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Original article

Long-term effects of vegetation control treatments for release of Engelmann spruce from a mixed-shrub community in Southern British Columbia

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Abstract – In British Columbia, vegetation management treatments are widely used to ensure successful establishment of young stands and achievement of free-growing requirements. A study was established in 1991 to examine the effectiveness of vegetation control treatments for release of Engelmann spruce (*Picea engelmannii* Parry) seedlings from a mixed-shrub community. The study consisted of eight treatments replicated three times in a completely randomized design. The treatments comprised six combinations of spring, summer and annual repeated manual cutting, a single application of glyphosate, and an untreated control. Controlling the mixed-shrub community one-year after planting using glyphosate and manual cutting treatments significantly improved spruce survival. Repeated manual cutting significantly improved survival over that achieved with only a single treatment. Consequently, the density of well-spaced trees was significantly increased in the repeated manual cutting and glyphosate treatments. In 2001, the untreated control only has 27% of well-spaced spruce trees that are free growing compared to more than 50%, 75% and 83% in single cutting, repeated manual cutting and glyphosate treatment, respectively. Treatments significantly increased height and groundline diameter from the third through the seventh year but not in year ten. Continued mortality of suppressed seedlings after year seven is a probable cause of lack of treatment differences in the tenth year. However, height-to-diameter ratio was significantly reduced in year ten for all treatments over the control and for repeated versus single cutting treatments. Ten-years after treatment, significant differences in vegetation community percent cover, richness, and diversity were not detected among treatments.

Engelmann spruce / vegetation management / repeated manual cutting / glyphosate / free growing

Résumé – Effets à long terme de traitements de contrôle de la végétation effectués pour dégager des épicéas d'Engelmann concurrencés par divers arbustes, en Colombie Britannique méridionale. En Colombie Britannique, on fait largement appel à des traitements de gestion de la végétation pour faciliter l'installation des jeunes peuplements et leur permettre de se développer librement. Une étude a été engagée en 1991 pour juger l'efficacité de traitements de contrôle de la végétation visant à dégager des épicéas d'Engelmann (*Picea engelmanii* Parry) concurrencés par divers arbustes. Cette étude comportait huit traitements, répétés trois fois selon un dispositif en blocs complets. Pour les traitements, il s'agissait de six combinaisons de dégagements par coupe effectués au printemps ou en été pendant une ou plusieurs années, d'une seule application de glyphosate, et enfin d'un témoin sans intervention. Le contrôle de la végétation arbustive par application de glyphosate un an après plantation, ou par les traitements dégagement par coupe, se traduit par une amélioration significative de la survie des épicéas. Des dégagements répétés pendant plusieurs années se révèlent nettement supérieurs à un seul dégagement, pour la survie. Il en résulte que la densité de plants convenablement répartis est améliorée de manière significative avec les traitements dégagement répétés plusieurs années ou application de glyphosate. En 2001 le témoin ne comportait que 27 % de plants convenablement répartis et poussant librement, contre respectivement 50 %, 75 % et 83 % pour les traitements un seul dégagement, dégagements pendant plusieurs années, et application de glyphosate. Ces traitements se traduisent par une augmentation significative de la croissance en hauteur et du diamètre au collet de la troisième à la septième année, mais sont sans effet la dixième année. Cette absence de différence entre traitements la dixième année est probablement due à la mortalité progressive des plants affaiblis après la septième année. Cependant, à l'année dix, le rapport hauteur sur diamètre était pour tous les traitements significativement inférieur à celui du témoin. Il était également inférieur avec des dégagements répétés comparé aux placeaux soumis à un seul dégagement. Dix ans après traitement, il n'a pas été possible de déceler des différences significatives concernant la couverture, la richesse et la diversité de la communauté végétale.

epicéa d'Engelmann / gestion de la végétation / dégagement manuel / glyphosate / croissance libre

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1. INTRODUCTION

The Interior Cedar Hemlock (ICH) biogeoclimatic zone of southern British Columbia contains the most productive forests of British Columbia's Interior, and supports the greatest diversity of tree species in the province [15, 31]. The productivity of these sites and the diversity of species and reproductive strategies make vegetation management relatively difficult in mixed-shrub complex communities in the ICH zone. After clearcutting, thimbleberry *(Rubus parviflorus* Nutt.), raspberry (*Rubus idaeus* L.), fireweed (*Epilobium angustifolium* L.), Sitka alder (*Alnus viridis* (Chaix) DC.), and numerous other species develop rapidly, especially on moist sites, achieving dense cover, and 2 m height within 2–3 years [22]. If left untreated, these communities can reduce the survival and growth of planted Engelmann spruce (*Picea engelmannii* Parry) by competing for available light [16, 20] and by vegetation and snow press [21, 47].

Manual, mechanical and chemical brushing treatments are widely used to ensure establishment and growth of coniferous seedlings on reforested areas. Forest vegetation management activities have steadily increased across British Colombia over the last 20 years. In the period from 1980 to 1989 brushing activities in British Columbia increased from 3000 ha in 1980–81 to about 60 000 ha and a cost of approximately $25 million in the 1989–90 fiscal year [8]. In 1990, British Colombia Ministry of Forests estimated that approximately 80 000 ha of forest land would require brushing every year over the next decade. 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 [10]. In the Nelson Forest Region 88% of the area brushed in 2000 was treated manually and 10% chemically by ground applications. The province-wide scale of operations, magnitude of investment, and constraints on choice of treatment, demand that vegetation management decisions should be driven by long-term vision and must consider social acceptability as well as environmental, economic and social sustainability.

Manual brushing methods are socially acceptable, and there are few, if any, environmental constraints. However, these treatments generally provide only short-term relief from competing vegetation. The control often lasts only for the balance of the growing season during which the treatment was applied [21, 22, 30, 39]. 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. In the ICH zone, thimbleberry has the ability to resprout vigorously to pre-cutting levels in the first or second season after cutting regardless of the timing [35]. This shrub may then reduce available light to very low levels [16]. Several studies have found that a single manual treatment is ineffective for controlling cover sufficiently to benefit seedling growth for more than a few years [22, 27, 29, 45, 55]. When cutting treatments are used to control vegetation around young conifer seedlings it may be necessary to treat the same site two or more times [17–19, 22, 25] to achieve longer-term control. For example, repeated cutting of competing species improves the 5 year height and stem diameter of Engelmann spruce in the very-cool ICH shrub-herb complex [22] and for Douglas-fir on the central coast of California [37]. A study by Harper et al. [29], reports that at least two subsequent years of cutting are required to change the dry-warm ICH site from a paper birch to a Douglas-fir dominated stand.

