Chemical, grazing, and manual cutting treatments in mixed herb-shrub communities have no effect on interior spruce survival or growth in southern interior British Columbia.

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Abstract: Interior spruce (*Picea engelmannii* Parry x *glauca* [Moench] Voss) plantations are commonly weeded of herbs, ferns, and shrubs using foliar glyphosate, livestock grazing, or manual brushing treatments, but it is unknown whether they result in improved conifer survival or growth. We found that despite reducing vegetation for 1-5 years, these treatments applied to mixed herb-shrub communities in southern interior British Columbia had no effect on 5-year survival or growth of interior spruce. Biogeoclimatic zone was the factor that most influenced spruce performance, with greater survival and height growth in the Interior Cedar Hemlock (ICH) zone than in the colder, higher elevation Engelmann Spruce-Subalpine Fir (ESSF) zone. Glyphosate caused larger reductions in vegetation cover and height than did grazing or manual cutting. Glyphosate also reduced plant species richness after 5 years, but none of the treatment methods affected species or structural diversity of the plant community. Structural richness was slightly greater in the ICH than ESSF zone. Our results indicate that the vegetation management treatments operationally applied to herb-shrub communities in southern interior British Columbia have been ineffective at releasing interior spruce.

Keywords: vegetation management, fireweed, ladyfern, thimbleberry, interior spruce
Introduction

Vegetation management treatments have been applied widely across western Canada during the past two decades based on the assumption that intensive silviculture improves conifer productivity (Lavender et al. 1990). Vegetation competition is only one of several factors limiting conifer performance on harvested sites, however, and treatments for improving survival and growth are unlikely to succeed where other factors are more limiting (e.g., harsh climate, insects, disease, livestock use), or where they remain unrelieved. Vegetation management treatments have not improved conifer survival and growth equally on all sites (Simard et al. 2001); on some, this is because vegetation was too sparse to impair conifer performance, and on others, vegetation was not adequately reduced by the treatments. At high elevation, climatic factors may be more limiting to seedling performance than vegetation competition.

A variety of vegetation communities develop in southern interior British Columbia following harvesting or site preparation, but those dominated by fireweed (*Epilobium angustifolium* (L.) Scop.), ladyfern (*Athyrium filix-femina* (L.) Roth), and thimbleberry (*Rubus parviflorus* Nutt.) are among the most common and quickest to develop in productive ecosystems. These mixed herb-shrub communities, which vary in relative abundance of the three dominant species, can threaten conifer seedling establishment (Kimmins and Comeau 1990) through competition for light (Comeau et al. 1993) and mechanical damage from vegetation- and snow-press (Hart and Comeau 1992). Herbs, ferns, and shrubs can also benefit tree and site productivity, however, by reducing pest attack (Gara et al. 1971), ameliorating damaging frosts (Spittlehouse and Stathers 1990), contributing to soil nutrients through rapid nutrient uptake and litter turnover (Hangs et al. 2003), and providing forage for wildlife and livestock (Kufeld 1973; Haeussler et al. 1990; Newsome et al. 1995).

Successful vegetation management in young forest plantations requires an understanding of interspecific competitive effects on seedling survival and growth, and the efficacy of
treatments that seek to relieve those effects (Wagner et al. 1999); however, different strategies may be appropriate for high- than low-elevation sites where vegetation may not be the most important limiting factor. Mixed herb-shrub communities occur across a broad elevation range in British Columbia, and are particularly common in the Interior Cedar-Hemlock (ICH) and Engelmann Spruce-Subalpine Fir (ESSF) biogeoclimatic zones (Meidinger and Pojar 1991). The ESSF zone, because of its higher elevation, is a harsher growing environment than the ICH (Lloyd et al. 1990), and presents greater challenges for conifer seedling establishment. Low soil temperatures, summer frosts, and late melting snowpacks have all been shown to negatively affect seedling performance (Carter et al. 1988; DeLucia and Smith 1987; Grossnickle 1988; Örlander et al. 1990; Farnden 1994; Dang and Cheng 2004). Severe vegetation management treatments may ameliorate some of the high-elevation climatic effects on seedling growth (Coates et al. 1991), but they could also negatively affect other ecosystem properties and processes. High-intensity mechanical site preparation treatments, for example, have increased abundance of non-native species (Haeussler et al. 1999), which could threaten indigenous plant diversity (Baskin 1996).

