A comparison of four treatments for weeding Engelmann spruce plantations in the Interior Cedar Hemlock Zone of British Columbia: ten years after treatment

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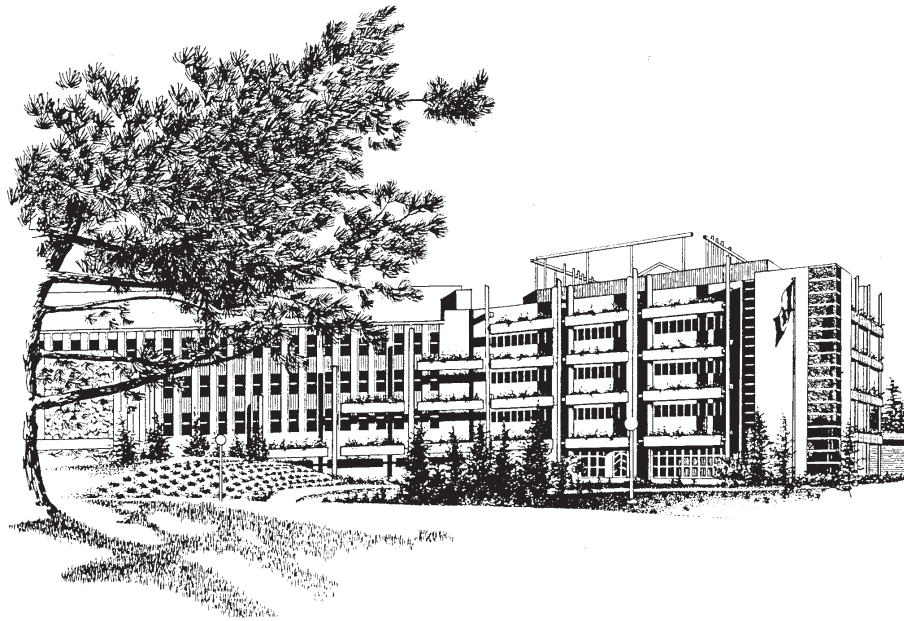**Pacific Forestry Centre, Victoria, British Columbia**

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A comparison of four treatments for weeding Engelmann spruce plantations in the Interior Cedar Hemlock Zone of British Columbia: ten years after treatment

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Abstract

In 1986, a field trial was established to test options for brushing young, shrub-dominated Engelmann spruce plantations in the moist warm Interior Cedar Hemlock biogeoclimatic subzone of British Columbia. Twelve 60 m × 60 m treatment plots were established in a randomized complete block design for three replicates of four treatments. Percent cover and height of thimbleberry, raspberry and fireweed was assessed before and up to five years after treatment. Conifer height, diameter and condition were measured before and up to ten years after treatment. Of the three treatments compared to an untreated control, broadcast application of glyphosate in late August at 1.8 kg a.i./ha was most effective in reducing cover and height of the major target complex. In comparison, manual cutting and broadcast application of 2,4-D amine at 3.0 kg a.e./ha had minor and short-lived effects. Engelmann spruce seedlings responded positively to reduction of cover and height of the target vegetation complex. Indicators of competitive stress, including seedling height:diameter ratio and competition index, were reduced following glyphosate treatment and remained at lower levels relative to all other treatments tested throughout the measurement period. Conifer height and diameter growth curves for the four treatments diverged over time, with seedlings in the glyphosate treatment growing at a faster rate than seedlings in all other treatments. Plots left untreated, manually cut, or treated with 2,4-D amine failed to meet minimum stocking standards in an operational silviculture survey conducted in 1993, eight years after treatment. By July of 1994, the plots treated with glyphosate satisfied all criteria for stocking, freedom from competition and annual growth rate set as standards for successful plantation performance in the ecosystem-specific guidelines of the Forest Practices Code of British Columbia.

Résumé

Un essai sur le terrain a été entrepris en 1986 pour vérifier diverses options de débroussaillement dans de jeunes plantations d'épinettes d'Engelmann dominées par des arbustes et situées dans la sous-zone biogéoclimatique humide et chaude à thuya et à pruche de l'intérieur de la Colombie-Britannique. Douze parcelles de 60 m^2 ont été implantées suivant un plan expérimental en blocs aléatoires complets comportant trois répétitions pour chacun des quatre traitements. Le pourcentage de couverture et la hauteur de la ronce à petites fleurs, du framboisier et de l'épilobe à feuilles étroites ont été évalués avant le traitement et jusqu'à cinq ans après. La hauteur, le diamètre et l'état des conifères ont été mesurés avant le traitement et jusqu'à dix ans après. Le traitement en plein au glyphosate effectué à la fin d'août, à raison de 1,8 kg m.a./ha, était celui des trois traitements qui, comparés à une parcelle témoin, a été le plus efficace pour réduire la couverture et la hauteur du principal complexe de mauvaises herbes ciblé. Par comparaison, le débroussaillement manuel et le traitement en plein au 2,4-D amine à une dose de 3,0 kg EA/ha ont eu des effets mineurs et éphémères. Les semis d'épinette d'Engelmann ont bien réagi à une diminution de la couverture et de la hauteur du complexe de mauvaises herbes ciblé. Les indicateurs du stress causé par la concurrence, y compris le rapport hauteur/diamètre des semis et l'indice de concurrence, ont diminué après le traitement au glyphosate et sont restés à des niveaux plus faibles que dans tous les autres traitements pendant la période de mesure. Les courbes d'accroissement en hauteur et en diamètre des conifères des quatre traitements divergeaient dans le temps, les semis traités au glyphosate présentant une croissance plus rapide que ceux de tous les autres traitements. Un relevé sylvicole opérationnel effectué en 1993, soit huit ans après les traitements, a permis de constater que les parcelles non traitées, débroussaillées à la main et traitées au 2,4-D amine ne satisfaisaient pas aux normes de densité relative minimale. Dès juillet 1994, les parcelles traitées au glyphosate étaient conformes aux critères de densité relative, d'autonomie de croissance et de taux annuel de croissance. Ces critères constituent les normes fixées dans les lignes directrices propres aux écosystèmes du Code de pratiques forestières de la Colombie-Britannique pour évaluer la performance d'une plantation.

Acknowledgements

Introduction

Background

Importance of vegetation management during forest crop establishment in the more productive ecosystems of British Columbia was broadly recognized by the mid nineteen eighties. The area of crown forest land treated for vegetation management increased from only 3000 ha in 1980 to 77 000 ha by 1990 (Hart and Comeau 1992). A need for ecosystem-specific information on the effectiveness of vegetation control treatments in specific brush complexes, and the longer-term response of conifer seedlings and plantations, was soon identified (Conard 1984; Sutton 1985a). A major research effort, funded primarily by the Canada-British Columbia Forest Resource Development Agreements, was initiated to address this need in British Columbia.

The most productive biogeoclimatic zone for timber growth in the interior of British Columbia is the Interior Cedar Hemlock (ICH) zone (Ketcheson et al. 1991). Mixed shrub and herb complexes often occupy moist and rich sites very soon after harvest and site preparation in this zone, and early survival and growth of conifer plantations can be severely reduced by physical damage or by competition for light and limited growing space (Coates et al. 1994). Species of major concern in the ICH include those which rapidly exploit openings through vegetative means after disturbance, such as thimbleberry (*Rubus parviflorus* Nutt.), red raspberry (*Rubus idaeus* L.) and fireweed (*Epilobium angustifolium* L.) (Haeussler and Coates 1986).

After extensive consultation with forest managers in the Nelson Forest Region during the winter of 1985, the Canadian Forest Service established a research trial in the Golden Forest District near Bush River to examine efficacy of four brushing options in a young Engelmann spruce (*Picea Engelmannii* Parry) plantation overtopped by a *Rubus-Epilobium* brush complex.

Objectives

The Bush River study had three main objectives:

• to compare the effect of four vegetation control treatments on percent cover and height of a *Rubus-Epilobium* brush complex;
• to compare the effect of four vegetation control treatments on survival and growth performance of planted Engelmann spruce seedlings; and,
• to describe the effects of four vegetation control treatments on vegetation community dynamics and on wildlife forage values.