The herbicide glyphosate will control a wide range of shrubs and herbs at fairly low rates whereas conifers have some resistance depending on their stage of development [50]. A single application of glyphosate at planting, or during the first few years after planting has been shown to be effective in improving conifer growth nine to twelve years later in a wide range of plant communities in various ecosystems in British Columbia [2, 4–7, 27, 28, 34, 45, 55]. The efficacy of glyphosate for vegetation control is due to its ability to suppress competing vegetation for more than one season. Simard and Heineman [45] showed thimbleberry was controlled for 3 years in a mixed hardwood shrub complex in southern British Columbia accompanied by a significant increase in growth of Douglas-fir. However, Simard and Heineman [44] found chemical and manual treatments ineffective in a willow dominated site. Heavy rain soon after application may have affected herbicide efficacy and the cover was marginally detrimental to the growth of Engelmann spruce.

Delay of vegetation control or planting after harvesting is generally detrimental to conifer plantation establishment. Using critical-period analysis, Wagner et al. [54] showed that stem diameter, stem volume and height-to-diameter ratio were all strongly affected in the first three years after planting by the timing and duration of herbaceous control for red pine, jack pine, white pine and black spruce. Early removal of vegetation influences seedling performance by modifying one or more of the four principle factors controlling conifer seedling performance: soil temperature, air temperature, light level, and soil moisture [14]. Because the relative importance of these controlling factors is site and community specific, extrapolation of results from one site to another must be based on a clear understanding of critical factors [21].

At the time when this study was initiated, limited information was available on the relative effectiveness of manual cutting treatments and the effect of treatment timing for most species, which compete with conifers in British Columbia [30]. Ten years ago, there were no studies established to compare the effectiveness of foliar herbicide (glyphosate) treatments to repeated manual brushing treatments in mixed-shrub communities found in southern interior of British Columbia. An expanding brushing program in the province created a need for better information on the long-term impacts of vegetation control treatments on tree growth, stand dynamics, stand structure, stand development, free growing, plant species diversity and timber yield. Taking into account the need for long-term information on implications of vegetation management treatments we have extended the objectives of this experiment, and marked the site as a permanent research installation for continuous monitoring and measurements.

The objectives of this experiment are:

(i) To compare the effectiveness of single and repeated manual cutting treatments and a single herbicide glyphosate application to control mixed-shrub vegetation for releasing Engelmann spruce seedlings;

(ii) To evaluate the effects of the different competition regimes created by each of these treatments on the performance of spruce seedlings;

(iii) To understand the long-term impacts of vegetation control treatments on the dynamics of the vegetation community;

(iv) To model the long-term growth and yield implications of manual cutting and herbicide treatments.

This article presents ten-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 are presented by Comeau et al. [22].

2. METHODS AND MATERIALS

2.1. Study site

This study was conducted at Soards Creek near Mica Dam in southeastern British Columbia. 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 and a rich soil nutrient and is classified as site series CwHw-Devils' Club-Lady Fern [13]. Aspect is 170°, slope ranges from 10% to 30%, and elevation is 860 m. The site was harvested in 1983/84, 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, probably due to intense vegetation competition at the study site. 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 one-year-old (1+0 PSB 415B) Engelmann spruce seedlings at a 2.7 m espacement in June of 1991.

2.2. Experimental design

This study was established in the fall of 1991, and used a completely randomized design (CRD) consisting of eight treatments replicated three times with treatments assigned to 30 m × 30 m plots. The treatments comprised six combinations of spring, summer and annual repeated manual cutting, a single application of glyphosate, and an untreated control (Tab. I). Within each treatment plots, 20 Engelmann spruce seedlings were selected and tagged for morphological measurements (e.g., height and diameter) and qualitative assessments (e.g., survival).

2.3. Treatment applications

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 L of glyphosate herbicide in 10 L spray volume (with water) was used per treatment plot. Wind speed ranged from 0 to 2 km h^{-1}, wind direction was 300°, relative humidity was 50% and air temperature was between 18 °C and 20 °C during the glyphosate application.

2.4. Measurements

Marked Engelmann spruce seedlings were measured in years 0 (pre-treatment), 1, 2, 3, 4, 5, 7, and 10. Measurements included total height, groundline diameter, crown diameter, and height to the crown base. Data on abundance (e.g., percent cover and modal height) was recorded for each vascular plant species occurring within a 1.26 m radius competition measurement plot centred on tagged crop seedling in each treatment plot. Vegetation was assessed for 20 seedlings in each treatment plots in 1992 and for 10 seedlings in each treatment plots in subsequent years. In manual cutting treatment plots that included spring cutting (a, c, e) and 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

Table I. A description of the eight treatments applied in the study.

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]✢	Repeated spring cutting	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	d	1992 + annually	July 25–28, 1992; July 20–22, 1993; July 21, 1994
Spr+sum (1992+) [2× yr^{-1} for 3 yr]✚	Cutting twice 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]	Cutting twice 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 ae ha^{-1}]	VISION® (Monsanto Canada Inc. Trade name)	g	1992	August 20, 1992
Untreated control	Control	h	–	–

✢ Spring 1992+ [1× yr^{-1} for 3 yr] = 1 cutting every year for 3 years; ✚ Spr+sum (1992+) [2× yr^{-1} for 3 yr] = 2 cuttings every year for 3 years.

years vegetation assessments were completed during mid-summer prior to any cutting treatments being applied.

In 2001, a 3.99 m radius regeneration measurement plot (RMP) was established in each treatment plot using EXPLORE methodology [3] to collect vegetation community data (e.g., species percent cover and modal height). Plant species diversity indices and species richness were used to assess species diversity in each treatment plot. Species richness was calculated from the total number of plant species in each RMP. Two types of indices were used to assess plant species diversity: (1) the modified Simpson's Diversity Index (SDI) and (2) the modified Shannon-Wiener Diversity Index (SWI) [32]. The SDI places most weight on the common species in the sample. In contrast, SWI places most weight on rare species in the sample. The species diversity indices were calculated from percent cover of each species present in each RMP in each treatment plot. The indices were subsequently used to describe diversity as follows: (1) $SDI = 1/\Sigma(n/N)$ and (2) $SWI = e^{H'}$, where n = percent cover of each species; N = sum of cover of all species; e = 2.718282; and, $H' = -(\Sigma(n/N * ln(n/N))$.

In addition to vegetation community data, the regeneration measurement plots (RMPs) were used to collect stand data (e.g., stocking and number of free-growing spruce trees). The density of well-spaced spruce trees (minimum inter-tree spacing 2 m) and free growing trees was recorded based on existing free-growing stocking standards for the Nelson Forest Region in 2001 [12]. To meet the free growing standards in the very wet cool subzone variant of the ICH zone, a well-spaced Engelmann spruce must be minimum of 1.0 m tall and must be 150% of the height of competing vegetation within a 1 m radius of effective growing space [12].

