Effects of vegetation control treatments for release of Engelmann spruce from a mixed-shrub community in southern British Columbia – Year 15 results

by Philip G. Comeau[1] and George J. Harper[2]

ABSTRACT

Fifteen-year results from a study initiated in 1992 to compare the effectiveness of repeated cutting treatments with treatments involving single cutting or a single application of glyphosate herbicide are presented. While treatments resulted in significant improvements in diameter and height of planted spruce at ages 3 to 7, these differences were no longer significant in year 15. All vegetation control treatments significantly increased survival in year 15 but did not significantly affect average spruce size. Despite apparent initial treatment effects on vegetation cover, the treatments applied in this study have had little lasting effect on non-crop vegetation.

Key words: vegetation management, herbicides, glyphosate, manual, interior spruce, mixed shrub complex, Interior Cedar Hemlock Zone.

RÉSUMÉ

Les résultats après 15 ans d'une étude amorcée en 1992 pour comparer l'efficacité des traitements de dégagement par coupes répétitives aux traitements de dégagement par coupe unique ou par application unique de l'herbicide glyphosate sont présentés dans cet article. Même si les traitements ont permis d'enregistrer des gains significatifs en termes de diamètre et de hauteur chez les semis d'épinette à la troisième et la septième année, ces différences n'étaient plus significatives à la quinzième année. Tous les traitements de contrôle de la végétation ont permis un accroissement du taux de survie 15 ans plus tard mais n'ont eu aucun effet significatif sur la taille moyenne des épinettes. Malgré les effets apparents dès le début sur le couvert végétal, les traitements réalisés dans cette étude ont eu que peu d'effet durable sur la végétation non prévue pour faire partie d'une récolte.

Mots clés : contrôle de la végétation, herbicides, glyphosate, manuel, épinette de l'intérieur, association d'arbustes, forêt de thuya et de pruche de l'intérieur

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Introduction

Vegetation management practices are recognized as being important to accelerating growth, achieving high yields and for maintaining certain types of forest structures in the landscape (Pitt *et al.* 2004, Pitt and Bell 2005, Wagner *et al.* 2006). However, some reports indicate substantial variation in the existence and magnitude of these growth gains (Comeau *et al.* 1999, Simard *et al.* 2001, Heineman *et al.* 2005).

Forest vegetation management activities have steadily increased across British Columbia (BC) over the last 30 years. Brushing activities in BC increased from 3000 ha in 1980/1981 to about 60 000 ha and a cost of approximately $25 million in the 1989/1990 fiscal year (BCMF 1991). In 1999/2000, 80 843 ha of public forest land across the province was brushed, of which 46 333 ha were treated manually (including manual and motor-manual cutting, bending and girdling). Manual brushing represented 62% of total brushing expenditures and 57% of the area brushed, at a cost of $29 million (BCMF 2000). In southeastern BC (Nelson Forest Region) 88% of the area brushed in 2000 was treated manually and 10% chemically by ground applications. In 2002/2003 the total hectares brushed provincially declined by approximately 29% from 89 526 ha in 2001/2002 and by another 25% in 2003/2004 to 46 952 ha. In 2006/2007, 40 087 ha of public forest land were brushed, of which 21 197 ha were manually treated (manual and motor-manual cutting, girdling, bending, clipping and mulching). In the Southern Interior Region, manual brushing accounted for 85% of all area treated. In the Northern Interior Region, manual brushing accounted for only 33% with ground and aerial herbicide application representing 63%.

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Manual brushing methods are socially acceptable, and they are subject to few, if any, environmental constraints. However, cutting treatments generally provide only short-term relief from competing vegetation with control often lasting only for the balance of the growing season during which the treatment was applied (Miller 1985; Hart and Comeau 1992; Comeau *et al.* 1999, 2000). Several studies have found that a single manual treatment may be ineffective for controlling cover sufficiently to benefit seedling growth for more than a few years (Harper *et al.* 1997a, b; 1998; Whitehead and Harper 1998; Comeau *et al.* 2000; Simard *et al.* 2001; Heineman *et al.* 2005). Consequently, when manual brushing is being used to control vegetation around young conifer seedlings it may be necessary to repeat treatments on an annual or more frequent basis (Ehrentaut and Branter 1990, Comeau *et al.* 1999). For example, repeated cutting of competing species improved the 5-year height and stem diameter of Douglas-fir on the central coast of California (McDonald *et al.* 1994). Harper *et al.* (1998) report that at least 2 subsequent years of cutting are required to change the dry-warm ICH site from a paper birch- to a Douglas-fir-dominated stand. However, manual cutting treatments can cost up to 3 times more per hectare than aerially applied herbicide (Comeau *et al.* 2000, Dampier *et al.* 2006).

Season of treatment has been shown to influence the effectiveness of cutting treatments applied to young broadleaf trees (Bell *et al.* 1999) and some information suggests that early to midsummer treatments may be more effective for fireweed control than spring treatments (Hart and Comeau 1992). However, there have been no published studies examining effects of timing of single and repeated cutting treatments in mixed-shrub communities in southern BC.

Treatments using herbicides such as glyphosate (Vision ®) generally provide vegetation control that can result in larger and more predictable growth responses. Glyphosate can provide control of a wide range of shrubs and herbs at fairly low rates whereas conifers have some resistance depending on their stage of development during the growing season. A single application of glyphosate during the first few years after planting has been shown to effectively improve conifer growth 9 to 20 years later in a wide range of plant communities in various ecosystems in British Columbia (Harper *et al.* 1997a, b; Whitehead and Harper 1998; Biring *et al.* 1999, 2000, 2001; Biring and Hays-Byl 2000; Simard *et al.* 2001; Harper *et al.* 2005; Boateng *et al.* 2006; Macadam and Kabzems 2006). The efficacy of glyphosate for vegetation control is due to its ability to suppress competing vegetation for more than one season.

