
NINE-YEAR RESPONSE OF LODGEPOLE PINE AND THE *DRY ALDER* COMPLEX TO CHEMICAL AND MANUAL RELEASE TREATMENTS ON AN ICHmk1 SITE NEAR KELOWNA

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Nine-year Response of Lodgepole Pine and the *Dry Alder* Complex to Chemical and Manual Release Treatments on an ICHmk1 Site near Kelowna

by

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ABSTRACT

A research trial was established in 1986 in the southern interior of British Columbia to study the effectiveness of glyphosate applied at 3 L/ha (1.07 kg ai/ha), glyphosate applied at 6 L/ha (2.14 kg ai/ha), and manual cutting to release naturally regenerated lodgepole pine seedlings and suppress the *Dry Alder* Complex. Pine seedlings and two target species (Sitka alder and fireweed) were assessed for the first 3 years, and again in the ninth year following treatment.

Within 2 years of treatment, stem diameter of seedlings in all treatments had increased significantly compared to the control, and this difference was maintained through year 9. There were no significant differences in height until 1995, by which time seedlings in all treatments were taller than in the control. There were no significant differences in seedling response among the three release treatments.

Manual cutting had the greatest effect on height and cover of Sitka alder for the duration of the study, but did not produce significantly larger lodgepole pine seedlings than the other treatments. That Sitka alder height reductions had no effect on pine growth suggests that competition for light was less important on this site than competition for soil resources (water and nutrients). Seedlings in plots treated with glyphosate at 6 L/ha tended to have the largest height and stem diameter in 1995, while growing among 15% cover of Sitka alder. This is consistent with earlier findings by Simard (1990), that a cover of Sitka alder (as much as 35%) may be beneficial to lodgepole pine seedlings instead of suppressing them.

None of the treatments were very effective at reducing fireweed height and cover, although the glyphosate treatments had a slight effect for 1–2 years.

ACKNOWLEDGEMENTS

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The authors gratefully acknowledge review of this report by Ron Gray, Phil Comeau, and George Harper.

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DISCLAIMER

The use of herbicide trade and manufacturer names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the B.C. Ministry of Forests of any product or service to the exclusion of any others that may also be suitable.

¹ Bancroft, B., S. Simard, P. Youwe, and D. Sachs. 1991. Stand release trials in the Kamloops Forest Region: technical report. B.C. Min. For., Kamloops For. Reg., Kamloops, B.C. Unpubl.

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1 INTRODUCTION

Programs to manage competing vegetation in the southern interior of British Columbia have grown steadily since 1980, but quantitative information about the effectiveness of treatments on specific vegetation communities is required to justify the continued expenditure. In 1994–1995, it was estimated that the Kamloops Forest Region manually brushed 7500 ha at an average cost of \$560/ha, and chemically brushed 1105 ha at an average cost of \$360/ha (J. Boateng, pers. comm., March 1996). A series of research trials was established in 1986–1987 to study the effectiveness of these two treatment methods for controlling various vegetation complexes in the Kamloops Forest Region. This particular trial is concerned with the release of lodgepole pine seedlings growing in competition with the *Dry Alder* Complex.

The *Dry Alder* Complex is one of the vegetation communities identified as a competitive threat to conifer seedlings in the southern interior of British Columbia (Kimmins and Comeau 1990). It is typically composed of three major species, Sitka alder (*Alnus viridis* ssp. *sinuata*), fireweed (*Epilobium angustifolium*), and pinegrass (*Calamagrostis rubescens*), and it occurs on dry to fresh sites in the Interior Cedar–Hemlock (ICH), Montane Spruce (MS), and Sub-Boreal Spruce (SBS) biogeoclimatic zones.

Sitka alder is common in the understory of pine forests of the southern interior of British Columbia, and, because it varies widely in shade tolerance (Klinka and Scagel 1984), the sudden increase in light levels following harvesting often stimulates a rapid growth response. Sitka alder may increase in height and cover to levels where it is competing with conifer seedlings for light and/or soil resources, and is causing physical damage to seedlings through whipping and snowpress (Haeussler *et al.* 1990). Although there is no well-defined threshold at which Sitka alder becomes a competitive threat to seedling survival and growth, Simard (1990) found that the stem diameter of lodgepole pine seedlings decreased when alder cover exceeded between 10 and 35%, depending

on site quality. Below that threshold, seedlings appeared to benefit from the presence of alder.

Sitka alder has several attributes that can benefit conifer growth. It is particularly well known for its ability to fix nitrogen, although Sachs and Comeau² recently found nitrogen fixation rates of Sitka alder in the southern interior of British Columbia to be lower than those measured on Vancouver Island by Binkley (1981, 1982). Even so, Sachs and Comeau³ suggest that when alder cover is approximately 35%, which is suggested as a competition threshold by Simard (1990), it will contribute from 1.5 to 8 kg/ha/yr of nitrogen to a site. Sitka alder leaf fall also contributes biomass to the forest floor and cycles nutrients, improving long-term site productivity (Crocker and Major 1955). Sachs and Comeau used the FORECAST model⁴ to simulate the effects of Sitka alder removal on lodgepole pine yield following clearcutting in Montane Spruce forests, and found that reductions in Sitka alder density below 2500 ha⁻¹ resulted in lower pine yield, particularly when coupled with slash burning and/or whole-tree harvesting. There is also evidence that alder may contribute directly to lodgepole pine nutrition through a shared association with the common ectomycorrhizal fungus *Paxillus involutus*. In a study in Sweden, *Alnus glutinosa* (L.) and lodgepole pine were interconnected by the mycelium of *P. involutus*, and 5–15% of the nitrogen fixed by alder was transferred directly to the connected pine (Arnebrant *et al.* 1993).

Sitka alder is considered to have limited value as a wildlife browse species; however, some birds feed on the seeds, and it also provides cover for ungulates (Haeussler *et al.* 1990). Small mammals such as snowshoe hares,

² Sachs, D. and P.G. Comeau. 1991. Determination of nitrogen fixation by Sitka alder at two sites in the southern interior of British Columbia. FRDA Project CO3, Res. Br., B.C. Min. For., Victoria, B.C. Unpubl.

³ Ibid.

⁴ Sachs, D. and P.G. Comeau. 1992. Calibration and initial testing of FORECAST for stands of lodgepole pine and Sitka alder in the interior of British Columbia. Res. Br., B.C. Min. For., Victoria, B.C. Unpubl.

red squirrels, and voles commonly find cover in Sitka alder, and can browse neighbouring seedlings in lodgepole pine plantations (Sullivan 1985; Simard 1990).

Previous studies have shown that Sitka alder levels may be affected both by glyphosate and by manual cutting. Biring *et al.* (1996) report 60–90% injury to Sitka alder when glyphosate was applied at 1.5–2.1 kg ai/ha (4–6 L/ha) from May through October. Lloyd and Heineman⁵ observed 50–70% reductions in Sitka alder crown volume and height when glyphosate was applied at 6 L/ha from May to October, with reductions lasting for at least 3 years. Their study also found that manual cutting was very effective for reducing height and crown volume of alder, and that the date of cutting was irrelevant.

2 OBJECTIVES

This trial is one of a series of six vegetation management trials established in the Kamloops Forest Region from 1986 to 1987. The trial had the following specific objectives:

1. to study the effects of a single manual cutting treatment and two levels of broadcast foliar glyphosate application (3 L/ha and 6 L/ha) on naturally established lodgepole pine (*Pinus contorta* var. *latifolia*)

3 STUDY AREA

This study is located between Mission and Belgo Creeks in the Penticton Forest District, approximately 40 km east of Kelowna. The site

Fireweed also competes with conifer seedlings in the southern interior of British Columbia, although it is more of a problem on subhygric sites than on mesic sites (Lindeburgh 1995). Fireweed may become dominant on freshly logged sites within 1–2 years, and often persists for a decade or more (Haeussler *et al.* 1990). It produces copious amounts of wind-borne seed, and once established, spreads rapidly by seed and rhizomes (Rowe 1983). Fireweed damages young seedlings mainly through snowpress of dead shoots, and also by reducing light levels under its canopy (Comeau *et al.* 1989). Once a forest canopy develops, however, fireweed generally dies out (Haeussler *et al.* 1990). Various studies indicate that glyphosate effectively reduces both height and cover of fireweed (Expert Committee on Weeds 1984, 1985; Lindeburgh 1995; Lloyd and Heineman⁶), but reports vary on how long treatment effects last.

seedlings and two target species (Sitka alder and fireweed) over a period of 9 years;

2. to study trends in abundance of other vascular plant species that may have been affected by treatment; and
3. to provide a demonstration site for the Penticton Forest District.

was clearcut in 1981–1982, and left to regenerate naturally to lodgepole pine. It is at an elevation of 1320 m in the ICHmk1/03–04

⁵ Lloyd, D. and J. Heineman. 1994a. Treatment of Sitka alder (*Alnus viridis* ssp. *sinuata*) in the southern interior of British Columbia by three methods: aerial glyphosate, manual cutting, and glyphosate applied to cut stumps. FRDA project 3.41, Res. Br., B.C. Min. For. and For. Can., Victoria B.C. Unpubl.