2.5. Data analysis

The data analyses were carried out with SAS® software Version 8.02 [43]. The experiment was analysed as a single factor, completely randomised design with eight treatments and three replications. Analysis of variance was performed to test for significant differences in pre-treatment values among treatments. Due to significant ($p \leq 0.05$) pre-treatment differences in seedling height and groundline diameter, analysis of covariance (ANCOVA) was used to analyse 1992–2001 data using 1991 values as co-variates. Fisher's Least-Significant-Difference (LSD) test was used to make comparisons among treatment means. Polynomial contrasts were used to make comparisons between treatment means at a specified p-value (Tab. II). Logistic analysis was used to test for treatment effects on seedling survival.

3. RESULTS

3.1. Vegetation community dynamics

Three years of repeated cutting and glyphosate treatments resulted in significant short-term reductions in vegetation percent cover and modal height compared to the untreated control that lasted for the first few years. However, ten years after treatment application there were no significant ($p = 0.89$) differences in overall vegetation percent cover in manual cutting and glyphosate treatments compared with the untreated control (Tab. III).

When comparing percent cover of component strata, significant ($p = 0.041$) differences were found in the broadleaf layer, related primarily to treatments reducing cover of black cottonwood (*Populus balsamifera* ssp. *trichocarpa* (T. & G.) Brayshaw) (Tab. III). The LSD pairwise comparison test indicate that single manual cutting (treatment a and b), repeated manual cutting (treatment d, e and f), and glyphosate application (treatment g) areas have significantly less broadleaf percent cover compared to untreated control areas (Tab. III). The broadleaf percent cover varied between 2% to 9% in glyphosate and manual cutting treatments compared with 10% in the untreated control (Tab. III). Overall significant differences in conifer, shrub, herb and bryophyte percent cover were not detected. However, there were some noticeable differences in the conifer, shrub and herb percent cover among treatments (Tab. III). The conifer layer percent cover, mainly Engelmann spruce, was 24% in

Table II. Coefficients for planned polynomial contrasts between treatments.

Contrast	Coefficients							
Treatment symbol	a	b	c	d	e	f	g	h
Single cutting vs. untreated control	1	1	0	0	0	0	0	–2
Single cutting vs. repeated cutting (all)	1	1	–1	–1	0	0	0	0
Single cutting vs. repeated cutting (spring)	1	0	–1	0	0	0	0	0
Single cutting vs. repeated cutting (summer)	0	1	0	–1	0	0	0	0
Repeated (all-once) vs. untreated control	0	0	1	1	0	0	0	–2
Repeated spring cutting vs. untreated control	0	0	1	0	0	0	0	–1
Repeated summer cutting vs. untreated control	0	0	0	1	0	0	0	–1
Repeated cutting (2 × 1992+) vs. untreated control	0	0	0	0	1	0	0	–1
Single spring cutting vs. single summer cutting	1	–1	0	0	0	0	0	0
Repeated spring cutting vs. repeated summer cutting	0	0	1	–1	0	0	0	0
Repeated annual cutting vs. repeated twice annually cutting	0	0	1	1	–2	0	0	0
Repeated twice annually 1992 vs. repeated twice annually 1993	0	0	0	0	1	–1	0	0
Glyphosate vs. single cutting	1	1	0	0	0	0	–2	0
Glyphosate vs. repeated cutting annually	0	0	1	1	0	0	–2	0
Glyphosate vs. repeated cutting twice annually	0	0	0	0	1	0	–1	0
Glyphosate vs. untreated control	0	0	0	0	0	0	1	–1

Table III. Effects of treatment on vegetation community composition (10th year data).

Treatment	Treatment symbol	Percent cover						No. of Spp.	SDI✦	SWI★
		Total	CONF†	BRDL☨	SHRB‡	HERB✠	BRYO✡			
Spring (1992) [1 cutting]	a	94 ± 2.3◆	13 ± 1.5abc	2❣ c	21 ± 5.2ab	46 ± 10.3ab	9 ± 8.8	21 ± 1.7ab	8.3 ± 0.77a	11.9 ± 1.05
Summer (1992) [1 cutting]	b	93 ± 3.9	13 ± 3.3abc	4 ± 2.5bc	45 ± 7.1a	32 ± 6.5b	13 ± 5.2	25 ± 1.9a	7.2 ± 0.33ab	10.7 ± 0.51
Spring (1992+) [1× yr^{-1} for 3 yr]✢	c	95 ± 2.9	24 ± 6.2a	5 ± 2.0abc	21 ± 6.3ab	44 ± 8.8ab	26 ± 24.0	22 ± 1.8ab	6.5 ± 0.89ab	9.3 ± 1.2
Summer (1992+) [1× yr^{-1} for 3 yr]	d	95 ± 2.6	14 ± 1.0abc	9 ± 1.5ab	26 ± 8.9ab	50 ± 6.8ab	5❣	22 ± 1.8ab	7.5 ± 0.81ab	10.7 ± 0.93
Spr+sum (1992+) [2× yr^{-1} for 3 yr]✚	e	89 ± 7.2	13 ± 2.9bc	3 ± 1.2c	32 ± 12.0ab	54 ± 3.9ab	35❣	22 ± 1.2ab	6.0 ± 0.58ab	9.0 ± 1.0
Spr+sum (1993+) [2× yr^{-1} for 2 yr]	f	90 ± 7.6	14 ± 3.3abc	2 ± 0.5c	37 ± 10.4ab	37 ± 2.9ab	16 ± 2.5	22 ± 3.5ab	6.9 ± 2.1ab	10.0 ± 2.4
Glyphosate [2.1 kg ae ha^{-1}]	g	92 ± 3.3	20 ± 5.3ab	2 ± 0c	15 ± 7.0b	38 ± 11.4ab	29 ± 4.3	22 ± 0.9ab	6.1 ± 0.33ab	9.1 ± 0.39
Untreated control	h	97 ± 1.5	5 ± 1.5c	10❣ a	41 ± 15.8ab	58 ± 9.1a	3❣	18 ± 2.2a	5.3 ± 1.25b	8.3 ± 1.7
p-value		0.895	0.087	0.041	0.358	0.327	0.575	0.528	0.440	0.591

†CONF = Coniferous; ☨BRDL = Broadleaves; ‡SHRB = Shrub; ✠HERB = Herbs; ✡BRYO = Bryophytes; ✦SDI = modified Simpson's Diversity Index; ★ SWI = modified Shannon-Wiener Diversity Index; ◆Treatment means ± standard error; ❣ no SE recorded only in one plot; ✢1× = 1 cutting; and, ✚2× = 2 cutting. * Letters indicate significant differences within columns among treatments detected using Fishers Least-Significant-Difference Test at α = 0.05.

repeated spring manual cutting (treatment c) and 20% in glyphosate treatment (treatment g) compared with only 5% in the untreated control (Tab. III). The herb layer percent cover, was 58% in the untreated control compared to only 7% in single summer manual cutting (treatment b). Minor differences in each layer detected based on LSD test must be interpreted cautiously, because of smaller sample size (3 RMPs for each treatment).

