.3±1.3	51.7±1.1	45.7±0.8	46.4±0.9	56.3±1.1	50.6±0.8	49.4±1.0
	Control	65.5±1.2	64.0±1.4	57.5±1.1	59.4±1.3	66.6±1.4	59.3±1.0	56.9±1.7
	p-value	*0.07*	*0.0001*	*0.0001*	*0.0001*	*0.0001*	*0.0001*	*0.0003*
Crown radius (cm)	Glyphosate	0.17±0.004	0.22±0.01	0.23±0.01	0.31±0.01	0.30±0.01	0.42±0.01	0.87±0.03
	Control	0.15±0.004	0.20±0.01	0.19±0.01	0.24±0.01	0.27±0.01	0.32±0.01	0.71±0.03
	p-value	0.0001	0.32	0.0001	0.0001	0.29	0.0001	0.03
Volume (m^3 /ha)	Glyphosate	0.04±0.003	0.11±0.01	0.27±0.02	0.38±0.02	0.71±0.05	1.32±0.09	12.8±1.4
	Control	0.04±0.004	0.07±0.01	0.16±0.02	0.18±0.02	0.35±0.03	0.59±0.05	6.3±0.8
	p-value	*0.30*	*0.0001*	*0.0001*	*0.0001*	*0.0001*	*0.0001*	*0.0001*

[a] 1988 p-values from ANOVA, and 1989–1998 p-values from ANCOVA.

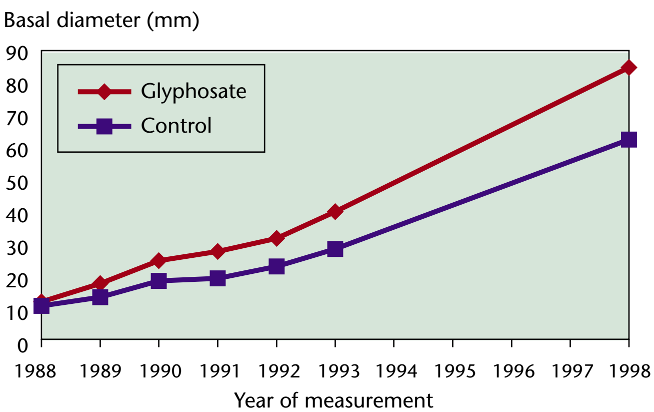

FIGURE 1 *Effects of treatment on basal diameter of white spruce, 1988–1998.*

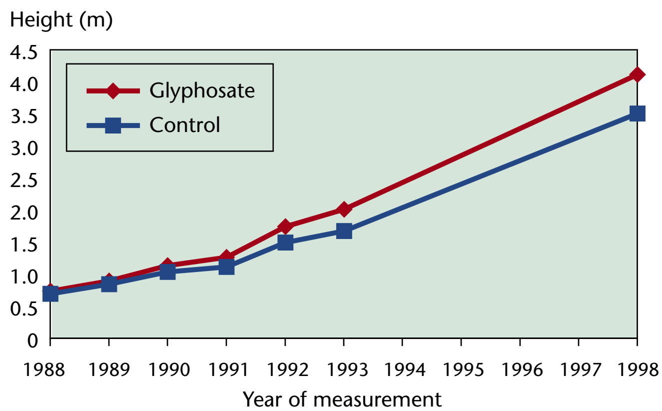

FIGURE 2 *Effects of treatment on height of white spruce, 1988–1998.*

TABLE 2 *Means and standard errors for density: stand, conifers, white spruce, other conifers, white spruce well-spaced, white spruce free-growing, and white spruce free-growing based on the proposed (D+HDR) criteria, 14 years after planting*

Treatment	Stand (sph)	Conifers (sph)	White spruce (sph)	Other conifers (sph)	White spruce well-spaced (sph)	White spruce free-growing (sph)	White spruce free-growing (Density + HDR criteria) (sph)
Glyphosate	3800±804	2300±351	2050±330	250±126	1350 ± 50	1150±150	300
Control	4400±735	1350±126	1250±96	100±58	1150±96	500 ± 129	0
p-value[a]	*0.60*	*0.044*	*0.06*	*0.32*	*0.11*	*0.017*	–

[a] p-values from ANOVA.

stocked 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 significantly increased the number of free-growing spruce. At this stage (14 years after planting), white spruce treated with glyphosate meets the minimum (1150 sph) free-growing requirements (B.C. Ministry of Forests and BC Environment 1995). Conversely, data from the untreated control plot (500 sph) 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) were also examined. Based on density and HDR criteria, neither control nor treated plots are free-growing due to high broadleaf densities (>1000 sph) (Table 3).

Broadleaf Stand Development

Ten years after treatment, broadleaf density in the glyphosate-treated plot was less than one-half of that in the untreated control plot (Table 3). The broadleaf density in the untreated control area was 3050 sph, consisting of 87% paper birch (*Betula papyrifera*), 8% trembling aspen, and 5% balsam poplar (Table 3). The absence of vegetation control resulted in a two-storey mixedwood stand with 7.5 m tall broadleaf species in the overstorey and 3.5 m tall suppressed spruce in the understorey. In addition to reductions in broadleaf density (1500 sph), the glyphosate treatment modified the broadleaf species composition (60% balsam poplar, 40% paper birch, and no aspen). 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) may be needed.