⁶ Lloyd, D. and J. Heineman. 1994b. The use of three rates of glyphosate to treat fireweed (*Epilobium angustifolium* L.) on various growing season dates. FRDA project 3.41, Res. Br., B.C. Min. For. and For. Can., Victoria B.C. Unpubl.

(Interior Cedar–Hemlock Thompson Moist Cool variant, site series 03–04) (Lloyd *et al.* 1990). The study site is situated on a uniformly gentle (20%) slope with a westerly aspect, in a mid-slope position. The soil is classified as an Orthic Dystric Brunisol (Canadian Soil Survey Committee 1978). Texture varies from sandy loam (0–13 cm) to sandy clay loam (>13 cm), with

coarse fragment content ranging from 20 to 35% as depth increases. The soil is moderately well drained, and although there is no root restricting layer, most of the roots are located in the top 30 cm. The forest floor is moderately thin (4 cm thick), and is classified as Orthimormoder (Klinka *et al.* 1981).

4 METHODS

4.1 Criteria for Site Selection

The site was chosen to satisfy the following conditions:

1. it was representative of the *Dry Alder Complex*;
2. conifers were suppressed by neighbouring vegetation, but were vigorous enough to respond to release treatments;
3. the site was deemed appropriate for treatment in the operational brushing program of the Penticton Forest District;
4. vegetation could be treated with a back-pack sprayer; and
5. the site was uniform with respect to vegetation, topography, and moisture regime.

4.2 Experimental Design and Treatments

The trial used a Randomized Complete Block Design with the following four treatments:

1. control;
2. glyphosate applied at a rate of 3 L/ha (1.07 kg ai/ha);
3. glyphosate applied at a rate of 6 L/ha (2.14 kg ai/ha); and
4. manual cutting.

Each treatment was randomly located within each of three blocks, and each treatment plot contained 20 subplots. Each plot was 50 x 60 m (0.3 ha), including a 5-m surrounding buffer strip, so that the actual treated area was 40 x 50 m (0.2 ha). The subplots had an area of

10 m² ($r=1.78$ m), and were centred on the measured pine seedlings. They were located by laying out a 4 x 5 grid within each treatment plot, and choosing the closest lodgepole pine seedling to each grid point as a subplot centre. Pine seedlings and woody target specimens were tagged to enable remeasurement.

Glyphosate (trade name Vision[®]) treatments were applied between 05:30 and 09:30 hr on August 22 and 23 1986, when alder leaves were fully developed and conifer buds set. During application, skies were clear, wind speeds were less than 3 km/h, temperatures ranged between 6 and 12°C, and relative humidity ranged between 68 and 81%. Glyphosate was mixed with water and delivered at a rate of 100 L/ha using CP-3 hand-pump back-pack sprayers. All vegetation in the treatment plots, including conifers, was broadcast sprayed with the glyphosate mix. Manual cutting was done once on June 12 1986, using hand-held shears. All woody vegetation in the treatment plots, excluding conifers, was cut at the root collar.

4.3 Measurements

Measurements were made according to Pollack and Herring (1985). One week before treatment in 1986, lodgepole pine seedlings were assessed for height, current-year height increment, and stem diameter (measured at the root collar). Target vegetation was assessed for species-specific percent cover, and the height of one average target specimen per woody species was measured.

Relative growth rates (RGR) were calculated for height and stem diameter of lodgepole pine. For example:

$$\text{Relative Height Growth 1987} \\ = (\text{Height 87} - \text{Height 86}) / \text{Height 86}.$$

Stem volume of lodgepole pine was also calculated to provide a measure that incorporated both seedling height and diameter. The formula for a cone was used:

$$\text{Stem volume} = (\pi((\text{Stem diameter}/2)^2) * \\ (\text{Height})) / 3.$$

Competition index was calculated as

$$\text{CI} = ((\text{Fireweed height} \times \text{cover}) + \\ (\text{Alder height} \times \text{cover})) / 100.$$

Measurements were repeated 1, 2, 3, and 9 years following treatment in 1987, 1988, 1989, and 1995, respectively. In addition, lodgepole pine seedlings were assessed for their tolerance to treatment, and target vegetation was assessed for treatment effect using the Expert Committee on Weeds (ECW)⁷ rating system.

A species inventory also was established in 1986 to track a number of wildlife browse species; however, these data were not consistently collected. In 1995, cover of all species was

⁷ ECW is based on subjective estimation of the level of vegetation control for a plant species, as evidenced by degree of top kill, defoliation, abnormal growth form, or mortality. A 0-100% rating scale is used, where 0 indicates no control and 100 indicates complete control (Expert Committee on Weeds Abstracts 1983; Walstad and Wagner cited in Herring and Pollack 1985).

recorded for five subplots in each treatment plot. From these data, diversity indices were calculated according to Simpson (1949)

$$\text{SDI} = 1 - \Sigma((n/N)^2)$$

and Shannon and Weaver (1963)

$$H = -(\Sigma(n/N)\log(n/N))$$

where n=cover of each species and N=sum of cover of all species.

4.4 Statistical Analysis

Analysis of variance (ANOVA) was used to test for significant differences among treatment means ($\alpha=0.10$), as shown in Table 1. The analysis was performed on treatment plot means because the design was balanced, the means were more normally distributed than the subsamples, and the objective was to investigate main effect differences rather than variation among subsamples within treatment plots (Sit 1995). Variables for pine seedlings that were tested were total height, relative height growth, stem diameter, relative diameter growth, and stem volume. Variables for target vegetation that were tested were specimen height, species-specific cover, ECW rating, competition index (CI), and diversity indices. Mean separation was carried out for 1986-1989 data using the Waller-Duncan Bayes Least Significant Difference test, and for 1995 data using Tukey's HSD test. Analysis for 1986-1989 data was carried out using SAS (1985), and for 1995 data using SYSTAT (1992).

TABLE 1. Analysis of variance table

Source of variation	Factor type	Level	Degrees of freedom	Expected F-test (df)
Block	random	n=3	n-1=2	<i>not testable</i>
Treatment	fixed	k=4	k-1=3	MST/MSE (3,6)
Error (BxT)			(n-1)(k-1)=6	
Total			kn-1=11	

5 RESULTS

5.1 Lodgepole Pine

In the second and third years following treatment (1988–1989), stem diameter of lodgepole pine seedlings was significantly larger in all three treatments than in the control, although the average difference was only 0.44 cm by 1989 (Figure 1; Table 1). In 1995, pine in both glyphosate treatments still had significantly larger stem diameters than in the control, with the largest stems occurring in plots treated with glyphosate at 6 L/ha (7.82 cm) compared to 6.67 cm in the control (difference of 1.15 cm).

From 1987 to 1989, there were no significant effects on the height of lodgepole pine seedlings, but by 1995, 9 years after treatment, seedlings in all release treatments were significantly taller than in the control (Figure 2). The tallest seedlings (468 cm) occurred in

the glyphosate at 6 L/ha treatment, and were 43 cm taller than seedlings in the control (425 cm).

Relative growth rates (RGR) for height and diameter of pine were calculated each year (Section 4.3). In 1987 and 1988, relative diameter growth was significantly greater in both glyphosate treatments than in the control. These differences disappeared by 1989, however. In 1989, relative height growth was significantly greater in plots treated with glyphosate at 6 L/ha than in the control, but this difference was not evident in 1995.

In both 1989 and 1995, the calculated stem volume of lodgepole pine was significantly greater in both glyphosate treatments than in the control. In 1995, stem volume of seedlings in the glyphosate at 6 L/ha plots was 45% larger than it was for seedlings in the control.