Ten-years after treatment, the herb species having the greatest percent cover with a modal height of 1.4 m, was bracken fern (*Pteridium aquilinum* (L.) Kuhn). The herb layer had numerous other species including Dewey's sedge (*Carex deweyana* Schwein), Mertens's sedge (*Carex mertensii* Prescott ex Bong), baneberry (*Actaea rubura* (Ait.) wild), cow parsnip (*Heracleum sphondylium* L.), fireweed (*Epilobium angustifolium* L.), stinging nettle (*Urtica dioica* L.), blue wildrye grass (*Elymus glaucus* Buckl.) and redtop grass (*Agrostis alba* auct. non L.). The shrub layer was dominated by up to 1.8 m tall thimbleberry *(Rubus parviflorus* Nutt.) with a minor component of various other species including raspberry (*Rubus idaeus* L.) and willow (Salix ssp.). However, no significant effects of treatment on species composition were evident.

3.2. Vegetation diversity

In the summer of 2001, ten-years after treatment, vegetation control treatments had no significant effect on plant species richness or number of vegetation species (Tab. III). In total, more than 21 plant species were present in manual cutting and glyphosate treatments compared with 18 species in the untreated control (Tab. III). Modified Simpson's Diversity Index (SDI) and modified Shannon-Wiener Diversity Index (SWI) were used to test treatment effects on vegetation community diversity. Overall no significant differences among the seven treatments and the untreated control were detected ten years after treatment.

3.3. Engelmann spruce survival

Tenth-year data showed that treatments significantly improved spruce survival ($p < 0.0001$) compared to untreated control (Fig. 1 and Tab. IV). Logistic analysis of spruce survival indicated that the significant differences in spruce survival appeared five-years after treatment application and continued thereafter (Fig. 1 and Tab. IV). Polynomial contrasts indicate that both manual cutting (single and repeated) and glyphosate treatments significantly ($p < 0.0001$) improved spruce survival (Fig. 1 and Tab. V). Repeated spring manual cutting (treatment c) improved spruce survival compared to single manual cutting (treatment a) (Tab. V). However, significant differences were not detected between glyphosate application and single or repeated manual cutting, the timing of repeated or single cutting or single cutting and delayed repeated cutting.

3.4. Engelmann spruce responses

Treated spruce seedlings exhibited a significant increase in groundline diameter from the end of the second growing season after treatment until year seven (Fig. 2 and Tab. IV). However, significant differences in spruce groundline diameter were not detected in the tenth-year analysis (Fig. 2 and Tab. IV). Similarly, the treatment resulted in significant differences in seedling height, crown diameter, crown length and

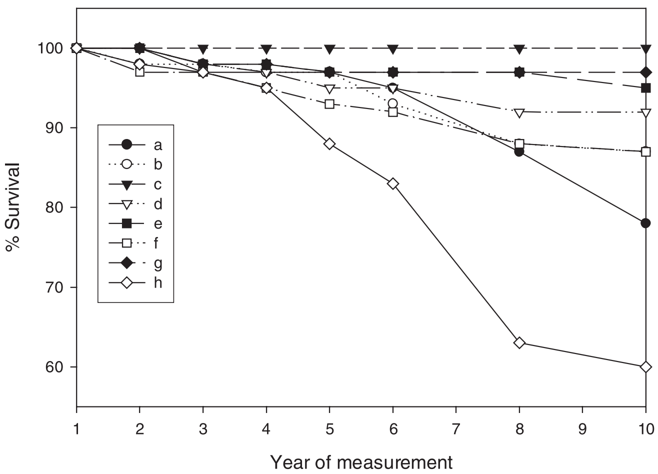

Figure 1. Effect of treatments on Engelmann spruce survival. Treatments: a = spring 1992 (1 cutting); b = summer 1992 (1 cutting); c = spring 1992+ (3 yr of cutting 1× yr^{-1}); d = summer 1992+ (3 yr of cutting 1× yr^{-1}); e = spring + summer 1992+ (3 yr of cutting 2× yr^{-1}); f = spring + summer 1993+ (2 yr of cutting 2× yr^{-1}); g = glyphosate (2.1 kg ha^{-1}); and h = untreated control.

crown volume only between years 3 and 7 after treatment application even though the treatment had no effect on these variables at the end of the 10th growing season (Fig. 2 and Tab. IV). However, the vegetation control treatments compared in this study had significantly ($p = 0.0086$) reduced the 10th year height-to-diameter ratio (HDR) of spruce seedlings as compared to control (Fig. 2 and Tab. IV). Polynomial contrasts indicated that repeated summer cutting (treatment d) significantly ($p = 0.002$) reduced HDR of spruce seedlings compared to single summer cutting (treatment b) (Tab. V).

3.5. Young stand development

Ten years after treatment, the vegetation control treatments had no significant impact on total stand density, broadleaf density and conifer density (Tab. VI). The RMPs established in 2001 to collect density information, that were independent of tagged spruce seedlings with minor overlap, indicated that more Engelmann spruce trees survived in treated plots compared to control plots (Tab. VI). The density of well-spaced spruce trees in repeated manual cuttings and glyphosate treated plots was significantly ($p = 0.0457$) different from that of the control (Tab. VI). LSD test indicate that single manual cutting (treatment b), repeated manual cutting (treatment c and d), and glyphosate application (treatment g) areas had more well-spaced spruce trees compared to untreated control areas (Tab. VI). In 2001 that is eleven years after planting, the untreated control had 733 (stems ha^{-1}) spruce trees that were well-spaced compared with more than 1000, 1068 and 1200 (stems ha^{-1}) in single manual cutting, repeated manual cutting and in herbicide treatments, respectively (Tab. VI). The treated and untreated plots both met the minimum stocking (more than 700 stems ha^{-1}) requirements based on existing free-growing stocking standards for the Nelson Forest Region in 2001 [12]. However, overall significant differences in free growing trees were not detected due to a smaller sample size (3 RMPs for each treatment). Eleven-years after planting, the untreated control had only 200 (stems ha^{-1}) spruce trees that met the minimum free-growing requirements [12] compared to more than 600, 800 and 1000 (stems ha^{-1}) in single manual cutting, repeated manual cutting and in herbicide treatments, respectively (Tab. VI).

4. DISCUSSION

Responses of vegetation communities to brushing treatments depend on the type of treatment, the ecosystem, the type of plant community, and the abundance of component species. In this study, with intense mixed-shrub competition, three years of repeated manual cutting and glyphosate treatments resulted in significant reductions in vegetation percent cover that lasted for a few years. However, at the end of 10 years, no major differences in total vegetation cover were detected among all treatments.

Maintaining and protecting plant species diversity to maintain healthy ecosystems and to maintain forest productivity is recognised world-wide. Ten years after treatment applications, no major differences in plant species richness and diversity of rare or common species were detected in either the treated or untreated vegetation communities. These results are consistent with the findings of several other studies including results reported in a similar mixed-shrub community [45] and other

Table IV. *P*-values for tests of treatment effect on spruce survival, groundline diameter, height, height-to-diameter ratio, crown diameter, crown length and crown volume.