Site conditions where vegetation management can improve conifer performance are not well understood. As a result, treatments may be applied on sites where they are not necessary. The possibility of unnecessary treatment has met with intense scrutiny by the forest companies and public because of high application costs, public opposition to herbicides, and unknown effects on biodiversity (Burton et al. 1992). Over $30 million was spent in 2003 to brush over 63,000 ha in British Columbia (BC Ministry of Forests 2003), for example, with little understanding of treatment effectiveness.

To increase our ecosystem-specific understanding about the long-term effects of common vegetation management treatments on conifers and plant communities, a large study was conducted in 13 vegetation complexes in southern interior British Columbia (Simard 1993). Here
we present 5-year conifer and plant community responses to foliar glyphosate, livestock grazing, and manual cutting treatments applied to mixed herb-shrub communities in interior spruce (*Picea engelmannii* Parry x *glauca* [Moench] Voss) plantations in the ICH and ESSF zones. The specific objectives were to quantify the effects of biogeoclimatic zone, vegetation management method, and presence of treatment on: (i) survival and growth of interior spruce, (ii) abundance of target vegetation, and (iii) composition and diversity of the plant communities. We also sought to identify competition thresholds for spruce diameter growth in the ICH and ESSF zones.

### Materials and methods

#### Study area

Nineteen study sites were located in the ICH and ESSF zones between 50°33’N and 52°23’N, and 117°08’W and 120°19’W, in the Montane Cordillera ecozone of British Columbia, Canada (Wiken 1986) (Table 1). The ICH zone is characterized by cool, wet winters and moderately dry summers, while the ESSF zone has high snow cover and short, cool summers. The nine ICH sites are in the moist, wet (ICHmw), wet, cool (ICHwk), and very wet, cool (ICHvk) subzones, which average 999 mm precipitation and 1583 growing-degree days (>5°C) annually. The 10 ESSF sites are in the wet, cold (ESSFwc) and dry, cold (ESSFdc) subzones, which average 1008 mm precipitation and 626 growing-degree days (Lloyd et al. 1990; Braumandl and Curran 1992). All sites have circum-mesic moisture regime and medium nutrient regime. Soils are Podzols or Brunisols (Soil Classification Working Group 1998) with silt clay loam to sandy loam texture. Sites were harvested between 1971 and 1993, site-prepared by broadcast burning, livestock grazing, or chemical or mechanical treatment between 1984 and 1994, and planted with interior spruce 0 to 22 years after the most recent harvesting or site preparation disturbance. Prior to brushing, sites were dominated to varying degrees by fireweed, lady fern, and thimbleberry. Red raspberry (*Rubus idaeus* L.), Devil’s club (*Oplopanax horridus* (Smith) Miq.), bracken
(Pteridium aquilinum (L.) Kuhn), and other minor herb and shrub species also occurred on some sites.

**Experimental design and treatments**

A split-split-plot treatment structure was used to investigate zone (ICH and ESSF), vegetation management method (foliar glyphosate, livestock grazing, and manual cutting), and treatment (treated and untreated control) effects on interior spruce and vegetation response variables (Peterson 1985). Each zone x method x treatment combination was replicated three or four times in a randomized complete block design, where each replicate was located on a separate clearcut site. On each site, the treatment and control were randomly assigned to two plots that measured 0.9 ha in size, including a 20 m surrounding buffer. Within each treated and control plot, 36 gridpoints were systematically located, with the closest undamaged interior spruce to each gridpoint serving as the sample tree. Circular subplots, measuring 10 m² in area and centered on each spruce tree, were used for plant community measurements.