This article presents 15-year results from a study initiated in 1991 to examine the effectiveness of various vegetation control treatments for controlling mixed-shrub communities and for increasing survival and growth of planted Engelmann spruce seedlings. Fifth-year results from this study were presented by Comeau *et al.* (2000) and 10-year results were presented by Biring *et al.* (2003). Yield forecasts for the treatments used in this study are presented by Harper *et al.* (2008).

The objectives of this paper are:

i) To compare the effects of single and repeated manual cutting treatments and a single glyphosate herbicide application on survival and growth of planted Engelmann spruce seedlings;
ii) To discuss the potential longer term impacts of these treatments on yield, stand structure, and plant community diversity,
iii) Evaluate the usefulness of early (age 5) measurements of competition and tree response for predicting future (age 16) tree response.

Methods

The study was established at Soards Creek near Mica Dam in southeastern British Columbia in the fall of 1991. The study site is located in the very wet cool subzone variant of the Interior Cedar Hemlock (ICH) biogeoclimatic zone. It has a subhygric soil moisture regime, a rich soil nutrient and is classified as site series CwHw–Devils' Club–Lady Fern (Braumandl and Curran 1992). Aspect is 170°, slope ranges from 10% to 30%, and elevation is 860 m. The site was harvested in 1983/1984, broadcast burned in October 1984, and planted with Engelmann spruce (1+0 PSB 313) in June 1985. Five years after planting in 1990, the plantation was declared a failure, primarily due to intense vegetation competition. Prior to replanting, the site was mechanically prepared using a D6 cat with an excavator in August of 1990. The site was subsequently planted with 1-year-old (1+0 PSB 415B) Engelmann spruce seedlings at a 2.7 m espacement in June of 1991.

The study used a completely randomized design (CRD) consisting of 8 treatments replicated 3 times with treatments assigned to 30 m × 30 m plots. The treatments comprised 6 combinations of spring, summer and annual repeated manual cutting, a single application of glyphosate, and an untreated control (Table 1). Within the central 20 m × 20 m portion of each treatment plot, 20 Engelmann spruce seedlings were systematically selected and tagged for morphological measurements (e.g., height and diameter) and qualitative assessments (e.g., survival).

Manual cutting treatments were applied to the entire plot using hand tools (e.g., grass whips, machetes, and hand shears) to cut all vegetation including broadleaf species to within 5 cm of ground level. The herbicide glyphosate was applied at a rate of 2.1 kg a.e. ha^{-1} with a backpack sprayer on August 20, 1992. Approximately 0.6 litres of glyphosate product (Vision ®) in 10 L spray volume (with water) was used per treatment plot. Wind speed ranged from 0 to 2 km/hr, wind direction was 300°, relative humidity was 50% and air temperature was between 18°C and 20°C during the glyphosate application.

The selected Engelmann spruce seedlings were measured in years 0 (pre-treatment), 1, 2, 3, 4, 5, 7, 10, and 15. Measurements included total height, groundline diameter, diameter at 1.37 m height (DBH), crown diameter, and height to the crown base. Vegetation was assessed for 20 seedlings in each treatment plot in 1992 and for 10 seedlings in each treatment plot in subsequent years. In the manual cutting treatment plots that included spring cutting (a, c, e) and the untreated control (h), pre-treatment vegetation assessments were completed on June 24th, 1992. Vegetation assessments were completed prior to summer brushing treatments in each of the 24 treatment plots in July of 1992. In subsequent years, vegetation assessments were completed during mid-summer prior to any cutting treatments being applied.

Data analyses were carried out with SAS® software Version 9.1 (SAS Institute Inc., Cary NC). The experiment was

Table 1. A description of the 8 treatments applied in the study (from Biring *et al.* 2003)

Treatment	Common treatment name	Treatment symbol	Year of application	Dates of application
Spring (1992) [1 cutting]	Single spring cutting	**a**	1992	June 25–26, 1992
Summer (1992) [1 cutting]	Single summer cutting	**b**	1992	July 25–28, 1992
Spring (1992+) [1 × yr^{-1} for 3 yr][a]	Repeated spring cutting for 3 years	**c**	1992 + annually	June 25–26, 1992; June 15–17, 1993; June 16, 1994
Summer (1992+) [1 × yr^{-1} for 3 yr]	Repeated summer cutting for 3 years	**d**	1992 + annually	July 25–28, 1992; July 20–22, 1993; July 21, 1994
Spr+sum (1992+) [2 × yr^{-1} for 3 yr][b]	Spring and summer cutting (in a year) for 3 years	**e**	1992 + annually	June 25–26, 1992; July 25–28, 1992; June 15–17, 1993; July 20–22, 1993; June 16, 1994; July 21, 1994
Spr+sum (1993+) [2 × yr^{-1} for 2 yr]	Spring and summer cutting (in a year) for 2 years	**f**	1993 + annually	June 15–17, 1993; July 20–22, 1993; June 16, 1994; July 21, 1994
Glyphosate [2.1 kg a.e. ha^{-1}]	Single VISION® treatment	**g**	1992	August 20, 1992
Untreated control	Control	**h**	–	–

[a]Spring 1992+ [1 × yr-1 for 3 yr] = 1 cutting every year for 3 years
[b]Spr+sum (1992+) [2 × 3 yr-1 for 3 yr] = 2 cuttings every year for 3 years.

analysed as a single factor, completely randomised design with 8 treatments and 3 replications. Due to significant ($p \leq 0.05$) pre-treatment differences in seedling height and groundline diameter, analysis of covariance (ANCOVA) was used to analyze the data for 1992 to 2006 using 1991 values as covariates. Fisher's Least-Significant-Difference (LSD) test was used to make comparisons among treatment means. Polynomial contrasts were also used to make comparisons between treatments (Table 2). Coefficients for planned polynomial contrasts between treatments can be found in Biring *et al.* (2003). Logistic regression was used to test for treatment effects on seedling survival.