Variable	Year of measurement						
	1	2	3	4	5	7	10
Seedling survival✚	0.2998	0.7896	0.5444	0.0997	**0.0103**⯌	**< 0.0001**	**< 0.0001**
Groundline diameter	0.5159	**0.0352**	**0.0062**	**0.0003**	**0.0016**	**0.0066**	0.1801
Height	0.8097	0.1868	**0.0466**	**0.0359**	0.0699	0.1338	0.4484
Height:diameter ratio	0.7725	0.0043	**0.0184**	0.0817	**0.0111**	**0.0023**	**0.0086**
Crown diameter	0.8091	0.2732	**0.0497**	**0.0026**	**0.0162**	**0.0386**	0.1144
Crown length	0.7350	0.2448	**0.0079**	**0.0102**	**0.0243**	**0.0323**	0.3736
Crown volume	0.7718	0.4099	0.0538	**0.0155**	**0.0217**	0.0644	0.2097

✚ Seedling survival *p*-values are based on chi-square (χ^2) test and all other *p*-values are based on analysis of covariance (ANCOVA); ⯌ Bold values indicate significant differences for the treatment effect.

Table V. *P*-values for polynomial contrasts of treatment effects (10th year data).

Contrast	*P*-values*						
	SURV◆	HT‡	GLD◀	HDR▼	CRD▶	CRL▲	CRV⬍
Single cutting vs. untreated control	**0.001**⩡	0.895	0.966	0.820	0.513	0.937	0.571
Single cutting vs. repeated cutting (all)	**0.000**	0.322	0.068	**0.002**	0.256	0.275	0.274
Single cutting vs. repeated cutting (spring)	**0.000**	0.689	0.900	0.129	0.701	0.735	0.779
Single cutting vs. repeated cutting (summer)	0.376	0.076	0.016	**0.002**	0.055	0.065	0.073
Repeated (all-once) vs. untreated control	**0.000**	0.563	0.192	0.027	0.148	0.389	0.180
Repeated spring cutting vs. untreated control	**0.000**	0.911	0.481	0.032	0.315	0.677	0.331
Repeated summer cutting vs. untreated control	**0.000**	0.360	0.103	0.060	0.108	0.261	0.147
Repeated cutting (2 × 1992+) vs. untreated control	**0.000**	0.262	0.091	0.020	0.035	0.179	0.050
Single spring cutting vs. single summer cutting	0.228	0.218	0.211	0.045	0.128	0.184	0.155
Repeated spring cutting vs. repeated summer cutting	0.008	0.344	0.252	0.756	0.437	0.392	0.537
Repeated annual cutting vs. repeated twice annually cutting	0.171	0.412	0.456	0.590	0.226	0.428	0.267
Repeated twice annually 1992 vs. repeated twice annually 1993	0.108	0.894	0.515	0.060	0.789	0.836	0.714
Glyphosate vs. single cutting	0.004	0.258	0.163	0.022	0.066	0.190	0.149
Glyphosate vs. repeated cutting annually	0.329	0.741	0.856	0.576	0.316	0.661	0.561
Glyphosate vs. repeated cutting twice annually	0.647	0.664	0.423	0.349	0.844	0.752	0.630
Glyphosate vs. untreated control	**0.000**	0.442	0.291	0.096	0.048	0.271	0.106

* Critical *p*-value = α / number of contrasts = 0.05 / 16 = 0.0031; ⩡ bold values indicate significant differences for the contrast; ◆ SURV = survival; ‡ HT = height; ◀ GLD = groundline diameter; ▼ HDR = height-to-diameter ratio; ▶ CRD = crown diameter; ▲ CRL = crown length; ⬍ CV = crown volume.

vegetation communities [2, 4–7, 23, 28, 36, 37, 40, 48, 49]. The results of the present study indicated that repeated manual cutting and a single application of glyphosate treatments have no long-term impact on plant species richness and diversity when assessed 7 or more years after treatment.

Although manual cutting and glyphosate applications had no lasting effect on total vegetation percent cover, richness, diversity and composition, community structures were altered by reducing black cottonwood percent cover and by increasing spruce percent cover. Reductions in cover and height of paper birch nine-years after glyphosate application in a mixed hardwood shrub complex were reported in another study [45]. Following manual cutting black cottonwood normally resprouts vigorously [26], however, in this study there was no increase in percent cover. It is possible that intensive or repeated cutting and glyphosate treatments had not allowed cottonwood to regenerate for the first few years after planting.

In the interior of British Columbia mixed-shrub complex vegetation can seriously reduce survival and growth of planted conifers particularly on wetter sites. Based on survival data available for a limited number of replicated trials in British Columbia, Comeau et al. [21] concluded that improvements in seedling survival through brushing during the first five years after planting should be expected only 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. However, it is somewhat surprising to see substantial seedling mortality in the untreated control plot five years after treatment when the majority of studies suggest most mortality occurs primarily during the first few years after planting. Long-term survival in this study is consistent with results presented by McMinn [38] showing a significant improvement in survival of white spruce 10 years after manual brushing of a mixed-shrub community. Another study in a mixed-shrub complex by Simard et al. [46] reported that a single manual cutting treatment was not effective in improving hybrid spruce survival for first few years after treatment. Also, the results of this study suggest that investment in repeated manual cutting particularly early season or spring cutting (treatment c) can improve spruce survival compared to single manual cutting treatment (treatments a and b).

Several studies have documented both short-term and long-term increases in conifer diameter growth after manual cutting or herbicide applications [2, 4–6, 28, 41, 42, 46, 47, 51, 52]. In this study treated spruce seedlings exhibited a significant increase in groundline diameter from the end of the second growing season after treatment until year seven. Similarly, increases in spruce height growth were observed in the third and fourth years after treatment. However, significant differences in spruce growth (e.g., groundline diameter, and height) were not detected in the tenth year analysis. Continued mortality of suppressed seedlings after year seven is a probable cause of lack of treatment differences in the tenth year, with mortality of small seedlings possibly resulting in an upward shift in mean height and diameter growth for the untreated.