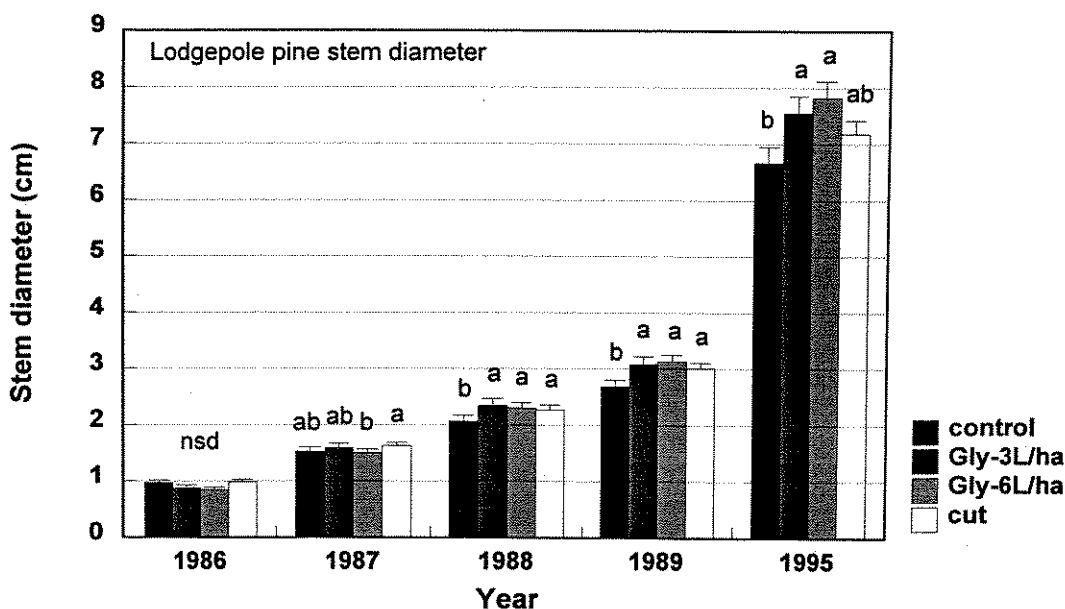


FIGURE 1. Lodgepole pine stem diameter from 1986 to 1995. Treatments with the same letter within a single year are not significantly different from one another at $\alpha \leq 0.10$; nsd=no significant difference; error bars are one standard error.

TABLE 2. Lodgepole pine measurements from 1986 to 1995

	Height (cm)	Stem diameter (cm)	Stem volume (cm ³)	Relative ht. growth	Relative diam. growth
PRE-: 1986					
Control	39.22* a <i>2.07**</i>	0.97 a <i>0.05</i>	15.33 a <i>2.77</i>		
Glyph-3L/ha	39.13 a*** <i>1.98</i>	0.88 a <i>0.05</i>	11.79 b <i>1.71</i>		
Glyph-6L/ha	35.33 a <i>1.67</i>	0.85 a <i>0.04</i>	9.32 b <i>1.37</i>		
Cut	36.42 a <i>1.58</i>	0.98 a <i>0.05</i>	12.11 ab <i>1.48</i>		
<i>p-value</i>	0.0974	0.1108	0.0150		
POST 1: 1987					
Control	63.68 a <i>2.84</i>	1.53 ab <i>0.08</i>	55.21 a <i>8.36</i>	0.66 b <i>0.03</i>	0.63 b <i>0.04</i>
Glyph-3L/ha	61.58 a <i>2.93</i>	1.59 ab <i>0.08</i>	58.75 a <i>8.23</i>	0.60 c <i>0.03</i>	0.85 a <i>0.05</i>
Glyph-6L/ha	57.22 a <i>2.41</i>	1.50 b <i>0.07</i>	43.95 b <i>5.46</i>	0.65 bc <i>0.04</i>	0.86 a <i>0.05</i>
Cut	61.62 a <i>2.31</i>	1.63 a <i>0.06</i>	53.09 ab <i>5.36</i>	0.74 a <i>0.03</i>	0.73 ab <i>0.04</i>
<i>p-value</i>	0.1521	0.0708	0.0330	0.0034	0.0386
POST 2: 1988					
Control	94.90 a <i>3.80</i>	2.07 b <i>0.10</i>	144.34 b <i>20.25</i>	0.52 a <i>0.03</i>	0.36 b <i>0.02</i>
Glyph-3L/ha	97.12a <i>4.06</i>	2.35 a <i>0.12</i>	195.68 a <i>27.56</i>	0.61 a <i>0.03</i>	0.49 a <i>0.02</i>
Glyph-6L/ha	91.30 a <i>3.51</i>	2.30 a <i>0.10</i>	163.08 ab <i>18.23</i>	0.63 a <i>0.03</i>	0.54 a <i>0.03</i>
Cut	93.75 a <i>3.10</i>	2.27 a <i>0.09</i>	152.67 ab <i>15.30</i>	0.56 a <i>0.04</i>	0.41 b <i>0.03</i>
<i>p-value</i>	0.4818	0.0174	0.0670	0.2878	0.0026
POST 3: 1989					
Control	140.03 a <i>4.78</i>	2.69 b <i>0.11</i>	335.32 c <i>38.88</i>	0.50 c <i>0.02</i>	0.34 a <i>0.02</i>
Glyph-3L/ha	148.87 a <i>5.36</i>	3.08 a <i>0.14</i>	484.52 a <i>60.16</i>	0.56 ab <i>0.02</i>	0.34 a <i>0.02</i>
Glyph-6L/ha	144.29 a <i>4.48</i>	3.13 a <i>0.12</i>	451.56 ab <i>47.55</i>	0.57 a <i>0.02</i>	0.36 a <i>0.02</i>
Cut	141.93 a <i>4.32</i>	3.01 a <i>0.10</i>	388.26 bc <i>30.64</i>	0.52 bc <i>0.01</i>	0.36 a <i>0.02</i>
<i>p-value</i>	0.3379	0.0047	0.0030	0.0286	0.6982
POST 9: 1995					
Control	425.31 b <i>11.74</i>	6.67 b <i>0.28</i>	6014.61 c <i>578.87</i>	0.36 a^ <i>0.02</i>	0.26 a^ <i>0.02</i>
Glyph-3L/ha	455.86 a <i>14.28</i>	7.55 a <i>0.30</i>	8046.00 ab <i>673.72</i>	0.36 a <i>0.02</i>	0.27 a <i>0.02</i>
Glyph-6L/ha	468.04 a <i>11.87</i>	7.82 a <i>0.30</i>	8743.88 a <i>772.88</i>	0.39 a <i>0.02</i>	0.26 a <i>0.02</i>
Cut	459.73 a <i>10.00</i>	7.18 ab <i>0.24</i>	6988.92 bc <i>531.64</i>	0.39 a <i>0.02</i>	0.24 a <i>0.02</i>
<i>p-value</i>	0.0080	0.0430	0.0080	0.3740	0.5540

* Mean (bold)

** Standard error (italics)

*** Means with the same letter within each column are not significantly different from one another at p=0.10.

^ 1995 RGR values obtained by using 1/6 of the change from 1989 to 1995

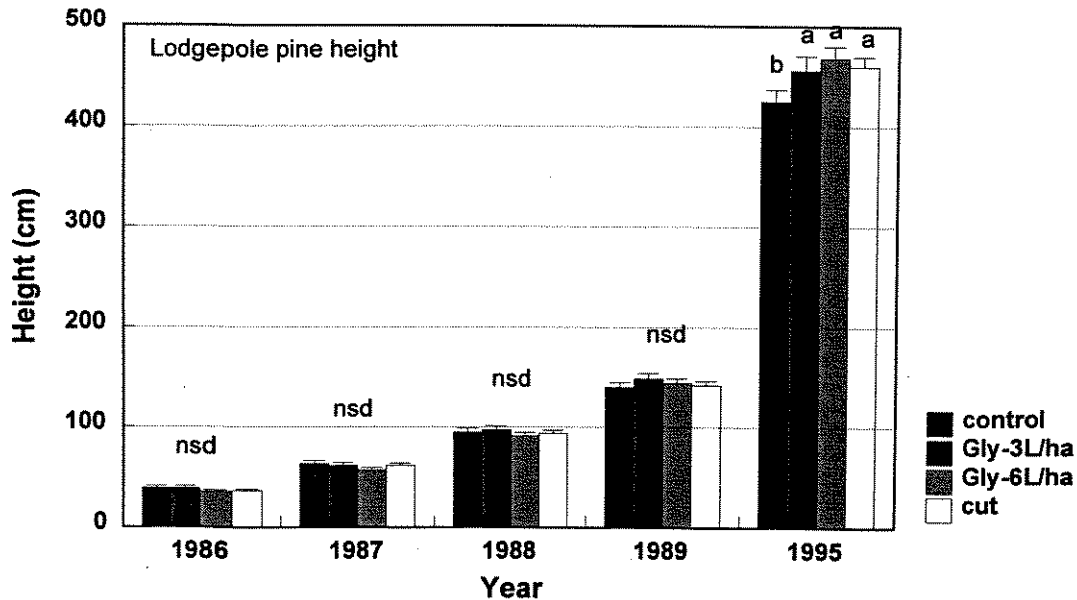


FIGURE 2. Lodgepole pine height from 1986 to 1995. Treatments with the same letter within a single year are not significantly different from one another at $\alpha \leq 0.10$; nsd=no significant difference; error bars are one standard error.

During the 1995 assessment, it was observed that the density of lodgepole pine stems was high enough in all treatment plots for intraspecific competition to be a contributing factor to growth rates. Unfortunately, the increase in pine density was not foreseen when the trial was established, and therefore was not monitored.

5.2 Target Vegetation

5.2.1 Sitka alder

Although there were some pre-treatment differences in alder height among treatments, the differences were small compared to the post-treatment height differences (Figure 3; Table 3). For all post-treatment assessments from 1987 to 1995, alder in manually cut plots was significantly reduced in height compared to the control. For 3 years following treatment, height of alder in plots treated with glyphosate

at 6 L/ha was also significantly less than in the control, but it had recovered to control levels by 1995. The 3 L/ha glyphosate treatment had no significant effect on alder height.