This report addresses the first two objectives, discussing vegetation control efficacy over a five-year period and conifer growth responses for a ten-year period following application of four treatment options. The third objective was addressed by Clement and Keeping (1996).

Study area

The study area is located on a site with mesic to subhygric hygrotope and meso to permosotropic trophotope at Lat. 51°55′N; Long. 117°21′W, in the ICHmw1 (Golden Moist Warm Interior Cedar Hemlock biogeoclimatic variant) (Braumandl and Curran 1992). The site is located on the lower mesoslope position above the Bush River at an elevation of approximately 900 m (Figure 1). The aspect is south-easterly (145˚) on a slope of between 5% and 20%. Above the block, the valley rises steeply to the spectacular backdrop of the Rocky Mountains.

The climate is typical for the ICHmw1 but influenced by cold air drainage from the surrounding mountains and ice

fields. Soil parent materials vary from glaciofluvial to morainal in origin and the soils are moderately well drained. Soils are silt loams with moderate to high coarse fragment content; however, surface conditions are variable due to frequent alluvial outwash activity in some areas. Before harvest, forest cover was of natural origin, consisting of a mixed stand dominated by interior hybrid spruce (*Picea glauca* (Moench) Voss × *engelmanni* Parry ex Engelm), growing with western redcedar (*Thuja plicata* Donn ex D. Don) (forest cover label SC-941-G) and, in one corner of the block, with sub-alpine fir (*Abies lasiocarpa* (Hook) Nutt.) (forest cover label SB-(C)-831-M).

The 26-ha block was clearcut[1] with ground skidding in the winter of 1981, broadcast burned for planting site preparation in the spring of 1983, and planted to Engelmann spruce (Se) 2+0 bareroot seedlings (seedlot 2618) in the spring of 1984. By the end of the 1985 growing season, these spruce were overtopped by a mixed shrub and herb complex composed mainly of thimbleberry, raspberry and fireweed. At initiation of this study, in June 1986, experimental areas within the site were fill-planted with Se 1+0 PSB 313B container-grown seedlings (seedlot 10202) due to poor survival of the seedlings planted in 1984.

Methods

Treatments studied and experimental design

Four levels of treatment (Table 1) were applied to twelve 60 m × 60 m treatment plots in a randomized complete block design with three replicates (Figure 2). Each treatment plot was sub-sampled before treatment (Figure 3), and revisited for assessment of target vegetation and Engelmann spruce seedlings (after Herring and Pollack 1985) on the schedule shown in Table 2.
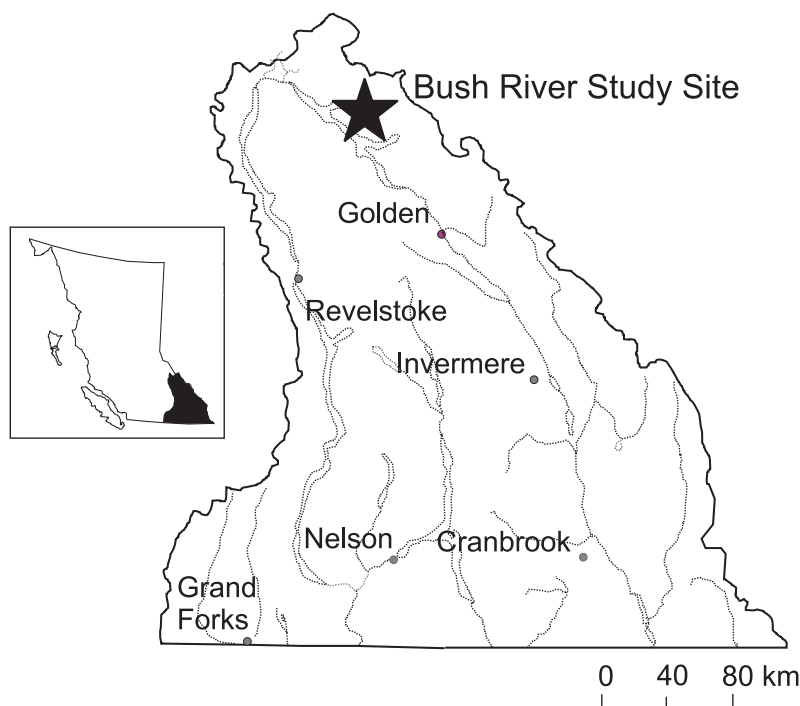
Figure 1. Location of study site

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[1] Forest License A17645 Cutting Permit 41 Block 12

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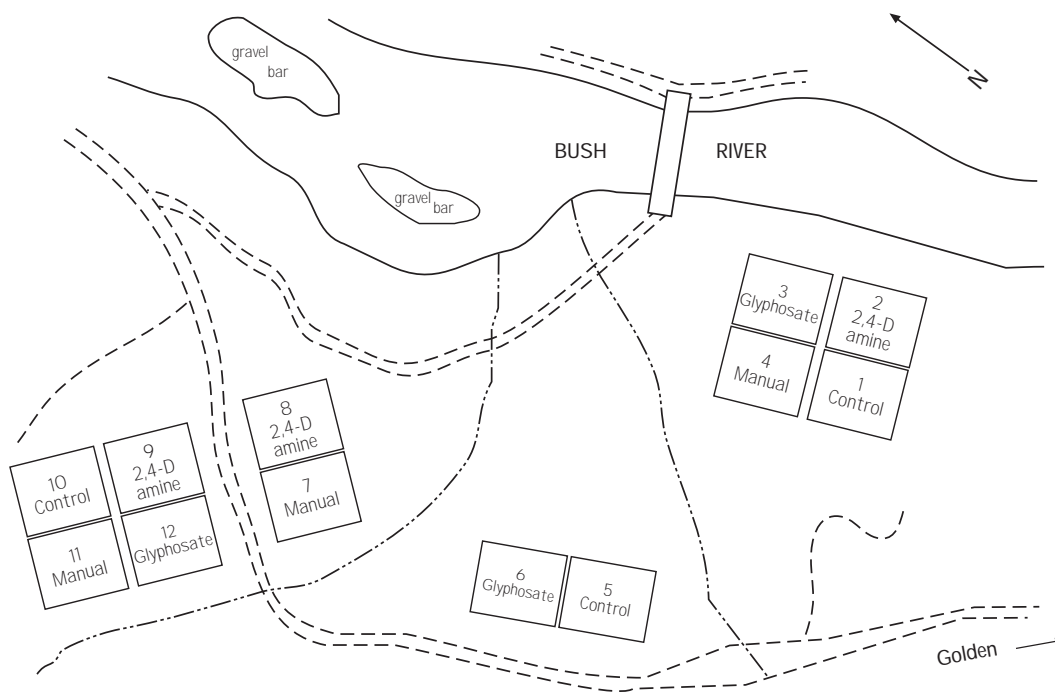
Figure 2. Plot layout in randomized complete block

○ **10-m² target species assessment plot**

◯ **50-m² survival assessment plot**

▮ **area where conifers were sampled**

▮ **400-m² plant community assessment plot**
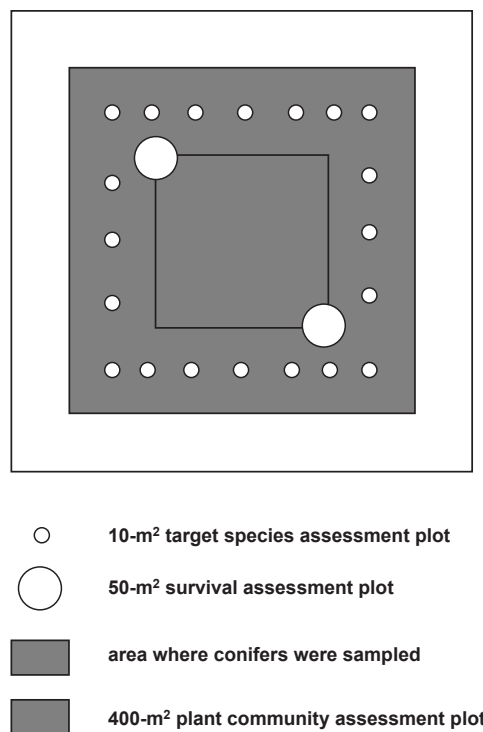
Figure 3. Subsampling within treatment plots

Table 1. Treatment levels tested

Treatment	Date
Glyphosate herbicide (as Roundup®) broadcast @ 1.8 kg a.i./ha	21-23 August, 1986
2,4-D amine herbicide (as Forestamine®) broadcast @ 3.5 kg a.e./ha	22-23 August, 1986
Manual brushing – non-crop vegetation cut as low to ground as practicable	19-27 August, 1986
Untreated control	n/a

Herbicides were broadcast applied in water carrier at 40L total solution per hectare using CP-3 backpack sprayers. Manual brushing was completed using Husqvarna 165r clearing saws with MAXI 255 circular blades.