Various studies indicate that height-to-diameter ratios (HDR) increase as vegetation competition increases. This results from rapid and nearly immediate reductions in diameter growth, while height growth is sustained until competition levels exceed critical thresholds [14, 33, 53]. In this study, repeated

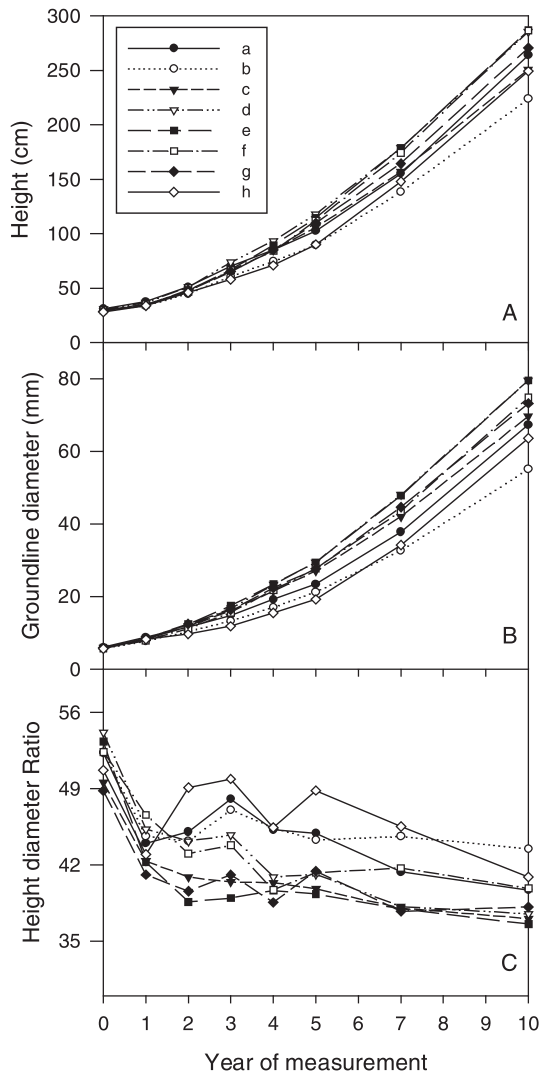

Figure 2. Effect of treatments on (A) height, (B) groundline diameter, and (C) height:diameter ratio of Engelmann spruce. Treatments: a = spring 1992 (1 cutting); b = summer 1992 (1 cutting); c = spring 1992$^+$ (3 yr of cutting 1× yr^{-1}); d = summer 1992$^+$ (3 yr of cutting 1× yr^{-1}); e = spring + summer 1992$^+$ (3 yr of cutting 2× yr^{-1}); f = spring + summer 1993$^+$ (2 yr of cutting 2× yr^{-1}); g = glyphosate (2.1 kg ha^{-1}); and, h = untreated control.

cutting treatments significantly reduced the height-to-diameter ratio of spruce seedlings as compared to the control.

The survival data from this study indicate the importance of timely application of treatments to minimize the risk of mortality or risk of loosing a spruce plantation. The improvements in seedling survival significantly increased the number of well-spaced spruce trees in repeated manual cutting and glyphosate treated plots compared with the untreated control. In British Columbia, legislation requires that conifer plantations be "free growing" within a specified period following harvesting [9]. On this mixed-shrub site the untreated control had only 27% of the well-spaced spruce trees that were free-growing [12] compared to more than 50%, 75% and 83% in single cutting, repeated manual cutting and glyphosate treatment, respectively.

Intense vegetation competition in the untreated control has elevated the seedling mortality to a level that might have future implications for stand development. In a recent report, Bergerud [1] projected merchantable volume of lodgepole pine at 700 free growing stems ha^{-1} is about 13% less than the potential that the site could yield at higher densities (e.g., 1200 free growing stems ha^{-1}). Deloitte and Touche [24] estimate that without control of competing vegetation, sustainable harvest would be reduced by as much as 9.4%. However, the long-term growth and yield implications of brushing in mixed shrub communities are very uncertain and further data is required.

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. [22] 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 [11] a single manual cutting treatment using hand tools would cost \$545 ha^{-1} or \$617 ha^{-1} using motorised brushsaws. To manually treat the same site three times using either hand tools or brushsaws would cost 3 times more; and, to apply glyphosate herbicide using backpack sprayers would be \$743 ha^{-1}. While no data are available for aerial applications in the Nelson Forest Region for year 2000, the average cost of aerial herbicide application for the province of British Columbia in 2000 was \$293 ha^{-1}. Cost effectiveness plays a key role in evaluating treatment options. This study demonstrated that the effect of repeated cutting in three successive years could have an effect on vegetation control and subsequent conifer growth equivalent to that obtained from a single application of glyphosate herbicide. To reduce treatment costs slightly an alternative approach could be to brush only a specified radius around each tree.

5. CONCLUSIONS

The results from this study suggest that:

(1) Vegetation control treatments including single manual cutting, repeated manual cutting and glyphosate treatments do not appear to have long-term effects on vegetation community percent cover, richness, and diversity;

(2) Controlling competing mixed-shrub vegetation community one year after planting using glyphosate and manual cutting treatments can significantly improve Engelmann spruce survival;

(3) Repeated manual cutting and glyphosate treatments significantly increased height and groundline diameter from the third through the seventh year but not in year ten due to continued mortality of suppressed seedlings after year seven in the untreated control;

(4) Improvements in spruce survival using glyphosate and repeated manual cutting treatments increased the density of well-spaced spruce significantly;

(5) In 2001, the untreated control only has 27% spruce trees that were free growing compared to more than 50%, 75% and 83% in single cutting, repeated manual cutting and glyphosate treatment, respectively.

Table VI. Effects of treatment on young stand density and composition.

Treatment	Treatment symbol	Stems ha^{-1}						
		TSD✢	BRDL†	CON☨	OCON‡	SE▲	WSSE▼	FGSE◆
Spring (1992) [1 cutting]	a	2267 ± 371‗	133 ± 133	2133 ± 467	333 ± 176	1467 ± 67abc*	1000 ± 115bc	800 ± 200ab
Summer (1992) [1 cutting]	b	4067 ± 636	667 ± 353	3400 ± 306	1000 ± 503	1533 ± 240abc	1200 ± 116ab	600 ± 346ab
Spring (1992+) [1× yr^{-1} for 3 yr]✤	c	3667 ± 706	733 ± 267	2933 ± 706	467 ± 371	2068 ± 406a	1600 ± 200a	1267 ± 176a
Summer (1992+) [1× yr^{-1} for 3 yr]	d	3400 ± 1137	667 ± 333	2733 ± 933	667 ± 333	1733 ± 133ab	1267 ± 66ab	1000 ± 0a
Spr+sum (1992+) [2× yr^{-1} for 3 yr]✘	e	2267 ± 353	667 ± 333	2000 ± 643	467 ± 240	1067 ± 67bc	1133 ± 33bc	933 ± 133a
Spr+sum (1993+) [2× yr^{-1} for 2 yr]	f	2933 ± 1378	333 ± 333	2600 ± 1058	400 ± 231	1467 ± 291abc	1068 ± 67bc	800 ± 200ab
Glyphosate [2.1 kg ae ha^{-1}]	g	3933 ± 1073	800 ± 115	3133 ± 1157	467 ± 133	1733 ± 371ab	1200 ± 306ab	1000 ± 346a
Control	h	1600 ± 902	333 ± 333	1267 ± 570	466 ± 466	800 ± 115c	733 ± 67c	200 ± 200b
p-value		0.5045	0.6813	0.6071	0.8864	0.0527	0.0457	0.1212

* Letters indicate significant differences within columns among treatments detected using Fishers Least-Significant-Difference Test at $\alpha = 0.05$. ✢TSD = total stand density includes all species; † BRDL = broadleaf species; ☨CON = conifer density including ingress and naturals; ‡ OCON = other conifer species; ▲ SE = Engelmann spruce; ▼ WSSE = well-spaced Engelmann spruce; ◆ FGSE = free growing Engelmann spruce; ‗ treatment means ± standard error; ✤1× =1 cutting; and, ✘2× = 2 cuttings.