Alder mortality and some top dieback were observed in control plots between 1987 and 1989. Dieback was also present on new growth in the glyphosate treatments in 1988–1989. The cause is unknown, but it does not seem to have affected the comparison. No dieback was observed in 1995.

There was minimal sprouting of alder in the herbicide-treated plots in the first years after treatment, and virtually none in the manually cut plots.

Figure 4 compares height growth of lodgepole pine and Sitka alder among the control and the three release treatments. Lodgepole pine was shorter than Sitka alder before treatment in 1986, but surpassed it within 1–4 years, depending on the release treatment.

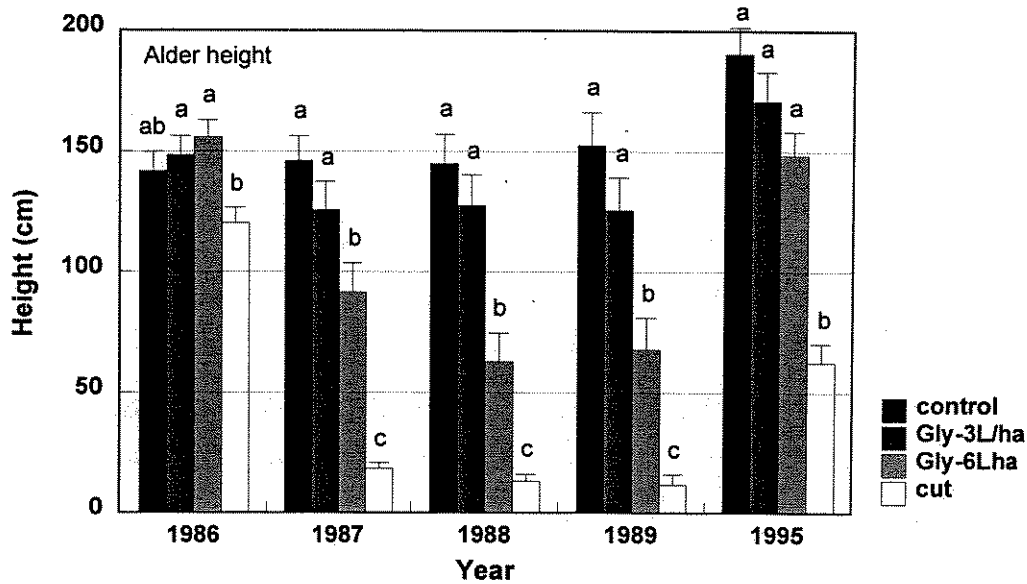


FIGURE 3. Sitka alder height from 1986 to 1995. Treatments with the same letter within a single year are not significantly different from one another at $\alpha \leq 0.10$; error bars are one standard error.

In comparison to the control, alder cover from 1987–1989 was significantly reduced by glyphosate applied at 6 L/ha and manual cutting, but not by glyphosate applied at 3 L/ha (Figure 5). In 1995, alder cover in manually cut plots was still significantly lower than in the control. Alder cover in the control remained constant at 21–23% throughout the 9 years of the study, and from 1987–1989, cover values in the various treatments also remained fairly constant at 16–18% in the 3 L/ha glyphosate plots, 7% in the 6 L/ha glyphosate plots, and less than 2% in the manually cut plots. In 1995, 9 years after treatment, cover of alder in the glyphosate at 6 L/ha plots had recovered to about 15%, but was unchanged in the other treatments.

The ECW rating for alder between 1987 and 1989 was significantly higher in the glyphosate at 6 L/ha and manual cutting treatments than in plots treated with glypho-

sate at 3 L/ha (Table 3). Manual cutting resulted in 93–97% control of Sitka alder for 3 years after treatment, whereas glyphosate applied at 6 L/ha resulted in 80–82% control, and glyphosate applied at 3 L/ha resulted in 38–46% control. Estimates of ECW rating were not carried out in 1995.

5.2.2 Fireweed

Glyphosate applied at both 3 L/ha and 6 L/ha resulted in significant reductions in fireweed height for 1 year following treatment (Figure 6 and Table 3). Baseline height of fireweed before treatment was 45–55 cm, which was reduced by about 50% in the glyphosate treatments. By 1988, 2 years after treatment, there were no longer any significant differences in fireweed height. In the manual cutting treatment, fireweed had recovered to control levels within 1 year of cutting.

TABLE 3. Sitka alder and fireweed measurements (1986–1995)

	Alder			Fireweed			Competition Index
	Height (cm)	Cover (cm)	ECW	Height (cm)	Cover (cm)	ECW	
PRE, 1986							
Control	141.81 ab	23.00 a		50.25 ab	10.83 ab		42.41 a
	<i>7.92</i> **	<i>2.16</i>		<i>1.71</i>	<i>0.83</i>		<i>4.22</i>
Glyph-3L/ha	148.48 a***	25.21 a		54.14 a	14.22 a		49.08 a
	<i>7.89</i>	<i>2.73</i>		<i>1.68</i>	<i>0.81</i>		<i>5.34</i>
Glyph-6L/ha	155.73 a	28.88 a		51.17 ab	12.37 ab		55.65 a
	<i>7.15</i>	<i>2.70</i>		<i>1.69</i>	<i>1.17</i>		<i>5.19</i>
Cut	120.20 b	16.00 a		46.16 b	8.97 b		25.50 a
	<i>6.34</i>	<i>1.34</i>		<i>1.14</i>	<i>0.53</i>		<i>2.10</i>
<i>p-value</i>	<i>0.0638</i>	<i>0.3024</i>		<i>0.1289</i>	<i>0.0897</i>		<i>0.1876</i>
POST 1, 1987							
Control	146.05 a	21.98 a	14.73 c	63.58 a	11.67 a	1.50 c	46.23 a
	<i>10.30</i>	<i>2.24</i>	<i>3.76</i>	<i>1.73</i>	<i>0.88</i>	<i>1.50</i>	<i>4.67</i>
Glyph-3L/ha	125.51 a	15.75 ab	45.82 b	32.83 b	11.68 a	34.75 b	29.77 ab
	<i>11.91</i>	<i>2.20</i>	<i>4.26</i>	<i>1.78</i>	<i>0.94</i>	<i>3.05</i>	<i>4.53</i>
Glyph-6L/ha	91.43 b	7.00 bc	82.27 a	27.00 b	6.05 b	58.05 a	13.41 b
	<i>12.21</i>	<i>1.28</i>	<i>3.07</i>	<i>2.13</i>	<i>0.63</i>	<i>4.13</i>	<i>2.54</i>
Cut	18.23 c	1.63 c	93.47 a	56.67 a	12.50 a	0.00 c	7.69 b
	<i>2.40</i>	<i>0.20</i>	<i>1.07</i>	<i>1.91</i>	<i>0.84</i>	<i>0.00</i>	<i>6.38</i>
<i>p-value</i>	<i>0.0004</i>	<i>0.0219</i>	<i>0.0000</i>	<i>0.0001</i>	<i>0.0299</i>	<i>0.0000</i>	<i>0.0218</i>
POST 2, 1988							
Control	144.88 a	20.78 a	21.32 c	68.91 a	12.58 ab	6.08 b	47.68 a
	<i>12.18</i>	<i>2.24</i>	<i>4.41</i>	<i>2.05</i>	<i>0.94</i>	<i>2.16</i>	<i>5.06</i>
Glyph-3L/ha	127.38 a	16.32 ab	42.27 b	55.50 a	10.07 b	28.33 a	34.25 ab
	<i>12.78</i>	<i>2.18</i>	<i>4.73</i>	<i>2.26</i>	<i>0.77</i>	<i>3.45</i>	<i>4.66</i>
Glyph-6L/ha	62.77 b	6.72 bc	80.97 a	50.00 a	9.62 b	32.92 a	15.88 b
	<i>11.81</i>	<i>1.25</i>	<i>3.68</i>	<i>2.58</i>	<i>1.03</i>	<i>4.47</i>	<i>2.65</i>
Cut	13.03 c	1.25 c	93.83 a	69.08 a	16.58 a	2.67 b	12.41 b
	<i>2.88</i>	<i>0.23</i>	<i>2.05</i>	<i>1.93</i>	<i>1.18</i>	<i>1.36</i>	<i>1.08</i>
<i>p-value</i>	<i>0.0005</i>	<i>0.0219</i>	<i>0.0000</i>	<i>0.1101</i>	<i>0.0180</i>	<i>0.0050</i>	<i>0.0340</i>
POST 3, 1989							
Control	152.43 a	21.23 a	19.47 b	76.17 a	9.80 a	2.92 b	51.39 a
	<i>13.64</i>	<i>2.44</i>	<i>4.77</i>	<i>2.57</i>	<i>1.17</i>	<i>1.69</i>	<i>5.79</i>
Glyph-3L/ha	125.48 a	18.48 ab	38.31 b	68.33 ab	6.92 a	39.49 a	38.58 ab
	<i>13.64</i>	<i>2.60</i>	<i>5.43</i>	<i>2.71</i>	<i>0.59</i>	<i>4.17</i>	<i>5.90</i>
Glyph-6L/ha	67.87 b	6.42 bc	81.87 a	57.50 b	6.48 a	38.42 a	14.62 bc
	<i>13.12</i>	<i>1.36</i>	<i>3.57</i>	<i>2.70</i>	<i>0.48</i>	<i>4.08</i>	<i>2.96</i>
Cut	11.60 c	0.50 c	97.25 a	69.17 ab	9.90 a	0.00 b	7.34 c
	<i>4.33</i>	<i>0.11</i>	<i>1.07</i>	<i>2.24</i>	<i>0.63</i>	<i>0.00</i>	<i>0.58</i>
<i>p-value</i>	<i>0.0011</i>	<i>0.0198</i>	<i>0.0000</i>	<i>0.1322</i>	<i>0.1911</i>	<i>0.0060</i>	<i>0.0192</i>
POST 9, 1995							
Control	190.35 a	22.27 a		96.60 a	3.85 a		55.06 a
	<i>11.07</i>	<i>2.40</i>		<i>3.56</i>	<i>0.32</i>		<i>6.15</i>
Glyph-3L/ha	170.78 a	18.21 a		82.33 a	2.81 a		41.81 a
	<i>12.11</i>	<i>2.44</i>		<i>3.29</i>	<i>0.28</i>		<i>5.57</i>
Glyph-6L/ha	148.28 a	14.65 ab		87.81 a	3.33 a		30.92 ab
	<i>9.88</i>	<i>1.89</i>		<i>3.09</i>	<i>0.27</i>		<i>4.72</i>
Cut	62.30 b	2.93 b		89.08 a	3.77 a		7.09 b
	<i>7.90</i>	<i>0.50</i>		<i>3.36</i>	<i>0.25</i>		<i>1.08</i>
<i>p-value</i>	<i>0.0050</i>	<i>0.0200</i>		<i>0.3030</i>	<i>0.5770</i>		<i>0.0160</i>