Table 2. Crop seedling and target vegetation assessment dates

Assessment Date	Crop Tree Survival	1984 Planting Growth	1986 Planting Growth	Target Vegetation
July 1986	X	X		X
August 1987	X	X	X	X
August 1988	X	X	X	X
August 1989	X	X	X	X
August 1991	X	X	X	X
October 1993		X	X	
September 1996		X	X	

Table 3. ANOVA model for individual year conifer and target vegetation data

Source	Symbol		Degrees of freedom[1]	F-ratio
Block	B		2 (B-1)	MS(Block/MS(Block × Treatment)
Treatment	T		3 (T-1)	MS(Treatment)/MS(Block × Treatment
Block × Treatment	B × T		6 (B-1)(T-1)	MS(Block × Treatment)/MS(Error)
Subplots: Error	–		(N-1)BT	–
conifers (N=30)		348		
target vegn (N=20)		228		
Total	–			
conifers (N=30)		348		
target vegn (N=20)		228		

[1] Maximum numbers represented. Some subplots had missing values.

Measures and records

Percent cover and height of thimbleberry, raspberry, fireweed, and the major target complex (the same three species assessed as a single complex) were recorded at each of twenty 10-m^2 circular subplots in each treatment plot. At each assessment, heights were recorded for specific clumps of thimbleberry and raspberry (tagged pre-treatment), while estimates of subplot modal height were recorded for fireweed and the major target complex.

The number of tagged woody brush specimens available for height assessment after treatment was strongly affected by treatment-induced mortality. Height reported for woody species in post-treatment assessments was measured on the remaining live clumps. As a consequence, post-treatment heights reported for thimbleberry and raspberry do not reflect in-growth of new individuals, nor subplot averages. Post-treatment heights reported for fireweed, and for the major target complex, do reflect change due to in-growth after treatment.

A central 400-m^2 macroplot (Walmsley et al. 1980) was established in each treatment replicate to monitor gross change in plant community composition and structure over time. Analyses of data collected in these macroplots 8 years after treatment were reported by Clement and Keeping (1996).

Stem mapping, in standard regeneration plots established prior to treatment, was used to monitor direct treatment damage to conifer seedlings of both plantings. Circular plots (3.99 m radius) were centred on the northeast and southwest cornerposts of the plant community macroplots in each of the twelve treatment plots. Seedling condition, and cause of any damage, were recorded for all seedlings in each plot, by planting date, on each of the first five assessments dates.

A standard operational silviculture survey was conducted by Evans Products Co. Ltd. in 1993, using 3.99-m-radius plots established along a systematically located transect in each treatment plot (two assessment plots per replicate (three replicates per treatment). The number of conifers of acceptable species, number of well-spaced conifers, and number of free growing conifers[2] were recorded in each plot. Summary statistics were calculated on a per hectare basis for comparison.

Prior to treatment, thirty seedlings from the 1984 planting were located in each treatment plot for assessment of growth responses. Each seedling was marked with a uniquely numbered tag, and its location was mapped to facilitate remeasurement. Total height, inter-nodal lengths for the previous two growth increments, and basal diameter were recorded for each tagged seedling at each assessment. General condition of foliage, stem, and leader were noted (after Herring and Pollack 1985) and causes of any damage were assigned.

In the first growing season after treatments were applied (1987), seedlings from the 1986 fill-planting were also tagged for assessment of condition and growth response. It was not possible to locate thirty seedlings in all manually brushed or untreated control plots, and this resulted in unequal sample sizes across treatments.

Data summary and statistical analyses

Statistical analyses of response data were conducted separately for each assessment date as outlined in Nemec (1992), using the basic ANOVA design in Table 3 and SAS statistical software (SAS Institute Inc. 1985). Target vegetation response variables tested were height and percent cover of each of the three main target species and of the major target complex. Response variables tested for conifers (of both planting dates) were height and basal diameter. Pre-treatment values were used as a covariate for post-treatment comparisons whenever between-treatment differences were found to be significant in the pre-treatment year. Where significant treatment differences were found in the analyses of variance (or co-variance), Duncan's multiple range test was applied to determine which treatments differed.

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[2] Correlated guidelines for tree species selection (first approximation) and stocking standards (second approximation) for the ecosystems of British Columbia. Prepared by: Silviculture Interpretations Working Group, July 1993. Joint Publication of Natural Resources Canada and Province of British Columbia. 328 p.

A treatment-level competition index was approximated for each assessment date, by dividing the treatment mean for the sum of products of height and percent cover for the three individual target species by the treatment mean for seedling height, which is similar to the formula[3] used by Comeau and Braumandl (1991) and Comeau et al. (1993). Trend lines were plotted for graphical comparison. Height:diameter ratio was also calculated for each seedling at each assessment and treatment means were plotted for comparison of trends.

To examine the effect of time and of treatment × time interactions, crop tree height and diameter data were fitted to growth curves approximated by a quadratic function of the following form:

$$y_{ijkt} = \beta_{0,ijk} + \beta_{1,ijk}t + \beta_{2,ijk}t^2 + \varepsilon_{ijkt}$$

where i denotes the block, j is the treatment, k is the tree number, y_{ijkt} is the measured response (e.g., height) in year t, and ε_{ijkt} is the associated error. Estimates of the growth parameters ($\beta_{0,ijk}, \beta_{1,ijk}, \beta_{2,ijk}$ were obtained for each tree by fitting the above equation (by the method of least squares) to the response variables (height and diameter) and to their corresponding log transforms. Differences between the four treatment groups were then assessed with an ANOVA based on the following randomized block model (with sub-sampling):

$$b_{ijk} = \mu + \alpha_i + \tau_j + \alpha\tau_{ij} + \delta_{ijk}$$

where b_{ijk} is the least-squares estimate of ($\beta_{0,ijk}, \beta_{1,ijk}$ or $\beta_{2,ijk}$ for tree k, Treatment j, and block i, μ is the overall mean, α_i is the random effect of block i, τ_j is the fixed effect of treatment j, $\alpha\tau_{ij}$ is the random interaction of the block and treatment effects (combined with the random variation among treatment plots within blocks), and δ_{ijk} is the random effect of variation among trees. Owing to the unequal number of trees for each treatment and block combination, differences between treatments were assessed with an approximate F-test (the denominator sum of squares is a linear combination of the treatment × block and tree sum of squares). Residuals from the fitted model were examined for evidence of non-normality and other obvious problems.

A second analysis of treatment effect on tree growth was based on the block averages (over trees):

$$\bar{y}_{ijt} = \frac{\sum_{k=1}^{n_{ijt}} y_{ijkt}}{n_{ijt}}$$

where n_{ijt} is the number of trees receiving treatment j in block i and t is the year of measurement. Differences between treatment groups were assessed by carrying out a repeated-measures ANOVA of the sequence of means based on the following univariate model:

$$\bar{y}_{ijt} = \mu + \alpha_i + \tau_j + \alpha\tau_{ij} + \gamma_t + \alpha\gamma_{it} + \tau\gamma_{jt} + \omega_{ijt}$$

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[3] Both papers used the following formula for tree-centred, 5-m^2 circular plots: CI = (Ci × Hi)/Ht; where CI = Competition Index, Ci = percent cover of species i, Hi = height of species i; and Ht = seedling height

where μ is the overall mean, α_i is the random effect of block i, τ_j is the fixed effect of treatment j, $\alpha\tau_{ij}$ is the random interaction of block and treatment, γ_t is the fixed effect of time, $\alpha\gamma_{ij}$ is the random interaction of block and year, $\tau\gamma_{jt}$ is the fixed interaction between the effects of treatment and year, and ω_{ijt} is the effect of all other sources of random variation. Differences in the sample sizes n_{ijt} were ignored. Although the test for parallelism (i.e., no treatment × year interaction) makes no specific assumptions about the functional form of the time trends, it does require a particular type of correlation structure. To relax the stringent assumption of "sphericity" (i.e., constant variances and constant correlation between all pairs of repeated measures), the p-values for treatment × year were adjusted using the Huynh-Feldt method available in PROC GLM of SAS. Polynomial contrasts of the repeated measures were used to assess whether divergence of the growth curves could be attributed to different linear or quadratic (cubic, etc.) trends.