Results

In 2006, 16 growing seasons after planting (and 15 growing seasons after the start of the experiment), cover of conifers was significantly higher in the glyphosate and some of the other repeated cutting treatments (d and f) compared to the untreated control (Table 2). This is a result of greater conifer crown expansion and higher survival of both planted and natural regeneration in treated plots. Biring *et al.* (2003) reported that spruce densities in most treatments exceeded original planting densities, indicating natural regeneration. Spruce densities at age 10 were generally much greater in treated plots than in untreated. Densities of other conifers did not differ between treatments in year 10. While total vegetation cover was highest in the untreated, differences between treatments are non-significant, as are differences in cover of other layers. This contrasts with the significant differences in cover detected in years 1, 2 and 3 of the study (Fig. 1).

Table 3 presents treatment means for the 15th-year post-treatment measurement of the tagged spruce and Table 4 provides the results from the various planned polynomial contrasts. Tests for overall treatment effect (p-value) indicated that % survival was significantly influenced by the various treatments. Survival over the 16 years averages 56.7% in the untreated control. Survival results mirror those found in year 10 (Biring *et al.* 2003) where significantly higher survival was found in the manual cutting (single and repeated) and glyphosate treatments when compared to the untreated control. In addition, repeated cutting and the single glyphosate treatments resulted in improvements in survival over only 1 year of treatment. The untreated control and single summer cutting treatments were the only treatments where survival declined after the 10th year (Fig. 2).

While there are some apparent treatment differences in height (Fig. 3) and diameter growth (Table 3), no significant differences were noted in the 2006 treatment means for tagged spruce total height, height increment, DBH, diameter increment, stem volume (STV = m^3/tree*100) or height: diameter ratio (HDR; height and diameter increment results not shown). The glyphosate treatment did not result in significant changes in average height, diameter increment or DBH of surviving trees in 2006 compared to the other treatments.

Given the substantial interest in making decisions about the future growth of plots from survey data we present a simple illustration of relationships between earlier measurements and tree height and DBH in 2006. As Fig. 4 shows, relationships between size at age 16 (2006) and size in preceding years becomes stronger with age. The significant linear relationships indicate the importance of tree size to future development and the need to ensure early vigorous growth to optimize plantation performance.

Discussion

Plant community impacts

The lack of significant differences in cover indicates that treatments have had little impact on long-term vegetation develop-

Table 2. Effects of treatment on vegetation cover (15th year data)

Treatment		Percent cover						
		Total	CONF	BRDL	TSHR	LSHR	HERB	GRASS
Spring (1992) [1 cutting]	**a**	110 ± 4.2[a]	28 ± 2.2[bc]	4 ± 1.3	11 ± 3	29 ± 2.5	35 ± 3.4	3 ± 0.8
Summer (1992) [1 cutting]	**b**	114 ± 3	26 ± 2.7[bc]	11 ± 2.9	13 ± 3.3	32 ± 3.2	28 ± 3.5	4 ± 1.2
Spring (1992+) [1 × yr^{-1} for 3 yr][b]	**c**	108 ± 3.1	27 ± 1.6[bc]	10 ± 2.8	6 ± 1.4	22 ± 2.9	41 ± 2.9	2 ± 0.5
Summer (1992+) [1 × yr^{-1} for 3 yr]	**d**	115 ± 3.2	30 ± 2.2[ab]	10 ± 1.9	19 ± 4.1	25 ± 2.7	25 ± 2.8	6 ± 1.3
Spr+sum (1992+) [2 × yr^{-1} for 3 yr][b]	**e**	108 ± 3.8	30 ± 1.6[bc]	9 ± 2.1	9 ± 2.3	29 ± 3	26 ± 2.8	4 ± 1
Spr+sum (1993+) [2 × yr^{-1} for 2 yr]	**f**	116 ± 3.1	31 ± 2.4[ab]	7 ± 2.1	13 ± 2.9	32 ± 3.6	28 ± 3.8	5 ± 1.6
Glyphosate [2.1 kg a.e. ha^{-1}]	**g**	101 ± 3.4	39 ± 3.4[a]	3 ± 0.7	7 ± 2.9	13 ± 2.1	29 ± 3	11 ± 3.2
Untreated control	**h**	131 ± 3.7	21 ± 1.8[c]	12 ± 3.3	16 ± 3.2	38 ± 3	37 ± 4	7 ± 1.9
p- value		*0.0741*	***0.0344***	*0.7544*	*0.6808*	*0.1307*	*0.1529*	*0.6670*

CONF = Coniferous; BRDL = Broadleaves; TSHR = Tall shrubs; LSHR = Low shrubs; HERB = Herbs; GRAS = Grasses, sedges and rushes

[a]Treatment means ± standard error

[b]1 × = 1 cutting

[c]2 × = 2 cuttings

Letters indicate significant differences within columns among treatments detected using Fisher's Least-Significant-Difference Test at α = 0.05.