* Mean (bold)

** Standard error (Italics)

*** Means with the same letter within each column are not significantly different at p=0.10

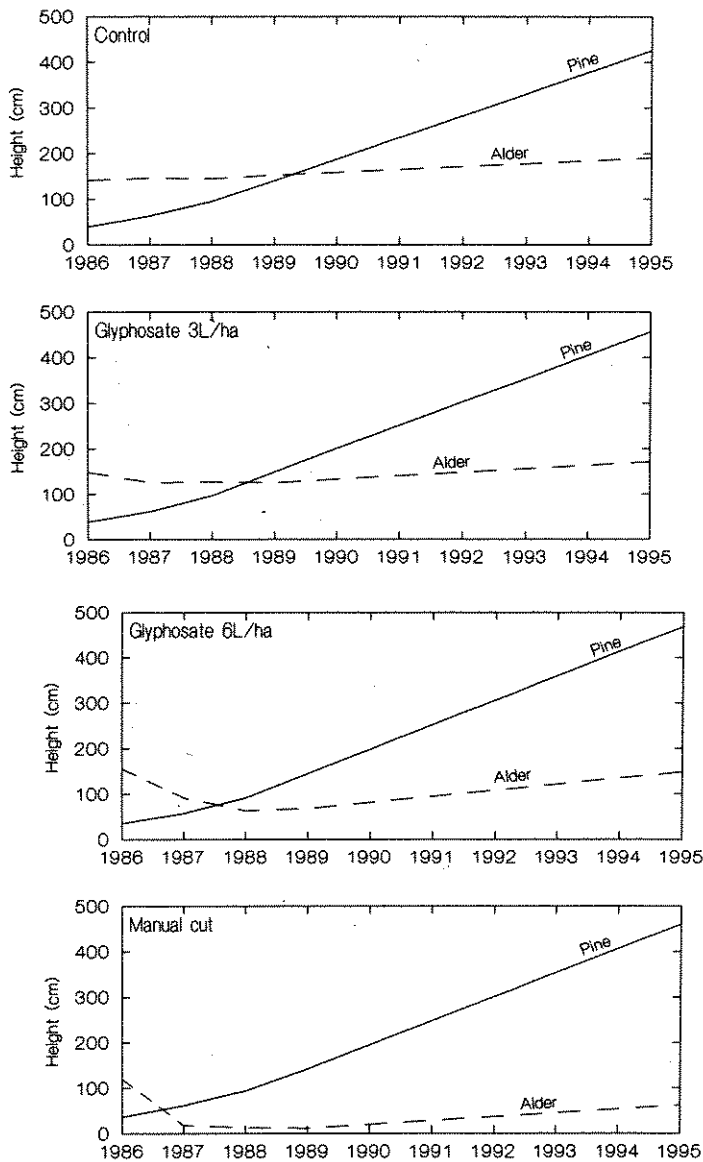


FIGURE 4. Comparison of height growth between lodgepole pine and Sitka alder.

Glyphosate applied at 6 L/ha was the only treatment that significantly reduced fireweed cover compared to the control, and this effect lasted only 1 year (Figure 7). Manual cutting tended to result in an increase in fireweed cover for 2 years following treatment.

By 1989, differences among all treatments had disappeared. Fireweed cover in the control was 11% in 1986 and 10% in 1989, but by 1995 it had further decreased to 4%, probably as a

result of the natural tendency for fireweed to decline in cover as a canopy develops above it.

The ECW ratings showed manual cutting to have no effect on fireweed (Table 3). Glyphosate applied at 6 L/ha resulted in 60% control of fireweed in the first year after treatment, and 33% and 38% in the second and third years, respectively. Glyphosate applied at 3 L/ha controlled fireweed 28–39% for 3 years after treatment.

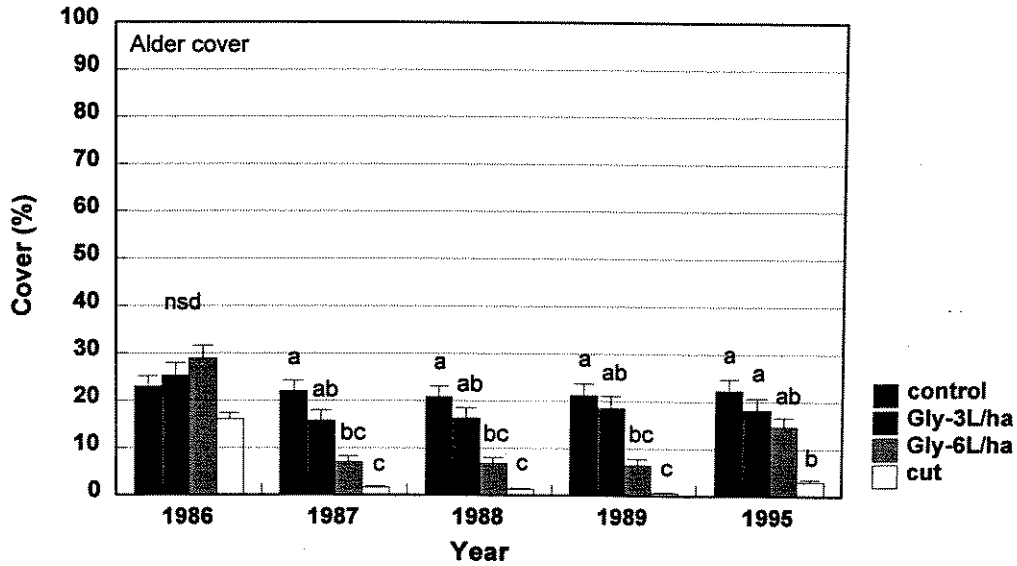


FIGURE 5. Sitka alder cover from 1986 to 1995. Treatments with the same letter within a single year are not significantly different from one another at $\alpha \leq 0.10$; nsd=no significant difference; error bars are one standard error.