Results

Target vegetation control

Trends in percent cover of the major target complex (thimbleberry, raspberry and fireweed) from 1986 to 1991 are shown in Figure 4. Only the glyphosate application reduced percent cover significantly ($p<0.05$). This effect lasted throughout the five-year post-treatment assessment period. Modal height of the major complex was also significantly lower in the glyphosate treatment in comparison to the untreated control throughout the duration of the experiment and significantly lower than in all other treatments in the first and third post-treatment years (Figure 5). Effects of manual brushing and 2,4-D application on modal height are less definite, although there appears to be a general decline in modal height in both treatments.

Trends in percent cover of the three individual target species are presented in Table 4. Thimbleberry cover in the untreated control, manual brushing and 2,4-D plots varied only slightly throughout the five assessments (1986 to 1991), although levels in manually brushed plots were significantly lower than levels in untreated plots for the first two years after treatment was applied in 1986. In contrast, thimbleberry cover was sharply reduced in the plots treated with glyphosate to levels significantly lower than in all other treatments at all assessment dates, and it only recovered to 50% of the pre-treatment level after five years.

Glyphosate application also resulted in the largest reduction in thimbleberry height (Figure 6) which remained significantly lower than in any other treatment for the full five-year post-treatment assessment period. Manual brushing reduced thimbleberry height to levels significantly below the untreated control for one year only and application of the 2,4-D amine had no significant effect.

Both fireweed and raspberry cover declined in all treatments over the five-year duration of the experiment to about 50% of pre-treatment values. There was no significant treatment effect evident on raspberry cover or height (Figure 7). Both glyphosate and 2,4-D applications reduced cover of fireweed to levels significantly below those in manually brushed or untreated plots one year following treatment. Fireweed height was reduced by the glyphosate application, to levels significantly lower than in all other treatments, for one year only (Figure 8).
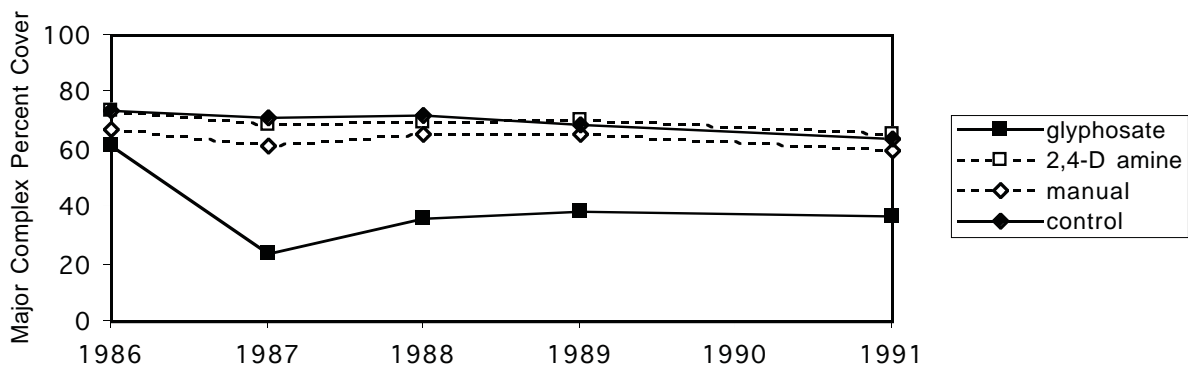
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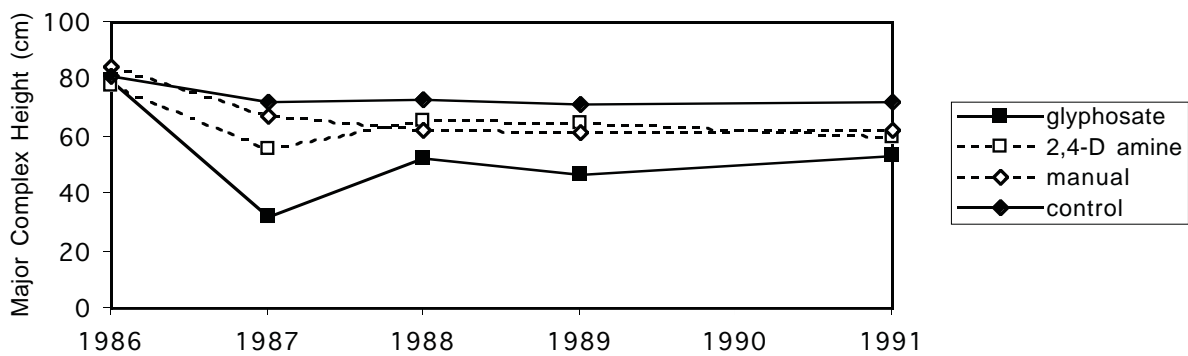**Figure 4. Percent cover of major target complex 1986-1991**

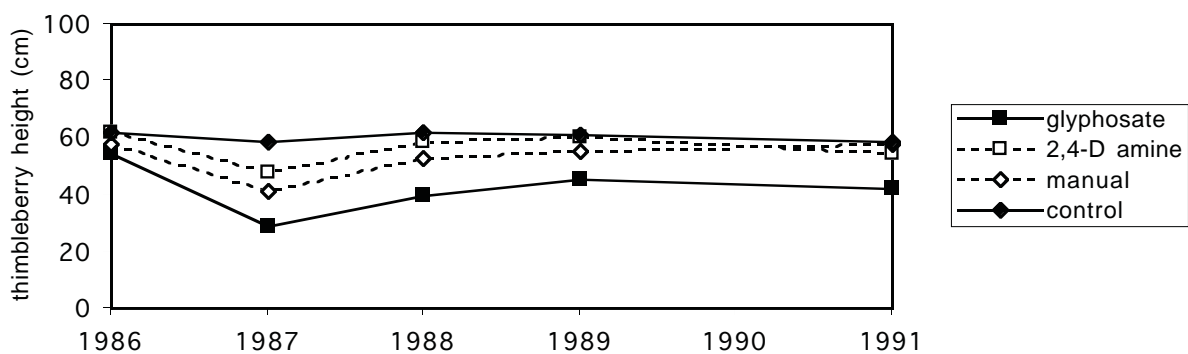**Figure 5. Modal height of major target complex 1986-1991**

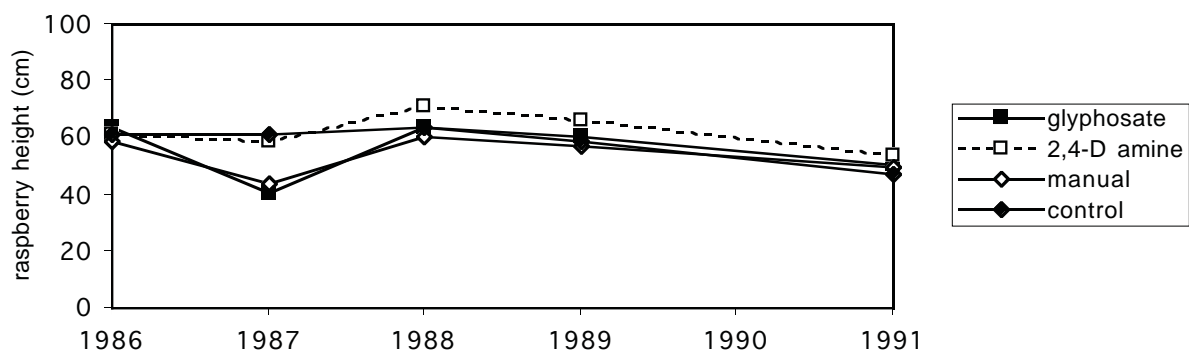**Figure 6. Mean height of thimbleberry, by treatment, 1986-1991**