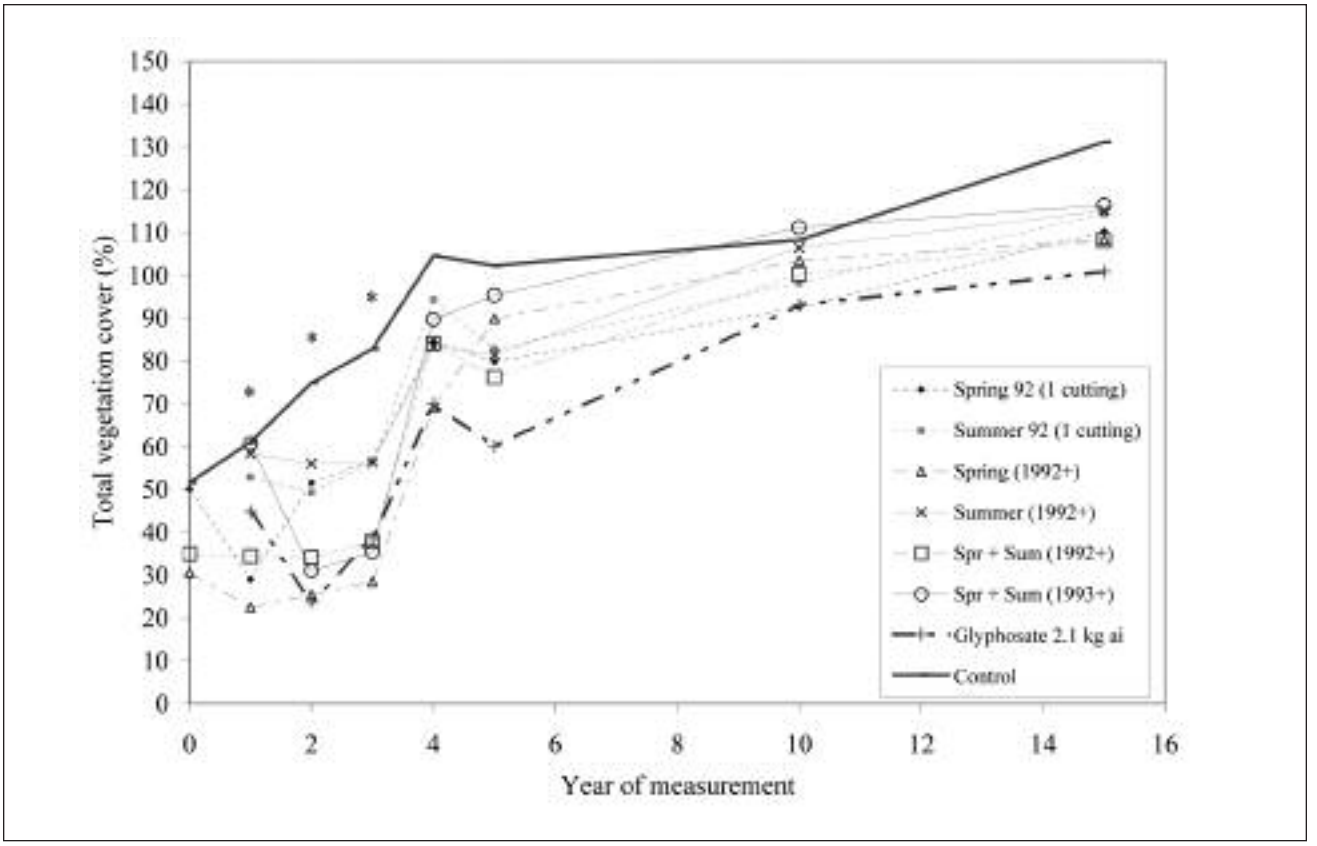

Fig. 1. Treatment total vegetation percent cover over year of measurement. Asterisk indicates years where significant treatment effect found ($p \leq 0.05$).

Table 3. Treatment means for tagged spruce (15th year data)

Treatment		SURVIVAL (%)	HT (cm)	DBH (cm)	STV (m^3/tree*100)	HDR
Spring (1992) [1 cutting]	**a**	80	521 ± 24[a]	8.7 ± 0.5	1.409 ± 0.170	29.0 ± 1.1
Summer (1992) [1 cutting]	**b**	80	464 ± 22	7.8 ± 0.4	0.976 ± 0.114	29.3 ± 1.3
Spring (1992+) [1 × yr^{-1} for 3 yr]	**c**	100	496 ± 24	8.9 ± 0.4	1.381 ± 0.146	27.5 ± 1.1
Summer (1992+) [1 × yr^{-1} for 3 yr]	**d**	91.7	556 ± 23	9.4 ± 0.4	1.634 ± 0.153	30.0 ± 1.0
Spr+sum (1992+) [2 × yr^{-1} for 3 yr]	**e**	95	573 ± 19	9.8 ± 0.4	1.743 ± 0.170	28.6 ± 0.5
Spr+sum (1993+) [2 × yr^{-1} for 2 yr]	**f**	86.7	578 ± 20	9.8 ± 0.4	1.762 ± 0.156	29.1 ± 1.3
Glyphosate [2.1 kg a.e. ha^{-1}]	**g**	96.7	547 ± 19	9.0 ± 0.4	1.446 ± 0.135	29.2 ± 0.7
Control	**h**	56.7	519 ± 20	9.1 ± 0.4	1.316 ± 0.162	27.9 ± 1.0
p- value		**<0.0001**	*0.6014*	*0.7294*	*0.5690*	*0.7722*

SURV = % Survival; HT = Spruce height (cm); DBH = Diameter breast height (cm); STV=stem volume (m^3/tree*100); HDR = Height-to-diameter breast height ratio
[a]Treatment means ± standard error.