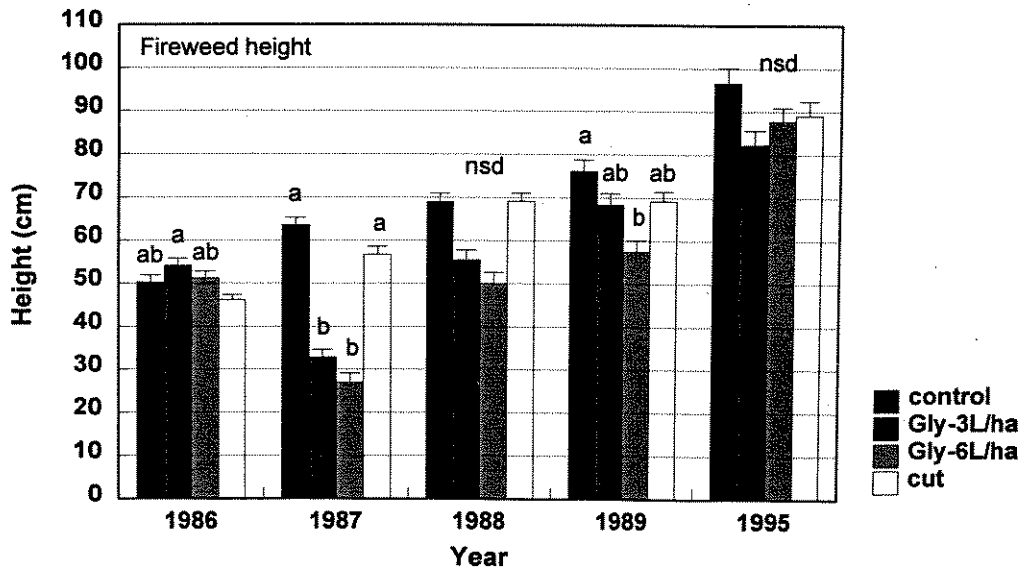


FIGURE 6. Fireweed height from 1986 to 1995. Treatments with the same letter within a single year are not significantly different from one another at $\alpha \leq 0.10$; nsd=no significant difference; error bars are one standard error.

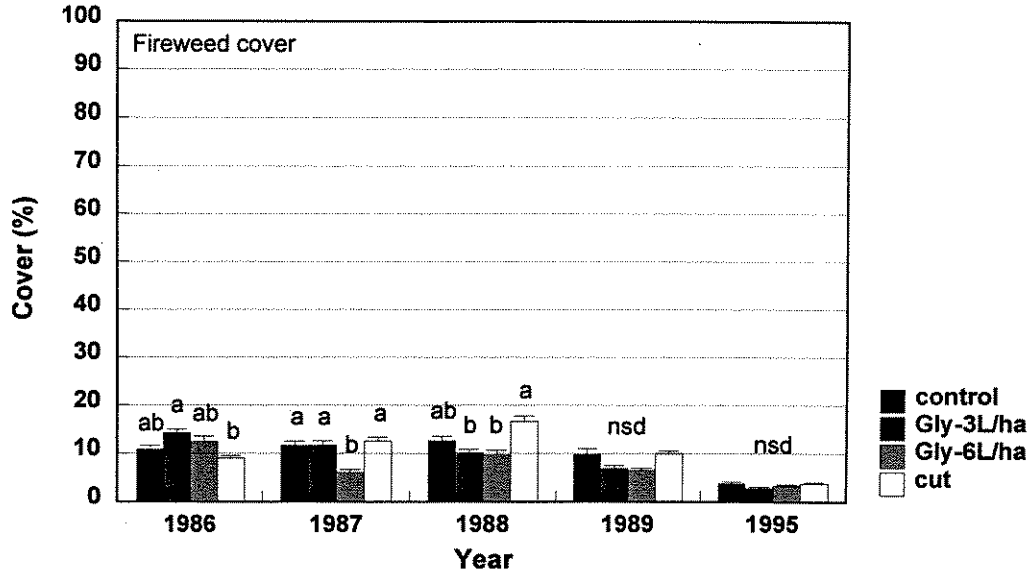


FIGURE 7. Fireweed cover from 1986 to 1995. Treatments with the same letter within a single year are not significantly different from one another at $\alpha \leq 0.10$; nsd=no significant difference; error bars are one standard error.

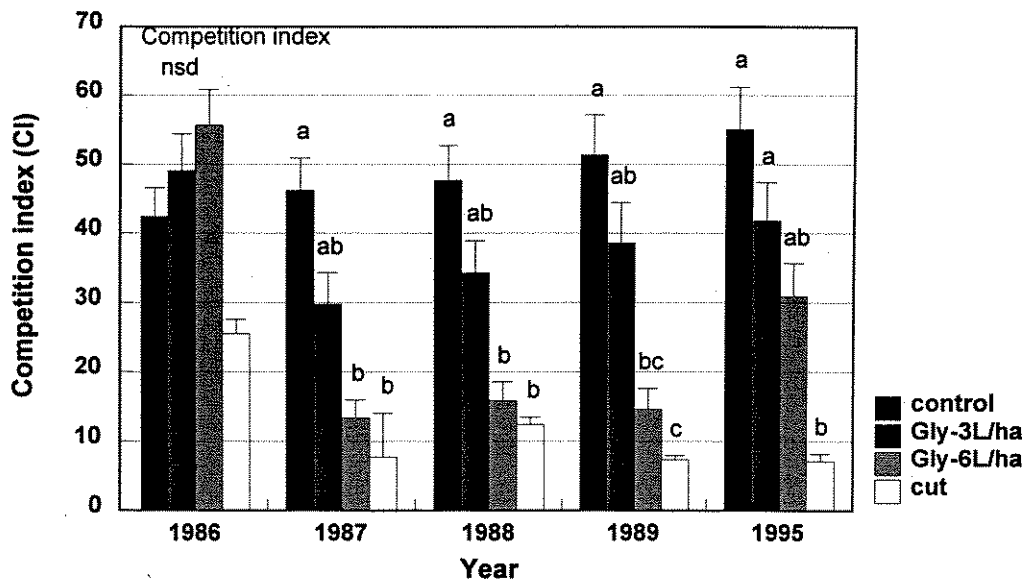


FIGURE 8. Competition index from 1986 to 1995. Treatments with the same letter within a single year are not significantly different from one another at $\alpha \leq 0.10$; nsd=no significant difference; error bars are one standard error.

5.3 Competition Index (CI)

In this study, 'competition index' was calculated as the sum of (height x cover) for alder and fireweed.

As shown by Figure 8, manual cutting produced the lowest CI, which was consistently less from 1987 to 1995 than the CI for the control. For 3 years following treatment, the CI for the glyphosate at 6 L/ha treatment was also significantly lower than for the control. The CI indicates that manual cutting had the longest-lasting effect on alder and fireweed.

5.4 Winter Forage Species for Ungulates

The presence/absence of key winter forage species was recorded in 1986 and 1995 for five subplots in each treatment plot. During the 9 years of the study, the presence of snowberry

and blueberry decreased somewhat in the glyphosate treatments, but otherwise there were no major changes. Table 4 shows the percentage of plots in which each forage species occurred in 1986 and 1995.

5.5 Species Composition, 1995

Percent cover of all species was recorded in five subplots in each treatment plot in 1995. A full species list is located in the Appendix. Species richness (total number of species present) was significantly lower in manually cut plots than in the control, but species diversity was not significantly affected (Table 5). Although the presence of 50 non-target species was recorded in the trial area, only 12 species had greater than 1% mean cover values in at least one treatment. Only two species (not including Sitka alder and fireweed) had greater than 5% cover.

TABLE 4. Percentage of subplots sampled in which each forage species occurred in 1986 and 1995

Species	Common name	Control		Gly-3 l/ha		Gly-6 l/ha		Manual cut	
		1986	1995	1986	1995	1986	1995	1986	1995
<i>Epilobium angustifolium</i>	Fireweed	100	100	100	93	100	100	100	100
<i>Paxistima myrsyintes</i>	Falsebox	100	100	87	93	100	100	100	93
<i>Vaccinium spp.</i>	Blueberry	60	73	87	47	80	73	67	73
<i>Symphoricarpos albus</i>	Snowberry	27	20	20	27	53	7	20	27
<i>Arctostaphylos uva-ursi</i>	Kinnikinnick	13	0	7	0	20	7	0	0
<i>Carex spp.</i>	Sedge	7	20	7	0	7	7	0	7
<i>Mahonia nervosa</i>	Oregon grape	0	0	7	7	0	7	0	0
<i>Salix spp.</i>	Willow	0	0	0	0	0	7	0	0

TABLE 5. Diversity indices and species richness, 1995

	Simpson's diversity index	Shannon's diversity measure	Species richness
Control	0.859	1.081	37 a
Glyph-3L/ha	0.791	0.894	26 ab
Glyph-6L/ha	0.821	0.958	33 ab
Cut	0.870	1.096	26 b
<i>p-value</i>	<i>0.2020</i>	<i>0.6340</i>	<i>0.0900</i>

6 DISCUSSION

This study provides data about the effectiveness of glyphosate and manual cutting treatments for release of lodgepole pine seedlings in competition with the *Dry Alder* Complex for a 9-year period. Most trials involving vegetation management have focused on the response of seedlings and target vegetation within 3–5 years of treatment, but this trial provides information on slightly longer-term effects.