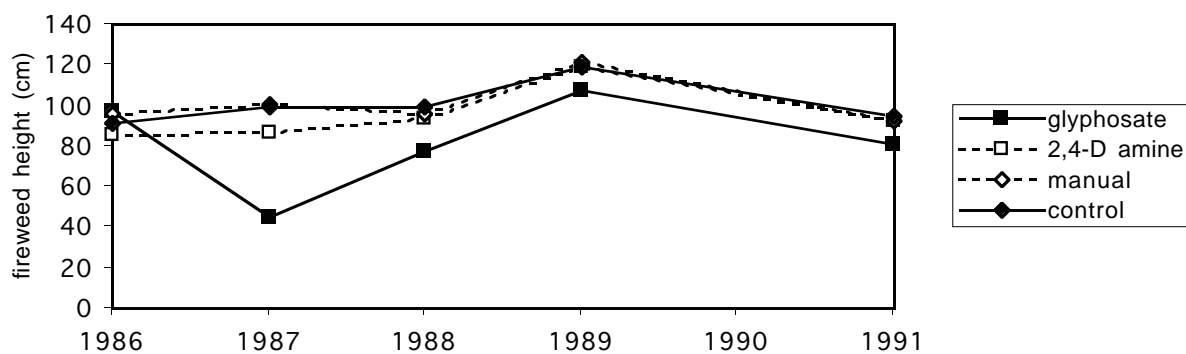**Figure 7. Mean height of raspberry, by treatment, 1986-1991**

Figure 8. Mean height of fireweed, by treatment, 1986-1991

Table 4. Mean percent cover of target vegetation by species, treatment, and year

Species	Treatment	Year 1986	1987	1988	1989	1991
Thimbleberry	glyphosate	22.93 (21.42)[2]	6.48 c[1] (11.84)	8.9 c (15.2)	9.33 b (14.32)	11.78 b (15.23)
	2,4-D amine	46.25 (18.72)	45.88 a (22.52)	48.5 ab (22.31)	47.05 a (20.66)	46 a (19.48)
	manual	40.07 (20.75)	36.15 b (22.85)	40.63 b (24.5)	40.27 a (23.39)	39.23 a (21.85)
	control	49.33 (21.38)	51.38 a (24.13)	54.92 a (21.3)	49.1 a (20.7)	47.47 a (19.34)
ANCOVA[3] $p>F$			**0.003**	**0.002**	**0.009**	**0.037**
Fireweed	glyphosate	28.6 (14.07)	11.77 b (6.16)	17.68 (9.87)	16.4 (10.22)	14.55 (9.23)
	2,4-D amine	24.62 (15.04)	14.83 b (8.53)	16.98 (11.21)	17.18 (11.88)	14.28 (8.09)
	manual	30.52 (16.41)	21.9 a (12.63)	24.98 (15.06)	22.72 (14.76)	16.57 12.0301
	control	28.03 (18.1)	24.55 a (15.84)	24.97 (14.96)	19.3 (10.68)	15.17 (8.56)
ANOVA $p>F$		0.822	**0.020**	0.262	0.379	0.808
Raspberry	glyphosate	28.52 (14.47)	9.22 (9.49)	14.32 (16.26)	14.35 (13.94)	12.82 (7.58)
	2,4-D amine	21.85 (15.77)	15.12 (12.31)	13.35 (12.53)	11.82 (8.95)	9.08 (8.46)
	manual	19.95 (15.0)	10.5 (6.73)	9.62 (6.12)	8.83 (5.88)	7.95 (4.68)
	control	15.4 (13.75)	13.28 (12.56)	8.4 (8.11)	7.18 (6.59)	6.13 (5.17)
ANOVA $p>F$		0.340	0.637	0.808	0.667	0.299

[1] Cover values followed by different letters are significantly different at $p \leq 0.05$.

[2] Standard deviation.

[3] Due to significant between treatment differences in mean percent cover for thimbleberry prior to treatment, analysis of covariance was necessary, using pre-treatment percent cover as the co-variate.

Conifer survival

Results of survival assessments (1986 to 1991) and of the 1993 operational silviculture survey are presented in Table 5 and Table 6.

Table 5. Percent survival of conifer seedlings following treatment

	1986	1987	1988	1989	1991
1984 Planting					
glyphosate (n=21)	100	100	100	100	100
2,4-D (n=17)	100	100	94	94	94
manual (n=20)	100	85	85	85	80
untreated (n=22)	100	100	96	96	96
1986 Planting					
glyphosate (n=28)	100	96	93	86	86
2,4-D (n=22)	100	100	100	100	100
manual (n=20)	100	100	95	95	95
untreated (n=24)	100	100	100	100	100

Table 6. Results of operational silviculture survey conducted in October 1993

Stocking (stems/hectare)	glyphosate	2,4-D amine	Manual Cutting	Control
Total conifers	2067	900	833	1467
Well-spaced conifers (lower confidence limit 90%)	1000 (853)	667 (398)	833 (531)	933 (645)
Free growing conifers	300	67	33	67

Conifer height

Trends in mean seedling height, by treatment, are shown in Figure 9 and Figure 10. Analysis of covariance for the 1984 planting gives only a weak indication of difference between treatment groups ($P<0.1$ at all assessments 5 years or more post-treatment). There is stronger indication of a treatment effect in the 1986 planting ($P<0.05$ for most post-treatment years). In both cases, multiple range testing suggests that mean height in plots treated with glyphosate is higher than in all other treatments. For the 1986 planting, mean height of seedlings in manually cut plots is significantly lower than in all other treatments ($P<0.05$) except the untreated control from 1991 onward. There is no significant difference between the 2,4-D and control treatments.

Analyses of variance for estimated growth parameters of individual trees (Table 7) yielded results consistent with analyses of individual year data. These results suggest that treatment had a significant effect on height growth for

the second planting; i.e., there is a significant treatment difference (P= 0.01) in the estimated linear co-efficient for log(height). Repeated measures ANOVA on the sequence of block means (Table 8) strengthens this conclusion, in that height growth curves for the second planting diverge significantly (the treatment × year interaction is significant at P=0.03 for height and P=0.02 for log(height)). Comparison of group means for total height increments (1996 height - 1987 height) indicates that mean height increment for the glyphosate group (151 cm) was significantly greater than mean height increment in all other treatments (127 cm for 2,4-D amine, 115 cm for manual brushing and 117 cm for the control) which did not differ significantly from each other (P=0.06 for the treatment effect).
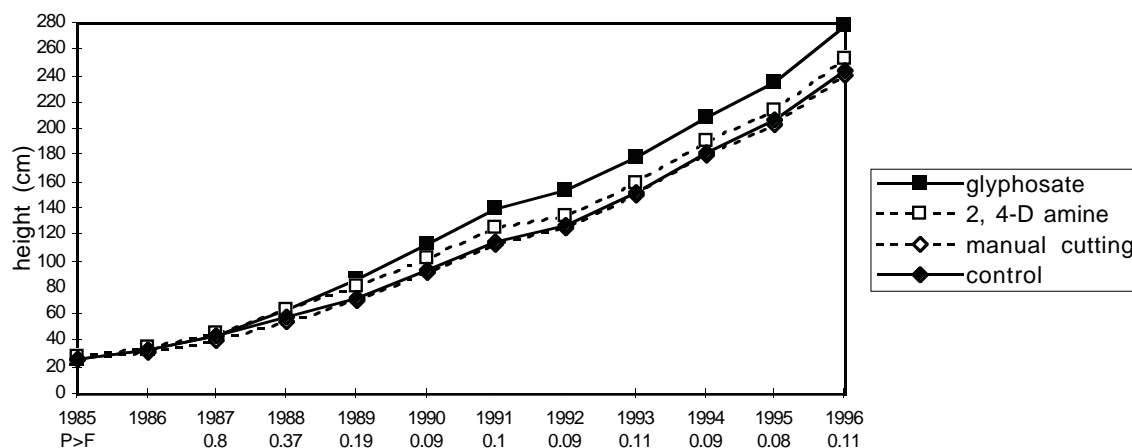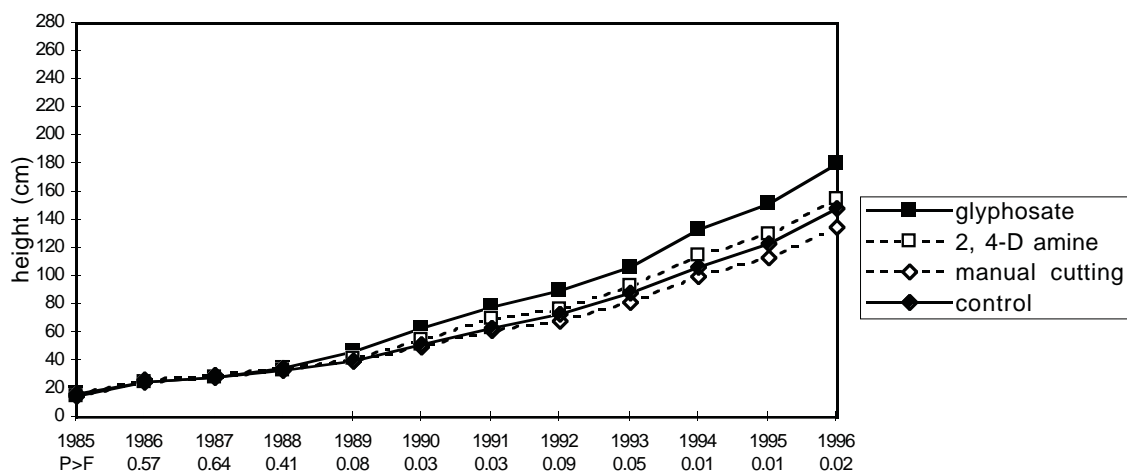