Table 4. P-values for test of treatment effect and planned polynomial contrasts between treatments (15th year data)

Contrast	SURV	HT	DBH	STV	HDR
Single cutting vs. untreated control	**0.001***	0.679	0.624	0.768	0.394
Single cutting vs. repeated cutting (all)	**<0.001**	0.499	0.437	0.461	0.688
Single cutting vs. repeated cutting (spring)	**<0.001**	0.710	0.864	0.729	0.295
Single cutting vs. repeated cutting (summer)	0.063	0.194	0.213	0.176	0.644
Repeated (all-once) vs. untreated control	**<0.001**	0.962	0.965	0.819	0.558
Repeated spring cutting vs. untreated control	**<0.001**	0.755	0.821	0.920	0.799
Repeated summer cutting vs. untreated control	**<0.001**	0.697	0.761	0.613	0.196
Repeated cutting (2 × 1992+) vs. untreated control	**<0.001**	0.439	0.505	0.303	0.654
Single spring cutting vs. single summer cutting	1.000	0.389	0.423	0.326	0.830
Repeated spring cutting vs. repeated summer cutting	0.008	0.410	0.534	0.473	0.072
Repeated annual cutting vs. repeated twice annually cutting	0.171	0.320	0.394	0.263	0.915
Repeated twice annually 1992 vs. repeated twice annually 1993	0.108	0.998	0.960	0.864	0.738
Glyphosate vs. single cutting	**0.001**	0.251	0.527	0.444	0.955
Glyphosate vs. repeated cutting annually	0.329	0.530	0.973	0.876	0.686
Glyphosate vs. repeated cutting twice annually	0.647	0.742	0.435	0.395	0.659
Glyphosate vs. untreated control	**<0.001**	0.614	0.987	0.747	0.406
Overall Treatment effect (ANCOVA)	***<0.0001***	*0.6014*	*0.7294*	*0.569*	*0.7376*

Critical p-value = α / number of contrasts = 0.05 / 16 = 0.0031; *bold values indicate significant differences for the contrast; SURV = % Survival; HT = Spruce height (cm); DBH = Diameter breast height (cm); STV=stem volume (m^3/tree*100); HDR = Height-to-diameter breast height ratio; Seedling survival treatment effect p-values are based on chi-square (χ^2) test and all other treatment effect p-values are based on Analysis of Covariance (ANCOVA); Bold values indicate significant differences for the treatment effect.

ment while they have favoured some increase in spruce cover. At age 10 on this site, no effects on species richness and diversity were evident (Biring *et al.* 2003). While broadleaf cover was significantly lower in many of the treatments compared to the control at age 10, this was not detected at age 16. However, at age 16, broadleaf cover was lower (3%) in the glyphosate treatment compared to the untreated (12%). While differences in conifer cover were evident but not significant at age 10, the glyphosate and some of the repeated cutting treatments have significant increases in conifer cover at age 16.

The observed lack of long-term effects of either repeated cutting or a single application of glyphosate herbicide on plant species richness and diversity (other than accelerating development of conifer cover) is consistent with the findings

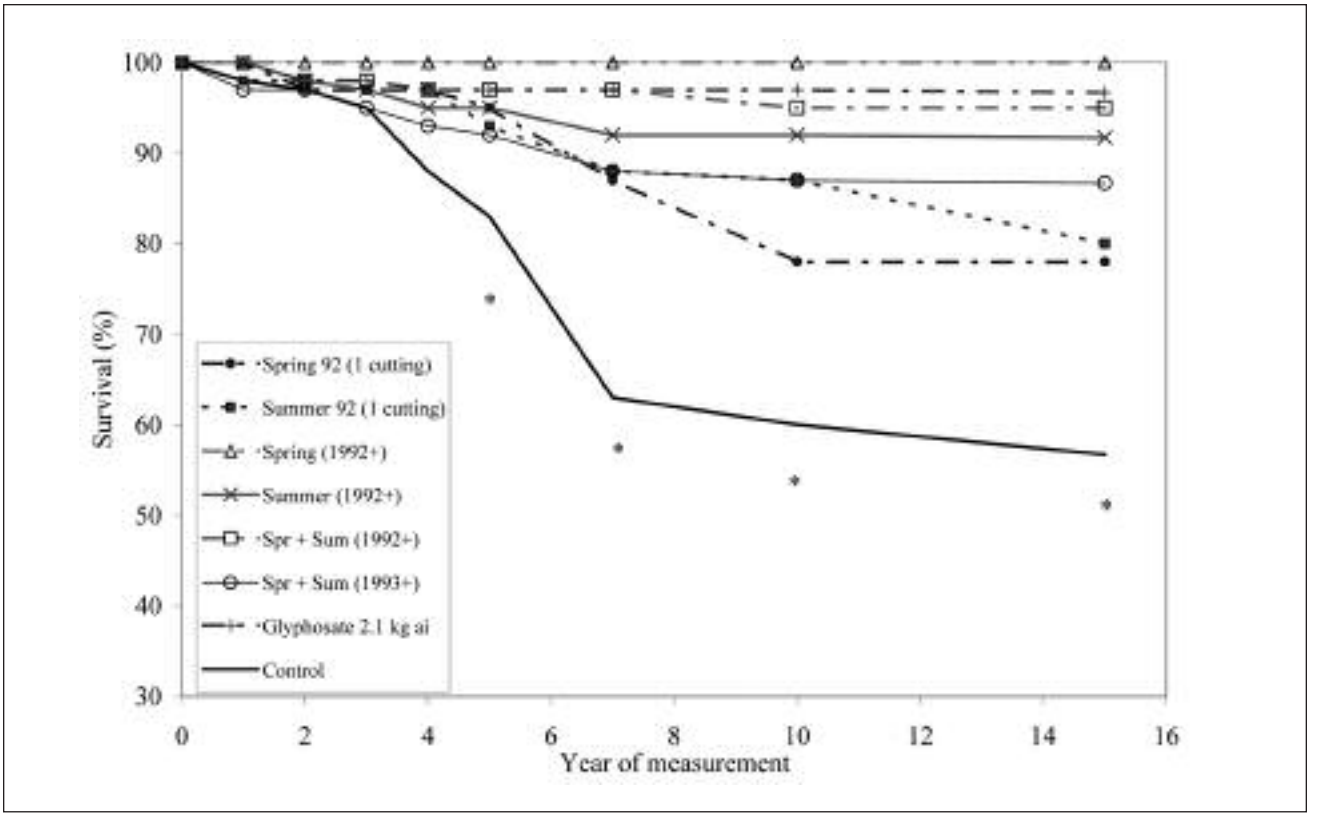

Fig. 2. Spruce percent survival by treatment over the 15 year measurement period. Asterisk indicates years where significant treatment effect found (chi-square test $p < 0.05$).