When treatments were applied in 1986, lodgepole pine seedlings were less than 40 cm tall and had stem diameters of less than 1 cm. The Sitka alder with which they were associated was, on average, 140 cm tall and had 20% cover. In 1989, 3 years after treatment, glyphosate applied at 3 L/ha, glyphosate applied at 6 L/ha, and manual cutting had all resulted in significant increases in pine stem diameter, but there was no effect on height. Although the largest increase in stem diameter in 1989 was only 0.44 cm compared to the control, the difference indicates a response to treatment. By 1995, lodgepole pine seedlings in all three treatments were, on average, 43 cm taller than in the control, and stem diameters were more than 1 cm larger in both glyphosate treatments than in the control. Others have observed that lodgepole pine stem diameter responds to brushing within 2–3 years, but height differences may not become significant until a few years later (G. Harper, pers. comm., March 1996). Simard (1989, 1990) also found that stem diameter of lodgepole pine was the most responsive measure of the early effects of release from competing vegetation dominated by Sitka alder.

In this study, manual cutting had the most severe impact on Sitka alder, resulting in significant reductions in both height and cover for the entire 9 years of the study; by 1995, alder in the manual cutting treatment was only 33% as tall as alder in the control, and had 87% less cover. Glyphosate applied at 6 L/ha also had a severe impact on alder for at least 3 years, but by 1995 there was no longer a

significant difference in height or cover of alder between the control and the 6 L/ha glyphosate treatment. Compared to the control, glyphosate applied at 3 L/ha did not significantly reduce the height or cover of Sitka alder.

The resources for which lodgepole pine seedlings and Sitka alder compete vary from site to site, and may depend on site quality. According to Simard (1990), regression models suggest that on higher-quality sites alder may limit light availability to lodgepole pine, whereas on lower-quality sites the availability of soil-based resources, especially water, may also be a limiting factor. In this study, manual cutting caused a significantly greater reduction in Sitka alder height and cover than either of the glyphosate treatments, but pine growth was not correspondingly better. Since alder height affects the amount of light reaching pine seedlings, this suggests that light availability was a less important limiting factor to lodgepole pine growth than the availability of soil resources. Further evidence of this is that, for 3 years, alder height was reduced significantly more by glyphosate applied at 6 L/ha than at 3 L/ha, but there was no corresponding improvement in pine growth as a result of increased light availability.

Compared to Sitka alder, the effect of the three treatments on fireweed was small. Height of fireweed was significantly reduced for 1 year by both glyphosate treatments, and cover was significantly reduced for 1 year by glyphosate applied at 6 L/ha. Treatment with glyphosate took place in late August 1986, slightly later than the mid-July to mid-August treatment window recommended for attaining the greatest effect on fireweed.⁸ Fireweed levels declined naturally by 1995 to about 3–4%, possibly as a result of increases in the lodgepole pine canopy. Fireweed is an early successional species, and naturally becomes less prominent as other species increase (Haeussler *et al.*

⁸ Lloyd, D. and J. Heineman. 1994b. The use of three rates of glyphosate to treat fireweed (*Epilobium angustifolium* L.) on various growing season dates. FRDA project 3.41, Res. Br., B.C. Min. For. and For. Can., Victoria B.C. Unpubl.

1990). By 1995, the density of lodgepole pine stems had greatly increased in all plots, and probably contributed to the decrease in fireweed cover regardless of any other effects this may have had.

Glyphosate applied at 6 L/ha, glyphosate applied at 3 L/ha, and manual cutting all improved growth of lodgepole pine seedlings compared to the control, but there were no significant differences among these three treatments. Chemical and manual treatments affect the shrub and herb components of the vegetation community differently, but in this case the effect on seedling growth was similar. Manual cutting reduced the height and cover of Sitka alder somewhat more than glyphosate treatments, and treatment with glyphosate had more effect on fireweed than did manual cutting. Although the cover and height of other plant species were not recorded in this trial, glyphosate is known to affect a range of herbs, and it can be assumed that the two glyphosate treatments reduced levels of most herbs for 1 or 2 years following treatment. The availability of soil resources to pine seedlings may have increased in all treatments because of reductions in noncrop vegetation, regardless of whether it was the alder canopy or the herb layer that was most heavily affected. Simard (1989) found that the greatest increase in lodgepole pine stem diameter occurred when both Sitka alder and herbs were reduced to 10% cover each, and that increased growth corresponded with increases in soil and air temperatures, light availability, and available $\text{NO}_3\text{-N}$.

Although there were no major differences in lodgepole pine growth among the three treatments, the largest seedlings were found in the glyphosate at 6 L/ha treatment, where there was about 7% cover of alder from 1987 to 1989, and 15% in 1995. These results are consistent with a study by Simard (1990), which showed some retention of alder to be beneficial to seedlings. In that study, there appeared to be a threshold that ranged between 10 and 35% alder cover. Above the threshold, lodgepole pine seedlings showed effects of competition, but below the threshold seedling

growth could have been reduced by low nitrogen availability. The range in thresholds between 10 and 35% corresponds with the natural variation in the quality of the sites on which they were measured. Using the FORECAST model, Sachs and Comeau⁹ found that inclusion of 2500 Sitka alder ha^{-1} resulted in higher lodgepole pine yields in all simulations, largely because of its contributions to forest-floor mass and to the availability of nitrogen. In the model, the presence of alder helped offset reductions in site productivity that were a result of slash burning and whole-tree harvesting. The authors caution, however, that the model is useful for examining long-term trends in nutrient cycling, but does not accurately simulate competition between alder and pine in the short term.

The effects of release treatments on the overall vegetation community and the quality of wildlife habitat also need to be considered, although in this particular study the effects appeared to be minimal. Manual cutting did reduce the number of species present, but diversity indices were not significantly affected. The abundance of shrubs such as blueberry (*Vaccinium* spp.) and snowberry (*Symphoricarpos albus*) was somewhat reduced in the glyphosate-treated plots, but otherwise there were few changes.

Nine years after treatment, it is still difficult to say whether brushing improved pine growth in this trial enough to warrant the expense of treatment. In 1995, lodgepole pine were significantly taller in all treated plots than in the control, but only by about 30–40 cm (less than 10%). Stem diameters were also larger in plots treated with glyphosate than in the control, but only by about 1 cm (about 15%). When volumes are calculated, the differences were larger (volume was 45% larger in the glyphosate at 6 L/ha treatment than in the control in 1995), but it is still difficult to predict whether gains in growth will continue through the rotation. On this site, the success or failure of natural regeneration with lodgepole pine did not depend on control of competing vegetation,

⁹ Sachs, D. and P.G. Comeau. 1992. Calibration and initial testing of FORECAST for stands of lodgepole pine and Sitka alder in the interior of British Columbia. Res. Br., B.C. Min. For., Victoria, B.C. Unpubl.

although there were slight gains in growth. Nor did achievement of free-growing status within the recommended assessment period (British

Columbia Ministry of Forests 1995) depend on vegetation control, since lodgepole pine was free-growing in control plots by age 10 years.

7 SUMMARY AND RECOMMENDATIONS

1. All three release treatments resulted in increases in lodgepole pine stem diameter over control levels after 2 years and increases in height after 5–9 years. Although reduction in the height of Sitka alder was greater as a result of manual cutting and glyphosate applied at 6 L/ha than as a result of glyphosate applied at 3 L/ha, seedling response was not correspondingly greater in the higher-impact treatments. This suggests that availability of soil resources was at least as limiting to seedlings as was light availability.
2. Reductions in Sitka alder cover from 22% in the control to 15–18% following application of glyphosate at 3 L/ha were sufficient to allow growth responses of lodgepole pine seedlings. This supports and helps refine the estimate of a 10–35% competition threshold for Sitka alder (Simard 1990), at which seedlings may benefit from the nitrogen-fixing ability of alder, but above which seedlings are negatively affected by competition for resources.
3. Lodgepole pine was shorter than Sitka alder when the trial was initiated, but was taller in all treatments, including the control, within 5 years of treatment. Lodgepole pine reached free-growing status by age 10 years in the control. Although treatment accelerated dominance by lodgepole pine, treatment was not necessary to achieve free-growing status within the recommended assessment period (British Columbia Ministry of Forests 1995).
4. Diversity of vascular plant species was unaffected by treatment. However, species richness was lower following manual cutting than in the control, possibly due to soil and microenvironment changes associated with Sitka alder reduction. Glyphosate treatments appeared to reduce the abundance of some berry-producing shrub species, but the effects were too variable to draw conclusions.