Figure 9. Height of seedlings planted in May 1984

Figure 10. Height of raspberry seedlings planted June 1986

Table 7. P-values based on ANOVA of estimated growth parametres

Response	Growth Parameter	1984 Planting	1986 Planting
Height	Intercept	0.3258	0.1345
	Linear	0.3732	0.1646
	Quadratic	0.8936	0.8688
Diameter	Intercept	0.1427	0.1244
	Linear	0.1406	0.2032
	Quadratic	0.5578	0.9179
Log (Height)	Intercept	0.3416	0.2092
	Linear	0.3177	0.0147
	Quadratic	0.3252	0.1250
Log (Diameter)	Intercept	0.1803	0.0965
	Linear	0.0779	0.0449
	Quadratic	0.0679	0.0648

Table 8. P-values based on repeated-measures ANOVA of block means of crop response variables

Response	Effect	1984 Planting	1986 Planting
Height	Treatment	0.1916	0.0887
	Treatment × Year	0.1023	0.0023
	Linear	0.1910	0.0402
	Quadratic	0.9234	0.5721
Diameter	Treatment	0.0490	0.1202
	Treatment × Year	0.0114	0.1019
	Linear	0.0681	0.1691
	Quadratic	0.4942	0.8496
Log (Height)	Treatment	0.1767	0.1986
	Treatment × Year	0.2059	0.0140
	Linear	0.2653	0.0574
	Quadratic	0.4137	0.7566
Log (Diameter)	Treatment	0.0400	0.1653
	Treatment × Year	0.0059	0.0317
	Linear	0.4201	0.2429
	Quadratic	0.0455	0.2823

Conifer diameter

Trend lines for mean seedling diameter, by treatment, are shown in Figure 11 and Figure 12. Analysis of variance and multiple range testing suggest that glyphosate application resulted in significantly larger mean diameters ($P < 0.05$) 2 to 3 years post-treatment, and that this effect continues through to ten years post-treatment ($P = 0.09$ for the 1984 planting; $P = 0.05$ for the 1986 planting). ANOVA for estimated growth parameters suggests a treatment effect on diameter growth ($P = 0.04$ for the linear co-efficient of log(diameter) in the 1986 planting; $P = 0.08$ and .07 for the linear and quadratic coefficients of log(diameter) in the 1984 planting). Tests for a Treatment × Year interaction on the sequence of block averages indicate that growth curves diverge significantly for both plantings ($P < 0.05$ for diameter and $P < 0.01$ for log(diameter) for the 1984 planting; P (0.10 for diameter and $P < 0.05$ for log(diameter) of the 1986 planting). For seedlings planted in 1984, comparison of group means for total diameter increment (1996 diameter - 1986 diameter) indicates that mean diameter increment for the glyphosate group (6.02 cm) was significantly greater than mean diameter increment in all other treatments (4.91 cm for 2,4-D amine, 4.63 cm for manual brushing and 4.72 cm for the control) which did not differ significantly from each other ($P < 0.05$ for all three comparisons, with no adjustment for the number of comparisons). Again, this effect was not as strong in the second planting, for which the mean diameter increments (1996 diameter - 1987 diameter) were 3.58 cm, 2.85 cm, 2.73 cm, and 2.50 cm respectively for glyphosate, 2,4-D amine, manual brushing, and control. In this case, only the difference between the glyphosate treatment and the control was statistically significant ($P < 0.05$).
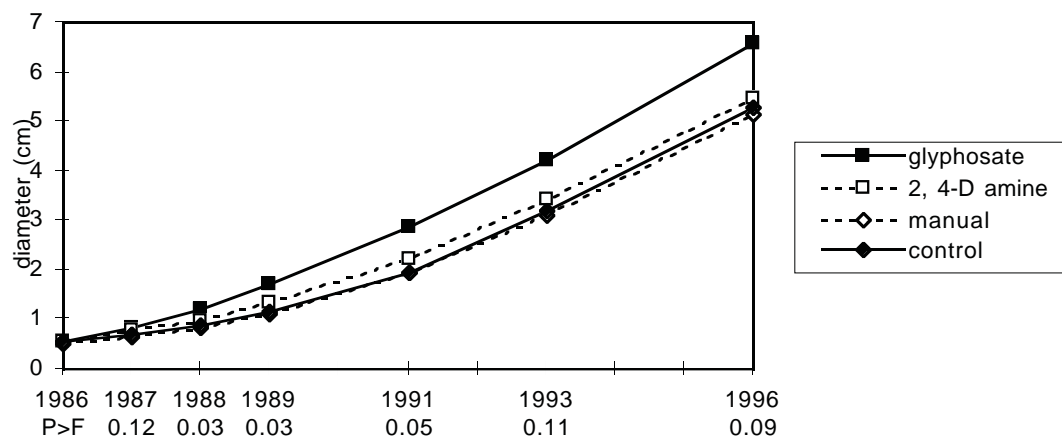

Figure 11. Diameter of seedlings planted May 1984
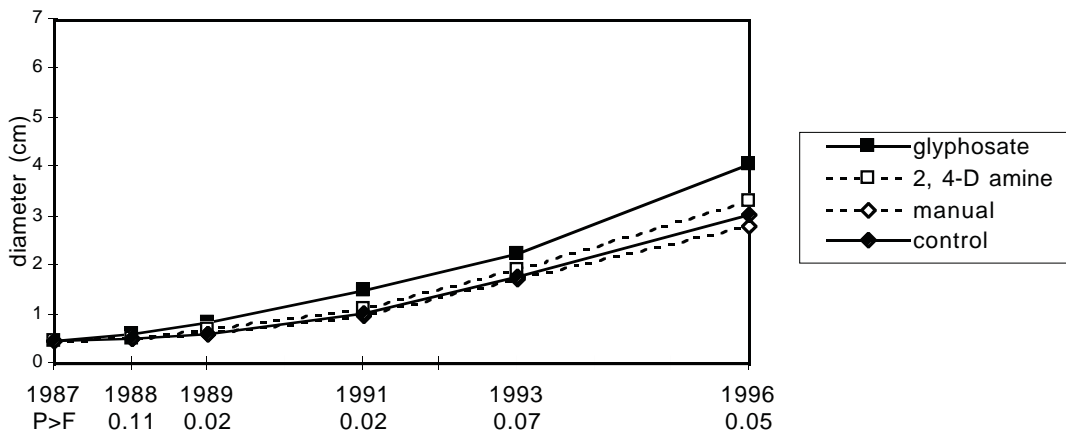
Figure 12. Diameter of seedlings planted June 1986