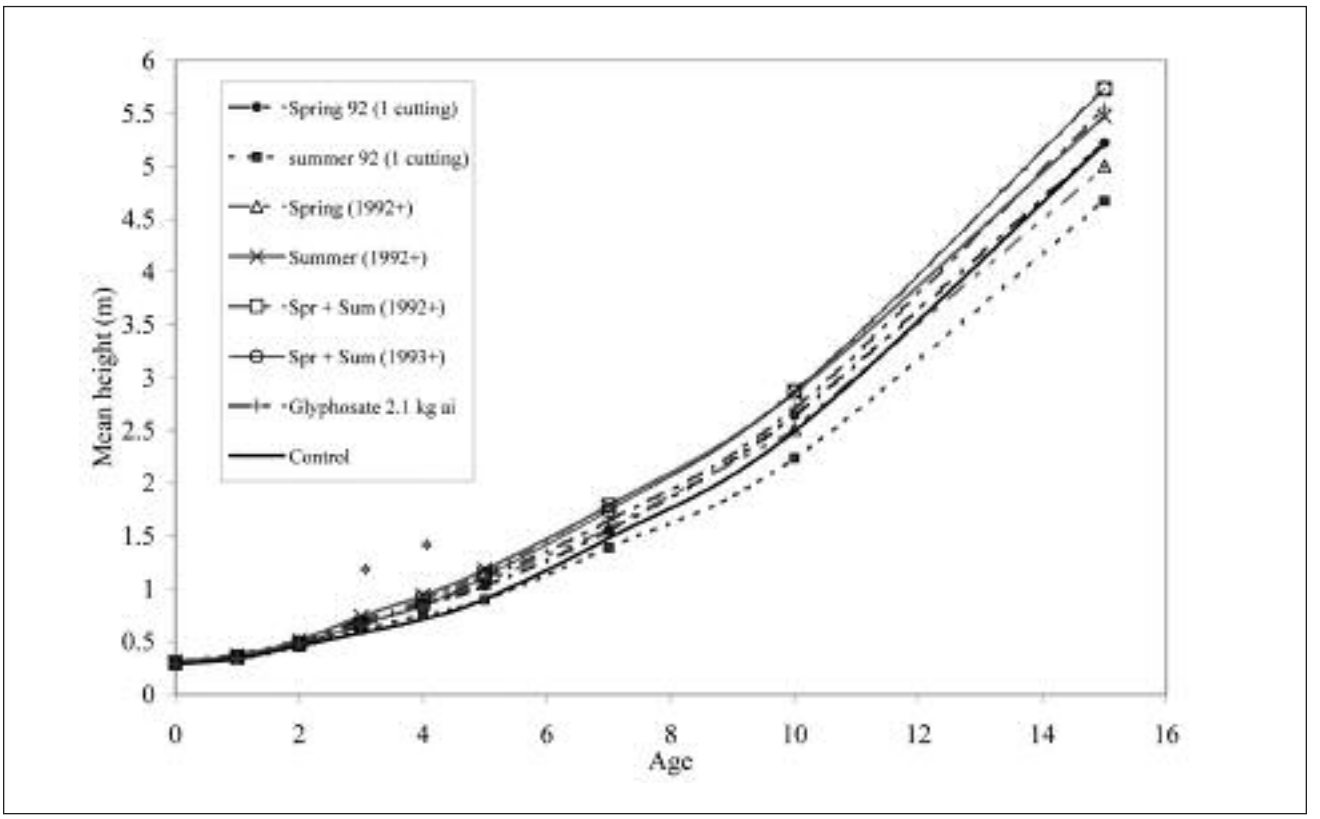

Fig. 3. Engelmann spruce mean height by treatment over the 15 year post treatment period. Asterisk indicates years where a significant treatment effect found (p value ≤ 0.05 for overall treatment effect).