Few replicated experiments are available to provide information on long-term implications of vegetation management in British Columbia. This study provides insight into some of the long-term implications of vegetation control treatments to vegetation community dynamics, seedling survival, and young stand development. The study also suggests that vegetation management treatments can contribute in achievement of free growing management objectives, when carefully planned and applied for stand establishment. Future remeasurements and monitoring of this installation will provide the information on the long-term growth and yield implications of these treatments.

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REFERENCES

[1] Bergerud W.A., The Effect of the Silviculture Survey Parameters on the Free-Growing Decision Probabilities and Projected Volume at Rotation, B.C. Min. For. Land Manage. Handb. No. 50, 2002.

[2] Biring B.S., Hays-Byl W.J., Ten-year conifer and vegetation responses to glyphosate treatment in the SBSdw3, B.C. Min. For., Res. Br., Victoria, B.C., Exten. Note 48, 2000.

[3] Biring B.S., Comeau P.G., Boateng J.O., Simard S.W., Experimental design protocol for long-term operational response evaluations (EXPLORE), B.C. Min. For., Res. Br., Victoria, B.C. Work. Pap. 31, 1998.

[4] Biring B.S., Hays-Byl W.J., Hoyles S.E., Twelve-year conifer and vegetation responses to discing and glyphosate treatments on a BWBSmw backlog site, B.C. Min. For., Res. Br., Victoria, B.C., Work. Pap. 43, 1999.

[5] Biring B.S., Yearsley H.K., Hays-Byl W.J., Pinchi lake operational herbicide monitoring: 10-year conifer and vegetation responses in the SBSdw3, B.C. Min. of For., Res. Br., Victoria, B.C., Exten. Note 46, 2000.

[6] Biring B.S., Yearsley H.K., Hays-Byl W.J., Ten-year responses of white spruce and associated vegetation after glyphosate treatment at Tsilcoh River, B.C. Min. of For., Res. Br., Victoria, B.C., Exten. Note 55, 2001.

[7] Boateng J.O., Haeussler S., Bedford L., Boreal plant community diversity 10 years after glyphosate treatment, West. J. Appl. For. 15 (2000) 15–26.

[8] British Columbia Ministry of Forests, 1989/1990 Annual report, Victoria, B.C., 1991.

[9] British Columbia Ministry of Forests, Forest Practices Code of British Columbia Act, Victoria, B.C., 1995.

[10] British Columbia Ministry of Forests, 1999/2000 Annual Report, Victoria, B.C., 2000.

[11] British Columbia Ministry of Forests, 2000/2001 Annual Performance Report, Victoria, B.C., 2001.

[12] British Columbia Ministry of Forests, BC Environment, Establishment to free growing, Revised Forest Practices Code Guidebook Nelson Forest Region, Victoria, B.C., 2000.

[13] Braumandl T.F., Curran M.P., A field guide for site identification and interpretation for the Nelson Forest Region, B.C. Min. For., Nelson, B.C., Land Manage. Handb. No. 20, 1992.

[14] Coates K.D., Emmingham W.H., Radosevitch S.R., Conifer-seedling success and microclimate at different levels of herb and shrub cover in a Rhododendron-Vaccinium-Menziesia of south central British Columbia, Can. J. For. Res. 21 (1991) 858–866.

[15] Coates K.D., Haeussler S., Lindeburgh S., Pojar R., Stock A.J., Ecology and silviculture of interior spruce in British Columbia, For. Can. and B.C. Min. For., Victoria, B.C. FRDA Rep. 220, 1991.

[16] Comeau P.G., Light attenuation by thimbleberry-fireweed communities in the ICH zone and its potential effects on conifer growth, in: Hamilton E., Watts S. (Eds.), Vegetation Competition and Responses: Proc. 3rd Ann. Veg. Manage. Work., Feb. 15–17, 1988, Vancouver, B.C., For Can. and B.C. Min. For., Victoria, B.C., FRDA Rep. 026, 1988, pp. 5–7.

[17] Comeau P.G., Effectiveness of repeated cutting treatments in a fireweed community, in: Expert Committee on Weeds, Research Report, Western Canada Section Meeting, Dec. 1–3, 1992, Winnipeg, Man., Vol. 2, 1992, p. 1081.

[18] Comeau P.G., Effectiveness of repeated cutting treatments in a mixed shrub/herb community: Sullivan Site 1, in: Expert Committee on Weeds, Research Report, Western Canada Section Meeting, Dec 1–3, 1992, Winnipeg, Man., Vol. 2, 1992, p. 1081.

[19] Comeau P.G., Effectiveness of repeated cutting treatments in a mixed shrub/herb community: Sullivan Site 2, in: Expert Committee on Weeds, Research Report, Western Canada Section Meeting, Dec. 1–3, 1992, Winnipeg, Man., Vol. 2, 1992, p. 1082.

[20] Comeau P.G., Braumandl T.F., Xie C.Y., Effects of overtopping vegetation on light and growth of Engelmann spruce (*Picea engelmannii*) seedlings, Can. J. For. Res. 23 (1993) 2044–2048.

[21] Comeau P.G., Biring B.S., Harper G.J., Conifer response to brushing treatments: a summary of British Columbia data, B.C. Min. of For., Res. Br., Exten. Note 41, 1999.

[22] Comeau P.G., Biring B.S., Harper G.J., Effectiveness of repeated manual cutting and glyphosate for release of Engelmann spruce from mixed-shrub herb vegetation, West. J. Appl. For. 15 (2000) 154–162.

[23] Curt T., Prévosto B., Klescewski M., Lepart J., Post-grazing Scots pine colonization of mid-elevation heathlands: population structure, impact on vegetation composition and diversity, Ann. For. Sci. 60 (2003) 711–724.

[24] Deloitte and Touche Management Consultants, Economic assessment of vegetation management in B.C. forests, Report prepared for B.C. Ministry of Forests, Silviculture Branch, Victoria, B.C., 1992.

[25] Ehrentraut G., Branter K., Vegetation management by manual and mechanical means in Alberta boreal forests, For. Chron. 66 (1990) 366–368.

[26] Haeussler S., Coates D., Mather J., Autecology of common plants in British Columbia: a review, B.C. Min. For, Res. Br., Victoria, B.C. FRDA Rep. 158, 1990.