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Height:diameter ratio

The overall trend in conifer height:diameter ratio is shown in Figure 13 and Figure 14. Initially, the ratio was around 60:1 in both plantings, but it declined to less than 50:1 over the duration of the experiment. There is a sharp reduction evident relative to other treatments immediately after treatment with glyphosate for seedlings planted in 1984. Although not as pronounced, there is a similar relationship between treatments in the 1986 planting. Mean height:diameter ratio remained steady or declined in the glyphosate group for the first five years post-treatment, but tended to rise in all other treatments.
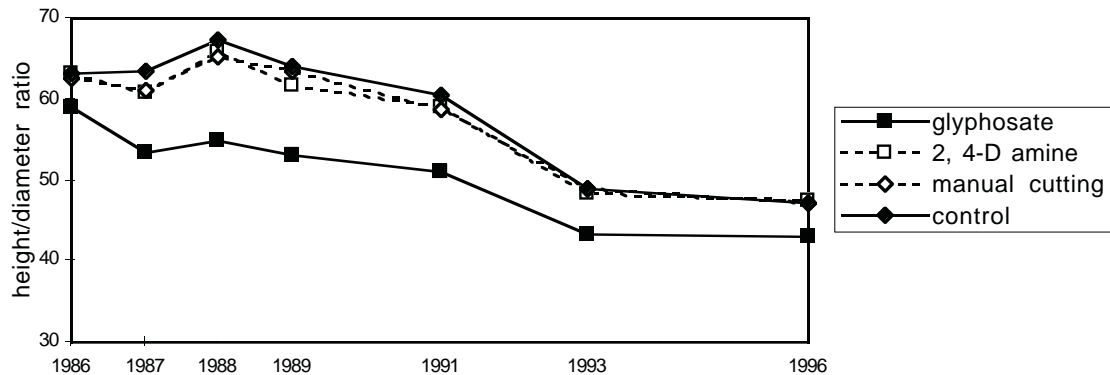
Figure 13. Height to diameter ratio of seedlings planted May 1984
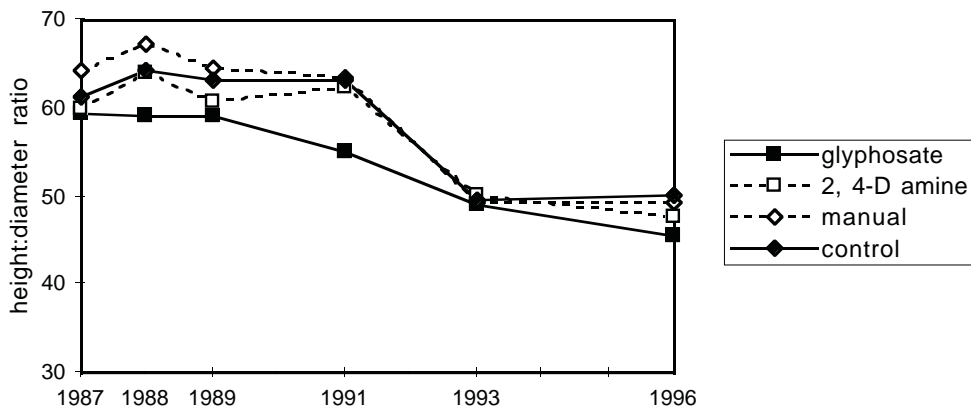
Figure 14. Height to diameter ratio of seedlings planted June 1986

Competition index

Competition index declined in all treatments over the first five years (Figures 15 and 16). The manual and 2,4-D treatments appeared to reduce competition index slightly relative to the untreated control for two growing seasons, while the glyphosate application provided a greater reduction, which lasted for at least five seasons.
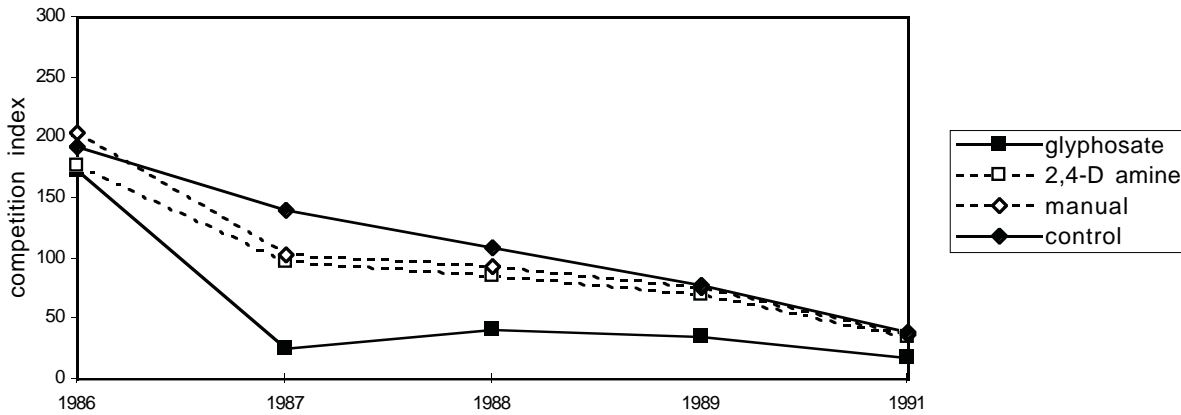
Figure 15. Competition index for five years post-treatment for 1986 planting
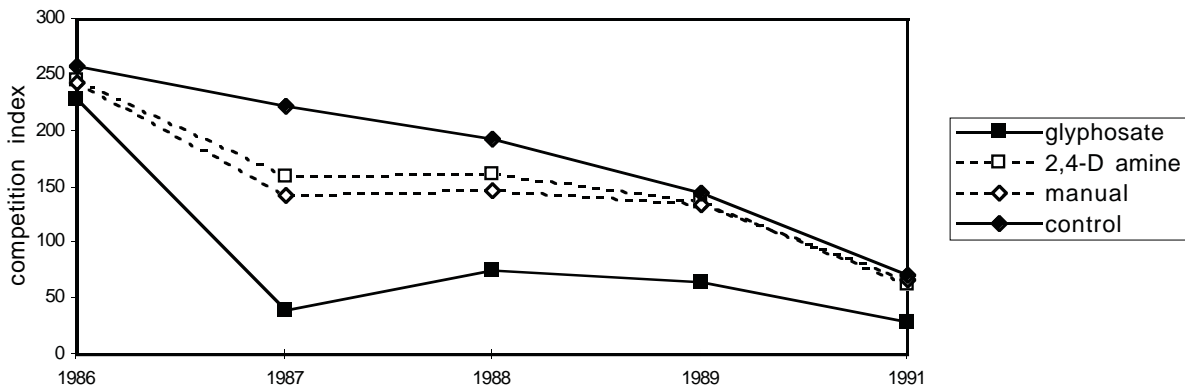
Figure 16. Competition index for five years post-treatment for 1984 planting

Discussion

Broadcast application of glyphosate had the most effect on the main competing species measured, reducing both height and percent cover to relatively low levels for at least five years after treatment. In comparison, broadcast application of 2,4-D amine and manual cutting treatments both had relatively short-term and minor effects on the main competing species. These observations are generally consistent with other studies comparing broadcast applications of glyphosate, manual cutting and untreated controls in this vegetation type over the short term (LePage and Pollack 1988; Haeussler and Coates 1986).

In their assessment of plant community composition and structure in the Bush River study plots, Clement and Keeping (1996) also reported that total vegetation cover, and percent cover and modal height of the shrub component were significantly lower than in any other treatment eight years after glyphosate treatment, suggesting that the treatment effects we observed lasted well beyond the period of our assessments.