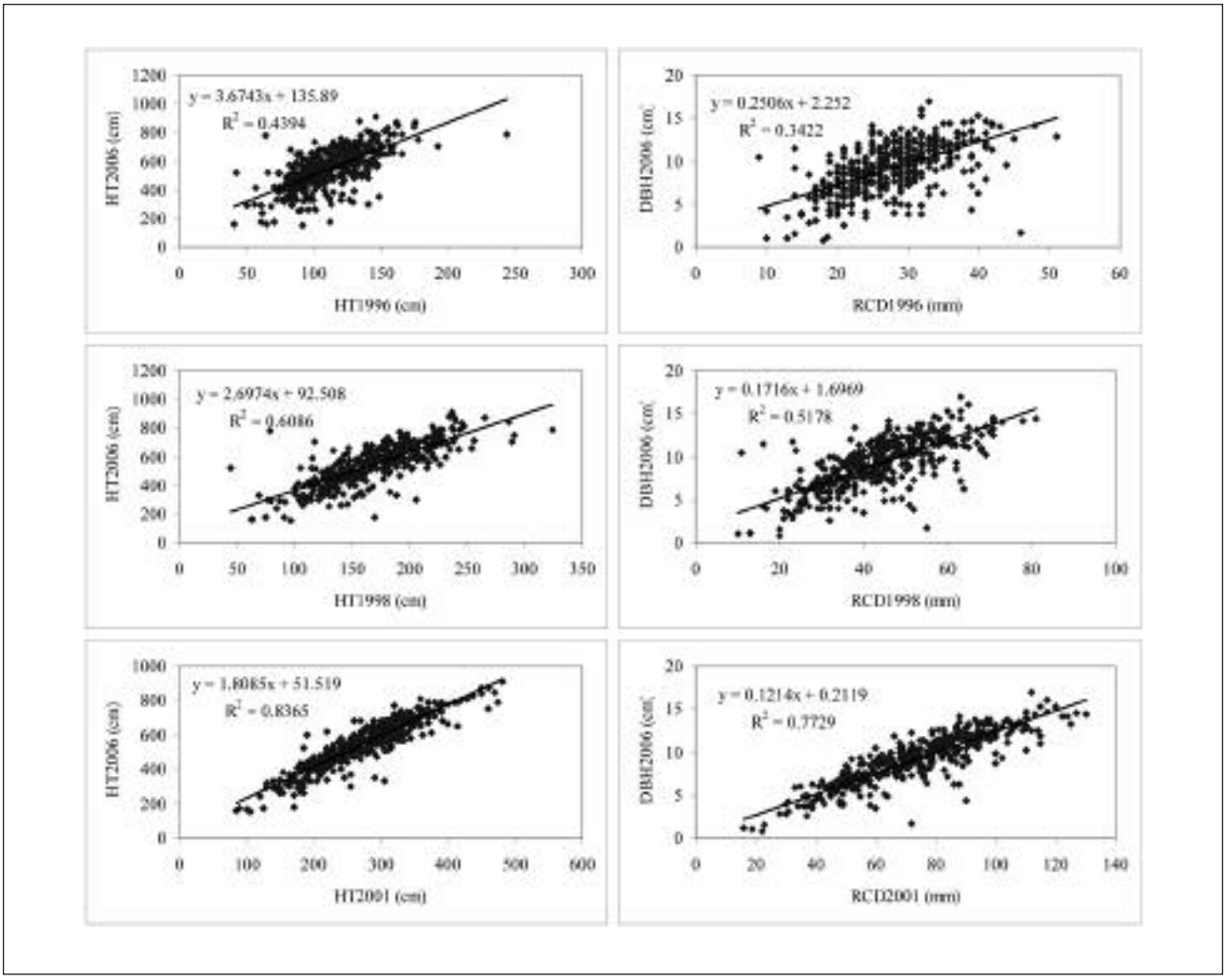

Fig. 4. Relationships between tree size in 2006 and tree size in 1996 (year 5), 1998 (year 7) and 2001 (year 10) for both height and diameter. (Sample size = 393 trees).

of several other studies, including results reported in a similar mixed-shrub community (Simard *et al.* 2001) and other vegetation communities (Newton *et al.* 1992; McDonald *et al.* 1994; Harper *et al.* 1997a, b; Sullivan *et al.* 1998; Biring *et al.* 1999, 2000, 2001; Biring and Hays-Byl 2000; Boateng *et al.* 2000; Lindgren and Sullivan 2001; Haeussler *et al.* 2002).

Black cottonwood and paper birch generally resprout vigorously following manual cutting (Haeussler *et al.* 1990). However, in this study there was no increase in broadleaf percent cover following either single or repeated cutting treatments. This may be the result of rapid development of other vegetation layers following treatment or other factors that may have limited broadleaf regrowth.

Spruce survival

Mixed-shrub complex vegetation can seriously reduce survival and growth of planted conifers, particularly on wetter sites in the interior of British Columbia. Based on survival data available for a limited number of replicated trials in British Columbia, Comeau *et al.* (1999) concluded that improvements in seedling survival through brushing during the first 5 years after planting should be expected on mixed-shrub sites where vegetation competition is very intense. Although initial survival was unaffected by treatment in this study, longer-term survival of planted spruce was improved significantly by treatment. Both manual cutting (single and repeated) and glyphosate treatments significantly improved survival over that in the untreated control at age 16. Repeated cutting also resulted in better survival than only a single cutting. McMinn (1982) also reports a significant improvement in survival of white spruce 10 years after manual brushing of a mixed-shrub community. Other studies in the mixed-shrub complex (Simard *et al.* 2001, Heineman *et al.* 2005) report that a single manual cutting treatment did not improve hybrid spruce survival.

Much of the mortality observed in our study occurred in years 4, 5, and 6 and differ from the widely held belief that mortality usually occurs during the first few years after planting. This may have been related to the delay in the development of vegetation cover, with maximum cover and competition levels being reached in the untreated plots in years 4 and 5 (Comeau *et al.* 2000). Delayed vegetation development was likely the result of the blading treatment applied to much of the study site in 1990. Repeated cutting and application of

glyphosate resulted in a small but significant improvement in 16-year survival over that provided by cutting only once. The repeated cutting provided similar results to a single application of glyphosate. In the absence of the blading treatment, more dramatic differences between treatments in survival and growth, and earlier onset of mortality would be expected. However, poor survival can also result from problems with planting stock (poor stock, storage and handling problems, poor planting), planting delay, microclimatic or microsite issues (frost, flooding, drought), browsing, insects, and other problems. Prior to 1985, problems with stock quality and planting delays were common in the BC Interior.