[27] Harper G.J., Biring B.S., Heineman J., Mackay river herbicide trial: Conifer response 9 years post-treatment, B.C. Min. For, Victoria, B.C. Res. Rep. 11, 1997.

[28] Harper G.J., Herring L.J., Hays-Byl W.J., Conifer and vegetation responses in the BWBSmw1 12 years after mechanical and herbicide site preparation, B.C. Min. For., Res. Br., Victoria, B.C., Work. Pap. 29, 1997.

[29] Harper G., Whitehead R., Thompson C.F., A comparison of manual brushing treatments in the ICHdw at Redfish Creek: 10-year results from blocks 10–13, B.C. Min. For., Res. Br., Victoria, B.C., Ext. Note 20, 1998.

[30] Hart D., Comeau P.G., Manual brushing for forest Vegetation Management in British Columbia: A review of current knowledge and information needs, B.C. Min. For.,Victoria, B.C., Land Manage. Rep. No. 77, 1992.

[31] Ketcheson M.V., Braumandl T.F., Meidinger D., Utzi G.F., Demarchi D.A., Wikeem B.M., Interior Cedar-Hemlock Zone, in: Meidinger D., Pojar J. (Eds.), Ecosystems of British Columbia, B.C. Min. For., Victoria, B.C., Special Rep. 6, 1991, pp. 167–181.

[32] Krebs C.J., Species diversity measures (Chap. 10), in: Ecological methodology, Univ. B.C. and HarperCollins (Publishers), Vancouver, B.C., 1989, pp. 328–369.

[33] Lanner R.M., On the insensitivity on height growth to spacing, For. Ecol. Manage. 13 (1985) 143–148.

[34] Le Page P., Coates K.D., Growth of planted lodgepole pine and hybrid spruce following chemical and manual vegetation control on a frost prone site, Can. J. For. Res. 24 (1994) 208–216.

[35] Le Page P., Pollack J.C., Coates K.D., Chemical and manual control of thimbleberry (*Rubus parviflorus*) in northwestern B.C.: rate and timing trial, West. J. Appl. For. 6 (1991) 99–102.

[36] Lindgren P.M.F., Sullivan T.P., Influence of alternative vegetation management treatments on conifer plantation attributes: abundance, species diversity and structural diversity, For. Ecol. Manage. 142 (2001) 163–182.

[37] McDonald P.M., Fiddler G.O., Harrison H.R., Repeated manual release in a young plantation: effect on Douglas-fir seedlings, hardwoods, shrubs, forbs, and grasses, USDA, Forest Service, Pacific Southwest Research Station, Albany, CA, Res. Paper PSW-221, 1994.

[38] McMinn R.G., Ecology of site preparation to improve performance of planted white spruce in northern latitudes, in: Forest regeneration at high latitudes: experiences from northern British Columbia, School of Agric.Land Resou. Manag. in cooperation with U.S.D.A. For. Serv. Pacific Northwest For. Range Experimental Stat., Miscellaneous Rep. 82–1, 1982, pp. 25–32.

[39] Miller D.L., Manual and mechanical methods of vegetation control – what works and what doesn't, in: Baumgartner C.M., Boyd R.J., Breuer D.W., Miller D.L. (Eds.), Weed control for forest productivity in the interior west – Symposium proceedings, February 5–7, 1985, Spokane, Washington, Washington State Univ., Coop. Exten., 1985, pp. 55–60.

[40] Newton M., Cole E.C., White D.E., McCormack M.L. Jr., Young spruce-fir forests released by herbicides I. Response of hardwoods and shrubs, N. J. Appl. For. 9 (1992) 126–130.

[41] Rose R., Ketchum J.S., Hanson D.E., Three year survival and growth of Douglas-fir seedlings under various vegetation-free regimes, For. Sci. 45 (1999) 117–1126.

[42] Rose R., Ketchum J.S., Interaction of initial seedling diameter, fertilization and weed control on Douglas-fir growth over the first four years after planting, Ann. For. Sci. 60 (2003) 625–635.

[43] SAS Institute Inc., Copyright® 1999–2001, The SAS System for Windows, Version 8.02, SAS Institute Inc., Cary, NC, USA, 1999.

[44] Simard S., Heineman J., Nine-year response of Engelmann spruce and the Willow complex to chemical and manual release treatments on an ICHmw2 site near Vernon, For. Can., B.C. Min. For., Victoria, B.C., FRDA Rep. No. 258, 1996.

[45] Simard S., Heineman J., Nine-year response of Douglas-fir and the mixed hardwood-shrub complex to chemical and manual release treatments on an ICHmw2 site near Salmon Arm, For. Can., B.C. Min. For., Victoria, B.C., FRDA Rep. No. 257, 1996.

[46] Simard S.W., Heineman J., Mather J., Sachs D., Vyse A., Brushing effects on conifers and plant communities in the southern interior of British Columbia: Summary of PROBE results 1991–2000, B.C. Min. For., Ext. Note 58, 2001.

[47] Simard S.W., Heineman J.L., Mather W.J., Sachs D.L., Vyse A., Effects of operational brushing on conifers and plant communities in the southern interior of British Columbia, Results from PROBE 1991–2000 Protocol for Operational Brushing Evaluations. Res. Prog., Min. For., Land Manage. Handb. No. 48, 2001.

[48] Sullivan T.P., Lautenschlager L.A., Wagner R.G., Influence of glyphosate on vegetation dynamics in different successional stages of sub-boreal spruce forest, Weed Technol. 10 (1996) 439–446.

[49] Sullivan T.P., Wagner R.G., Pitt D.G., Lautenschlager R.A., Chen D.G., Changes in diversity of plant and small mammal communities after herbicide application in sub-boreal spruce forest, Can. J. For. Res. 28 (1998) 168–177.

[50] Sutton R.F., Glyphosate Herbicide: An assessment of forestry potential, For. Chron. 54 (1978) 24–28.

[51] Sutton R.F., White spruce establishment: initial fertilization, weed control, and irrigation evaluated after three decades, New For. 9 (1995) 123–133.

[52] Thompson D.G., Pitt D.G., A review of Canadian forest vegetation management research and practice, Ann. For. Sci. 60 (2003) 559–572.

[53] Wagner R.G., To treat or not to treat: What is the threshold? Ont. Min. Nat. Resour., Ont. For. Res. Inst., Sault St. Marie, Ont. VMAP Rep. Vol. 3(2), 1994.

[54] Wagner R.G., Noland T.L., Mohammed G.H., Timing and duration of herbaceous vegetation control around four northern coniferous species, N. Z. J. For. Sci. 26 (1996) 39–52.

[55] Whitehead R., Harper G.J., A comparison of four treatments for weeding Engelmann spruce plantations in the Interior Cedar Hemlock zone of British Columbia: ten years after treatment, Can. For. Serv., Effects of Forestry Practices Network, Pac. For. Cent., Victoria, B.C., Inf. Rep. BC-X-379, 1998.