While Hart and Comeau (1992) suggest that manual cutting of thimbleberry in mid-July may result in a slight reduction of re-sprouting, they also caution that a single cutting of thimbleberry and fireweed will only provide control until the following spring. The most efficacious period for foliar application of 2,4-D is also early in the growing season, soon after full leaf out (Newton and Knight 1981), and the low level of vegetation control observed in this study may have been due to the late season of application. Phenological development of the vegetation at the Bush River site was quite advanced by late August 1986 when treatments were applied. Colour change had commenced in foliage of both *Rubus* species prior to the herbicide treatments, and seed dispersal had begun in the fireweed. Glyphosate application is very effective during this late summer and early fall period (LePage and Pollack 1988; Biring et al. 1996).

In this experiment, conifer growth responses were strongly related to the degree of vegetation control observed, implying that competition with the target species was limiting seedling growth. Trends observed in a calculated competition index (CI) and in seedling height:diameter ratio support this hypothesis. Competition index was above 200 in all treatments in the pre-treatment year, but declined in the years following treatment as trees gained in height relative to the competing brush. Manual cutting and 2,4-D amine treatments reduced the competition index slightly for two growing seasons following treatment, while application of glyphosate provided a much greater reduction lasting for at least five seasons. The glyphosate application reduced CI to well below 100 in the first year, three to four years in advance of all other options tested. When calculated using a similar basis, competition indexes above 100 have been considered limiting to conifer growth, because of reduction in amount of sunlight reaching seedling height (Comeau 1993; Comeau et al. 1993).

One of the first visual signs of seedling stress due to competition is an increase in height:diameter ratio (Newton and Comeau 1990). Simard (1990) discusses this change in morphology in terms of preferential allocation of carbon to various carbohydrate sinks, arguing that height:diameter ratios increase when seedlings are competing with neighbouring vegetation because elongating shoots take priority over cambial tissue. For Douglas-fir (*Pseudotsuga menziesii* var *menziesii* (Mirbel) Franco), height:diameter ratios of 45:1 to 55:1 are normal in open grown plantations (Cole and Newton 1987), and long-term height diameter and volume increment in response to release may be jeopardized when height diameter ratio exceeds 60:1 (Newton and Comeau 1990). In this study, the ratio was 60:1 or higher in both plantings at time of treatment, and tended to rise or remain steady in all but the glyphosate treatment for at least five years post-treatment. In contrast, mean height:diameter ratio of seedlings in the glyphosate treatment was reduced shortly after treatment, and remained at lower levels throughout the ten year measurement period.

Only the glyphosate treatment resulted in longer-term significant effects on tree diameter, tree height and growth pattern. In all cases, seedlings treated with glyphosate were outperforming seedlings in all other treatments ten years after treatment. Sutton (1985b) reported that early weed control was still exerting highly significant effects on performance of white spruce (*Picea glauca* [Moench] Voss) three decades after treatment. Analyses of growth curves provides some assurance that differences in the size and growth of trees observed in our study will persist, at

least to crown closure; i.e. the growth curves are diverging, with seedlings in the glyphosate treatment becoming progressively larger over time, relative to seedlings of the other treatments.

Survival assessments in 1986 through 1991 suggested that both manual cutting and glyphosate applications have potential to cause some crop injury. Direct injury from the saw was noted at time of assessment as the cause of all mortality recorded in manually brushed plots (20% in the 1984 planting; 5% in the 1986 planting). Lower mortality in the 1986 planting may have been due to higher visibility, or smaller size, of these seedlings (which had been planted into screefed spots one month before treatment). Mortality of 15-30% has been noted during other manual cutting studies (Hart and Comeau 1992; Holmsen and Whitehead 1988). Cause of mortality over the first three years following glyphosate application (none in the 1984 planting; 14% in the 1986 planting) was not attributed to direct chemical injury; however, reduction of vegetation cover to very low levels may have contributed to injury from radiation frosts (Stathers 1989).

The efficacy of a brushing treatment during plantation establishment is best measured relative to the silvicultural objective. In British Columbia, the Forest Practices Code of British Columbia Act and associated Regulations require forest managers to establish healthy and free-growing stands within ecosystem-specific timeframes on all Crown forest land harvested. Three important criteria[4] for evaluating plantation establishment are used in evaluating compliance with these regulations: stocking of healthy, well-spaced and ecologically suited trees; freedom from overtopping vegetation; and tree vigour. For the Bush River study site (ICHmw1), British Columbia Ministry of Forests guidelines specify a target stocking of 1200 well-spaced stems per hectare (700 minimum), at greater than 150% of surrounding brush height, and exceeding minimum leader growth standards (for Engelmann spruce, 15 cm average annual growth for the preceding three seasons) within 9 to 15 years of harvest.

The effect of treatment on well-spaced stocking was not adequately measured in the survival plots, as spacing was not recognized as a factor when examining seedlings for treatment-induced effects on condition and mortality; however, the operational free-growing survey conducted in 1993, ten years post-harvest, provides insight. The highest stocking (total, well-spaced and free growing) was recorded in plots treated with glyphosate. In fact, only the area treated with glyphosate met standards for well-spaced stocking at the time of assessment within 90% confidence limits; stocking in all other plots was below the allowable minimum.

Strata summary notes on the silviculture survey plot cards state that most seedlings were not considered free-growing in October of 1993 because "trees had still not outgrown the *Epilobium*" (i.e., they did not exceed 150% of fireweed height). Clement and Keeping (1996) reported modal heights for both spruce and fireweed, by treatment, from data collected at the Bush River study site in July of 1994. The ratio of modal spruce height to modal fireweed height was 2.21 in plots treated with glyphosate, 1.37 in plots treated with 2,4-D amine, 1.20 for the untreated control and 1.19 in the manually cut plots, suggesting that areas treated with glyphosate satisfied free-growing criteria in 1994, thirteen years after harvest.

Average annual leader growth over the three years preceding the silviculture survey for spruce seedlings planted in 1984 exceeded the required standards in all treatment plots (23.2 cm, 21.7 cm, 22.2 cm and 22.6 cm, respectively, for areas treated with glyphosate, 2,4-D amine, and manual cutting and for the untreated control). For the later planting, only those seedlings treated with glyphosate or 2,4-D amine met standards (17.8 cm, 15.5 cm, 13.6 cm, and 14.4 cm, respectively, for seedlings treated with glyphosate, 2,4-D amine, and manual cutting and for the untreated control).

Based on these criteria, the only silviculturally efficacious brushing treatment tested in this study was broadcast application of glyphosate at 1.8 kg a.i./ha in late August three years after site preparation.

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[4] Correlated guidelines for tree species selection (first approximation) and stocking standards (second approximation) for the ecosystems of British Columbia. Prepared by: Silviculture Interpretations Working Group, July 1993. Joint Publication of Natural Resources Canada and Province of British Columbia. 328 p.

Summary and conclusions

Of the three treatments compared to an untreated control, broadcast application of glyphosate in late August at 1.8 kg a.i./ha was most effective in reducing cover and height of fireweed, raspberry and thimbleberry. In comparison, manual cutting and broadcast application of 2,4-D amine at 3.0 kg a.e./ha had minor and short-lived effects.

Engelmann spruce seedlings, planted two years before treatment, or in the same year treatments were applied, responded positively to reduction of cover and height of a thimbleberry, raspberry and fireweed vegetation complex. Only the glyphosate treatment resulted in longer-term significant effects on tree diameter, tree height and growth pattern. For ten years following treatment, both diameter and height growth were greater after glyphosate application than after any other treatment tested.

Indicators of competitive stress in Engelmann spruce seedlings, including seedling height:diameter ratio and competition index were reduced following glyphosate treatment, and remained at lower levels relative to all other treatments tested for the duration of the measurement period, suggesting that early vegetation control has lasting effects on seedling performance. Analyses of growth curves suggest that differences in tree size between treatment groups will increase with time, at least to crown closure. Height and diameter growth curves for the four treatments are diverging, with seedlings in the glyphosate treatment growing at a faster rate than seedlings in all other treatments.

The efficacy of a brushing treatment applied early during plantation establishment is best judged by its impact on the silvicultural objective. Areas left untreated, manually cut, or treated with 2,4-D amine failed to meet minimum stocking standards in an operational silviculture survey conducted in 1993 twelve years after harvest. By July of 1994, the area treated with glyphosate satisfied all criteria for stocking, freedom from competition and annual growth rate set as standards for successful plantation performance in the ecosystem-specific guidelines of the Forest Practices Code of British Columbia.

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