Spruce growth

Several studies have documented both short-term and long-term increases in conifer diameter growth after manual cutting or herbicide applications (e.g., Sutton 1995; Harper *et al.* 1997a, b; Biring *et al.* 1999, 2000, 2001; Biring and Hays-Byl 2000; Simard *et al.* 2001; Fu *et al.* 2007; Rose and Ketchum 2003). In our study treated spruce seedlings exhibited a significant increase in groundline diameter from the end of the 2nd growing season after treatment until year 7. Similarly, increases in spruce height growth were observed in the 3rd and 4th years after treatment. However, the average diameter and height of surviving spruce did not differ between the vegetation control treatments or the untreated control at age 16. Continued mortality of suppressed seedlings after year 7 is a probable cause of lack of treatment differences in the 10th and 15th years after treatment, with mortality of small seedlings likely resulting in an upward shift in mean height and diameter for the untreated plots.

Simard *et al.* (2001) reported that a single manual cutting was not effective in controlling mixed shrub vegetation for more than one year on 3 ICH / ESSF sites in the southern interior of BC. A single manual cutting did not improve planted spruce survival; however, improvement in seedling diameter and a decrease in height:diameter ratio was noted 3 years post-brushing. Heineman *et al.* (2005) also found no effect of a single manual cutting on the 5-year survival or growth of planted hybrid spruce from 19 sites located in the ICH and ESSF. However, similar manual cutting treatments applied to ericaceous shrub-dominated vegetation on high-elevation ESSF sites in southern BC was found to improve survival and diameter growth of Engelmann spruce seedlings 3 years to 5 years post-brushing but not after 10 years (Heineman *et al.* 2007). These observations, and those from our study, serve to illustrate the potential effects of vegetation development, seedling development, and competition intensity on the results of applied vegetation management treatments. They also indicate the substantial variation in potential responses due to influences of site and past management practices, which necessitates site-specific prescriptions.

While cutting and glyphosate treatments resulted in significant improvements in survival at age 16, treatment effects on average spruce volume were not statistically significant. The substantial variability between plots and the small number of replications used in this study provided poor statistical power and a lack of statistical evidence to support apparent treatment differences. TASS simulations of the treatments indicated that the glyphosate and repeated cutting treatments may shorten physical rotation age by 7 years (a 14% reduction in rotation length), increase culmination MAI by between 11% and 12%, and increase merchantable volume at age 42 by 18% compared to the untreated control (Harper *et al.* 2008). Since these estimates do not include consideration of the small component of broadleaves present on this site (models for mixed-species stands are not yet available for this region), they are likely to slightly overstate differences in total (conifer plus broadleaf) yield.

It is not surprising that relationships between tree size at younger ages and size at age 16 become weaker as the time between measurements increases. While age 16 values appear to be strongly related to age 10 values, the fact that correlations become weaker with increasing time between measurements suggests a need for caution in trying to estimate long-term future trends from current tree size. However, given the change in size and position of trees relative to competing vegetation it may not be unreasonable to expect that measurements taken when trees have grown to a stage when they are no longer being influenced by the competing vegetation may be effective as predictors of future stocking and growth. Care must still be exercised in extrapolating results from age 16 to later years.

Treatment costs

While this study demonstrated that repeated cutting could be highly effective for vegetation control, several other issues such as cost and potential damage to crop seedlings must be considered. Comeau *et al.* (2000) discussed the cost implications of choosing a single manual cutting, repeated manual cutting or glyphosate treatments. Based on 2000 statistics for the Nelson Forest Region a single manual cutting treatment using hand tools would cost $545 per ha or $617 per ha using motorised brushsaws. To manually treat the same site 3 times using either hand tools or brushsaws would cost 3 times more; and, to apply glyphosate herbicide using backpack sprayers would be $743 per ha. While no data are available for aerial applications in the local area for year 2000, the average cost of aerial herbicide application for the province of British Columbia in 2000 was $293 per ha. Cost-effectiveness plays a key role in evaluating treatment options. This study demonstrated that the effect of repeated cutting in 3 successive years could have an effect on vegetation control and subsequent conifer growth equivalent to that obtained from a single application of glyphosate herbicide. An option for reducing costs on some sites could be to brush only a specified radius around each crop seedling.

Potential for environmental impacts must also be considered during treatment selection. Glyphosate herbicide has low toxicity to mammals and birds, does not bioaccummulate, is immobilized in most soils, and degrades rapidly in forest soils (Tatum 2004). As results from this study and others indicate, a single application of this herbicide appears to generally have only short-term effects on plant communities. While manual cutting tools pose little environmental hazard beyond risk of damage to crop seedlings and effects on community development, motorized brushsaws are frequently used for cutting treatments in woody and mixed vegetation complexes. Risks of gasoline and oil spillage, and exhaust emissions from brushsaws do pose potential environmental and health risks (Dubeau *et al.* 2003). Regulated use, low rates of application, requirements for untreated buffers, monitor-

ing, and requirements for applicator certification and training for the use of herbicides for forestry in Canada are important components in minimizing environmental risks from forestry herbicide use. Potential effects of mechanical site preparation on soils and site productivity should also be considered when developing prescriptions.

Conclusions

15-year data from this study indicates that repeated cutting treatments can result in similar improvements in survival responses to those provided by a single application of glyphosate herbicide. At this site, vegetation control treatments did not result in significant improvements in average height or diameter of spruce at age 16. However, yield increases are anticipated from these treatments from improved survival. Despite apparent initial effects on vegetation cover, the treatments applied in this study have had little detectable effect on non-crop vegetation at age 16. Periodic remeasurement of this and other similar studies is important to documenting the yield implications of vegetation management treatments. We recommend that future studies of this nature should focus on fewer treatments with more replication and strive for less uncontrolled variation in site and vegetation characteristics.

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