Vegetation Community Responses

A count of vegetation species was used to determine species richness in each treatment plot. The richness was similar in both plots. In total, 54 and 51 species were found in untreated control and treated plots, respectively (Table 4). The number of species of each lifeform was also similar in both treated and controls plots. 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.

The two treatment areas had similar plant species composition. Most shrub and herb species recorded in only one area had very low cover. Trembling aspen and Douglas-fir were found only in the untreated control plot and

TABLE 3 *Means and standard errors for density: stand, broadleaves, trembling aspen, balsam poplar, and paper birch, 10 years after treatment application*

Treatment	Stand (sph)	Broadleaves (sph)	Trembling aspen (sph)	Balsam poplar (sph)	Paper birch (sph)
Glyphosate	3800±804	1500±532	0	900±526[a]	600 ± 316
Control	4400±735	3050±723	250±250[b]	150±150[b]	2650±862
p-value[c]	*0.60*	*0.14*	*0.4*	*0.2*	*0.07*

[a] Recorded in two RMPS.
[b] Recorded in one RMP.
[c] p-values from ANOVA.

TABLE 4 *Means and standard errors for percent cover: total, conifers, broadleaves, shrubs, and herbs, 10 years after treatment application in summer of 1998*

	Total		Conifer		Broadleaves		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	97.5±1.9	51	31.3±3.1	2	7.8±5.8	2	40.0±5.8	14	65.0±2.9	31
Control	98.3±2.2	54	18.8±2.4	2	18.8±3.8	3	60.0±9.1	14	33.8±7.5	33
p-value[b]	*0.63*	–	*0.02*	–	*0.16*	–	*0.11*	–	*0.008*	–

[a] Total number of species include lichens and mosses.
[b] p-values from ANOVA.

FIGURE 3 *Vegetation community in the untreated control plot, August 15, 1998.*

FIGURE 4 *Vegetation community in glyphosate-treated plot, August 15, 1998.*

subalpine fir was found only in the treated plot. Differences in tree species composition may influence future development of both the canopy and understorey. Both treatment areas had many of the vascular plant species commonly found in mature forests in the SBSdw3/01, suggesting that the pre-disturbance community has partially survived or recovered from disturbance. This conclusion is weakened, however, by the lack of pre-disturbance data for this site.

Unlike species richness and composition, the abundance of plant species was distinctly different between the plant communities from the two treatments. The treated area had a lower percent cover of broadleaf trees (paper birch and trembling aspen) and shrubs (such as Sitka alder, willow, black twinberry, and thimbleberry), and a higher cover of some herbs than the control area (Table 4). Assuming the plant communities were the same before treatment, these results suggest that glyphosate shifted the plant community to herbs and conifers by reducing the cover of broadleaf trees and shrubs.

Mixed-stand Timber Yield

Ten years after treatment, the increases in white spruce growth attributes have resulted in significantly larger spruce stem volume within the glyphosate-treated plot (Table 1). Yield projections for the conifers based on MGM simulations suggest that glyphosate application can increase the conifer volume by up to 67% and reduce the rotation age by up to 20 years (at maximum mean annual increment) compared with the untreated control (Table 5). However, the glyphosate treatment also reduced broadleaf timber volume by up to 79% compared with the untreated area. If both stands are harvested using a two-pass harvesting system (i.e., broadleaves at 56 years and conifers after 71 years), the notable difference is a shorter conifer rotation, more conifer volume, and less broadleaf volume in the treated plot compared to the untreated control plot (Table 5). However, if plots are clearcut at 90 years of stand age, the model simulation indicates that conifer and total stand yield is more, and broadleaf yield is less, in the treated plot compared to the untreated control plot (Table 5).

TABLE 5 *Stand yield projections derived from the Mixedwood Growth Model*

	Broadleaves (B) @ 56 years	Conifers (C)		Stand yield (B+C) (two passes)	Stand yield @ 90 years from MGM			Stand yield @ 90 years from VDYP[a]
Treatment	Volume (m^3/ha)	Volume (m^3/ha)	Age (yr)	Total volume (m^3/ha)	Conifer (m^3/ha)	Broadleaves (m^3/ha)	Total (m^3/ha)	Total volume (7.5 cm+) (m^3/ha)
Glyphosate	40	388	71	428	428	29	457	420
Control	188	232	91	420	216	186	402	383

Conifer species: white spruce; Douglas-fir; subalpine fir. Broadleaf species: trembling aspen; balsam poplar; paper birch.

[a] VDYP = Variable Density Yield Prediction model.

Since broadleaf species are expected to occupy the site at least to maturity, it is logical to include broadleaf volume for total yield analysis. However, the stand at this stage is very dynamic, and various changes (e.g., reduction in broadleaf density) will have yield implications in the future.

Conclusions

The results from 10-year measurements suggest that:

- Controlling competing vegetation 4 years after planting using glyphosate increased white spruce basal diameter and crown radius, reduced height-to-diameter ratio, and improved white spruce vigour.
- Glyphosate treatment significantly improved white spruce height and the number of free-growing spruce per hectare 14 years after planting.
- Glyphosate treatment increased conifer and herb percent cover, and reduced broadleaf and shrub percent cover.
- Glyphosate treatment did not affect the plant species richness or total number of species.
- Glyphosate treatment will reduce conifer rotation age, increase conifer yield, and reduce broadleaf yield.

These findings indicate that application of glyphosate to control broadleaf trees and shrubs has the potential to improve white spruce growth and yield. However, the results of the study need to be interpreted with great care, due to lack of replication.

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