REFERENCES

- Arnebrant, K., H. Ek, R.D. Finlay, and B. Söderström. 1993. Nitrogen translocation between *Alnus glutinosa* (L.) Gaertn. seedlings inoculated with *Frankia* sp. and *Pinus contorta* Dougl. ex Loud seedlings connected by a common ectomycorrhizal mycelium. *New Phytologist* 130: 231–242.
- Binkley, D. 1981. Nodule biomass and acetylene reduction rates of red alder and Sitka alder on Vancouver Island, B.C. *Can. J. For. Res.* 11:281–286.
- _____. 1982. Nitrogen fixation and net primary production in a young Sitka alder stand. *Can. J. Bot.* 60:281–284.
- Biring, B.S., P.G. Comeau, and J. Boateng. 1996. Effectiveness of forest vegetation control methods in British Columbia. *Can. For. Serv. and B.C. Min. For., Victoria, B.C. FRDA Handb. No. 011.*
- British Columbia Ministry of Forests. 1995. Establishment to free growing guidebook, Kamloops Forest Region. *In Forest Practices Code of British Columbia. Province of British Columbia.*
- Canadian Soil Survey Committee, Subcommittee on Soil Classification. 1978. The Canadian system of soil classification. Ottawa, Ont. Can. Dept. Agric. Publ. 1646.
- Comeau, P.G., S.B. Watts, C.L. Caza, J. Karakatsoulis, S.M. Thompson, and A.B. McGee. 1989. Autecology, biology, competitive status and response to treatment of seven southern interior weed species. *B.C. Min. For. and For. Can., Victoria, B.C. FRDA Rep. No. 93.*
- Crocker, R.L. and J. Major. 1955. Soil development in relation to vegetation and surface age of Glacier Bay, Alaska. *J. Ecol.* 43:427–448.
- Expert Committee on Weeds. 1984. Research Report. Western Canada Section Meeting, December 3–4, 5–6, 1984, Winnipeg, Man.
- _____. 1985. Research Report. Western Canada Section Meeting, December 3, 4, and 5, 1985, Edmonton, Alta.
- Haeussler, S., D. Coates, and J. Mather. 1990. Autecology of common plants in British Columbia: A literature review. *B.C. Min. For. and For. Can., Victoria, B.C. FRDA Rep. No. 158.*
- Herring, L.J. and J.C. Pollack. 1985. Experimental design protocol for forest vegetation management research: level B trials (first approximation). *B.C. Min. For., Res. Rep. RR84013-HQ.*
- Kimmins, J.P. and P.G. Comeau. 1990. Forest vegetation management research strategy for the southern interior, British Columbia. *B.C. Min. For. and For. Can., Victoria, B.C. FRDA Rep. No. 132.*
- Klinka, K. and A.M. Scagel. 1984. Selected ecological characteristics of some tree and shrub species in British Columbia: genera *Juniperus*, *Taxus*, *Populus*, *Alnus*, *Betula*, *Quercus*, *Prunus*, *Rhamnus*, *Acer*, *Cornus*, and *Arbutus*. *Can. Cartographics Ltd. Coquitlam, B.C.*

- Klinka, K., R.N. Green, R.L. Trowbridge, and L.E. Lowe. 1981. Taxonomic classification of humus forms in ecosystems of British Columbia. B.C. Min. For., Victoria, B.C. Land Manage. Rep. No. 8.
- Lindeburgh, S. 1995. Effects of fireweed and associated vegetation on conifer survival and growth in the southern interior—fifth year results. B.C. Min. For. and For. Can., Victoria B.C. FRDA Res. Memo No. 226.
- Lloyd, D., K. Angore, G. Hope, and C. Thompson. 1990. A guide to site identification and interpretation for the Kamloops Forest Region. B.C. Min. For., Victoria, B.C. Land Manage. Handb. No. 23.
- Pollack, J.C. and L.J. Herring. 1985. Experimental design protocol for forest vegetation management research: level A trials (first approximation). B.C. Min. For., Res. Rep. RR84012-HQ.
- Rowe, J.S. 1983. Concepts of fire effects on plant individuals and species. *In* The role of fire in northern circumpolar ecosystems. R.W. Wein and D.A. MacLean (editors). John Wiley and Sons, Ltd.
- SAS Institute Inc. 1985. SAS[®] User's Guide: Statistics, Version 5 ed. SAS Institute Inc., Cary, N.C.
- Shannon, C. and W. Weaver. 1963. The mathematical theory of communication. University of Illinois Press, Urbana, Ill.
- Simard, S. W. 1989. Competition among lodgepole pine seedlings and plant species in a Sitka alder-dominated shrub community in the southern Interior of British Columbia. M.S. thesis. Oreg. State Univ., Corvallis, Oreg.
- _____. 1990. Competition between Sitka alder and lodgepole pine in the Montane Spruce zone in the southern interior of British Columbia. B.C. Min. For. and For. Can., Victoria, B.C. FRDA Rep. No. 150.
- Simpson, E.H. 1949. Measurement of diversity. *Nature* 163:688.
- Sullivan, T.P. 1985. Small mammal damage agents which affect the intensive silviculture of lodgepole pine. *In* Lodgepole pine: the species and its management. Proc. symp. May 14–16, 1984, Vancouver, B.C. D.M. Baumgartner, R.G. Krebill, J.T. Arnott, and G.F. Weetmann (editors). pp. 97–106.
- Sit, V. 1995. Analysing ANOVA designs. *Biom. Info. Handb. No. 5*. B.C. Min. For., Res. Br., Victoria, B.C. Work. Pap. 07/1995.
- SYSTAT Inc., 1992. SYSTAT for Windows: Statistics, Version 5 ed. Evanston, Ill. 750 p.

APPENDIX. Percent cover of vascular plant species in 1995

Species	Control	Gly-3L/ha	Gly-6L/ha	Manual cut
<i>Alnus viridis</i> ssp. <i>sinuata</i>	22.27	18.21	14.65	2.93
<i>Paxistima myrsinitis</i>	16.8	20.87	19.13	16.8
<i>Vaccinium scoparium</i>	6.87	4.07	4.73	9.53
<i>Orthilia secunda</i>	4.07	2.33	3.33	2.67
<i>Epilobium angustifolium</i>	3.85	2.81	3.33	3.77
<i>Spiraea betulifolia</i>	3.6	0.6	0.73	3.27
<i>Hieracium albiflorum</i>	3.4	2.53	2.27	1.87
<i>Linnaea borealis</i>	3.27	1.8	5	4.4
<i>Rubus idaeus</i>	2.87	1.6	1.27	1.8
<i>Chimaphila umbellata</i>	2.13	3.6	0.93	1.2
<i>Lonicera utahensis</i>	2.07	0	0	0
<i>Symphoricarpos albus</i>	1.33	0.8	0.07	2.13
<i>Vaccinium membranaceum</i>	1.27	0.4	0.87	2.4
<i>Rubus parviflorus</i>	0.8	0.07	0.13	0.4
<i>Clintonia uniflora</i>	0.73	0.6	0	1.53
<i>Juniperus communis</i>	0.47	0	0.13	0
<i>Ribes lacustre</i>	0.4	0	0.2	0
<i>Sambucus racemosa</i>	0.4	0.07	0.07	0.2
<i>Taraxacum officianale</i>	0.4	0.2	0.4	0.53
<i>Ameianchier alnifolia</i>	0.33	0	0.07	0
<i>Festuca occidentalis</i>	0.33	0.07	0	0
<i>Trisetum spicatum</i>	0.33	0	0.07	0.53
<i>Carex</i> spp.	0.27	0	0.07	0.33
<i>Fragaria virginiana</i>	0.27	0	0	0.47
<i>Goodyera oblongifolia</i>	0.27	0	0	0
<i>Smilacina racemosa</i>	0.27	0.07	0.13	0
<i>Calamagrostis rubescens</i>	0.2	0.07	1	0.73
<i>Lonicera involucrata</i>	0.2	0.07	0.13	0
<i>Pseudotsuga menziesii</i>	0.2	0.33	0	0
<i>Festuca saximontana</i>	0.13	0.53	0.07	0.13
<i>Sorbus</i> spp.	0.13	0	0	0
<i>Abies lasiocarpa</i>	0.07	0	0	0
<i>Bromus</i> spp.	0.07	0.33	0.27	0.73
<i>Cinna latifolia</i>	0.07	0	0	0
<i>Galium triflorum</i>	0.07	0	0	0
<i>Ilex aquifolium</i>	0.07	0	0	0
<i>Osmorhiza chilensis</i>	0.07	0.07	0	0.07
<i>Ranunculus</i>	0.07	0	0	0
<i>Smilacina stellata</i>	0.07	0	0	0.07
<i>Aira</i> sp.	0	0	0.2	0.13
<i>Arctostaphylos uva-ursi</i>	0	0	0.67	0
<i>Calamagrostis canadensis</i>	0	0	0.13	0
<i>Circaea alpina</i>	0	0	0	0.33
<i>Koeleria macrantha</i>	0	0	0.07	0
<i>Lilium columbianum</i>	0	0	0	0.07
<i>Mahonia nervosa</i>	0	0.07	0.07	0
<i>Picea glauca</i>	0	0.13	0.07	0
<i>Pyrola asarifolia</i>	0	0.2	0.27	0.33
<i>Pyrola minor</i>	0	0.27	0	0
<i>Salix</i> spp.	0	0	0.07	0
<i>Streptopus streptopoides</i>	0	0	0.07	0
<i>Vaccinium myrtilloides</i>	0	0	0.07	0