Treatments were applied once when seedlings were newly planted to five years-old, as part of the operational brushing program for the southern interior of British Columbia. Glyphosate was applied as a foliar spray at rates of 1.2-2.1 kg ai/ha in August. Grazing treatments were applied using sheep and cattle for a one-month period in June-August. For manual treatments, vegetation was cut in a 0.5-1.0 m radius around target trees using brush saws or weed whips in June-October.

**Measurement**

Measurements were made immediately before brushing (year 0), and 1, 3, and 5 years afterward. In each tree-centered subplot, spruce was evaluated for survival, total height (± 1 cm), root collar diameter (± 0.1 cm), leader length (± 1 cm), and damage cause. Using these parameters, height:
diameter (H:D) ratio was calculated. Seedling vigor (dead, poor, medium, and good) and competitive status (overtopped (shorter than neighbors), threatened (equivalent height to neighbors), and free-growing (taller than neighbors)) were visually assessed using criteria described by Simard (1993). Cover and modal height of all vegetation, the shrub layer, and the herb layer were evaluated within the 10 m² subplots.

Percent cover of all vascular plant species was recorded in four randomly selected subplots within each treatment and control plot. These data were used to calculate species richness (the number of species) and species diversity according to Shannon and Weaver (1949):

\[
H = -\sum_{i=1}^{n} \left( \frac{n_i}{N} \log \left( \frac{n_i}{N} \right) \right)
\]

where \( n = \) cover of each species and \( N = \) sum of cover of all species. Equation (1) was also used to determine structural diversity of the plant community based on eight vegetation groups: shade tolerant conifers, moderately shade tolerant conifers, shade intolerant conifers, tall broadleaves, tall shrubs, short shrubs, tall herbs, and short herbs. Richness of structural groups was also calculated. Treatment effects on the abundance of individual plant species were identified where species cover values increased or decreased by at least 50% in the treatment relative to the control on at least 50% of the replicate sites.

Competition thresholds were determined for each site based on relationships between 2-year post-harvest spruce diameter increment and initial post-treatment cover of the dominant vegetation group (fireweed, herbs, or shrubs, depending on the site). The thresholds were identified using a ceiling function that described the upper boundary of the data and enveloped at least 95% of the observations. This approach was first described by Goldberg (1987), and later applied by Wagner et al. (1989), Burton (1993), and Simard et al. (2004). The threshold occurred
at the vegetation level below which diameter was independent of decreasing cover, and above
which diameter declined as cover increased (i.e., where competition became the primary
constraint on diameter growth) (Figure 1).

Statistical analysis

All statistical analyses were performed using SAS for Windows, version 8.2 (SAS Institute Inc. 2001). Conifer, target vegetation, and plant diversity variables were compared between biogeoclimatic zones, vegetation management methods, and treatments for each year using a mixed-model analysis of variance (ANOVA) with three- or four-fold replication in a randomized complete block design (Kirk 1982, McKone and Lively 1993). Analysis of covariance (ANCOVA) was used for variables where pre-treatment differences existed. Transformation was not necessary for any of the variables based on examination of the distribution of residuals, tests for normality, and tests for equality of variance. Repeated measures analysis was not performed because of the small number of measurement years and the unequal time span between measurement years. Where ANOVA or ANCOVA showed significant method effects, means were separated using Bonferroni’s multiple comparison test ($\alpha=0.05$).

Results

Spruce survival and vigor

Survival of interior spruce did not differ, on average, between the treatment and control after 5 years (average 80%, $p=0.5736$, Table 2). However, there was a significant interaction between biogeoclimatic zone and vegetation management method ($p<0.0001$). Fifth year survival was 27% in the ESSF grazing treatment compared with 90% in all other treatments in the ESSF and ICH zones. Competing vegetation was identified as the cause of mortality for 52% of seedlings in the ESSF grazing treatment, compared with 7% in other zone x method combinations. Other
damage causes, including *Armillaria* root disease, weevils, defoliating insects, poor planting, snow and ice, and wildlife, accounted for less than 1% mortality each. On average, 2% of seedlings died from unknown causes.

Among surviving seedlings, the proportion that were of good, moderate, or poor vigor were approximately equal across zones, vegetation management methods, and treatments (Figure 2). In year five, 29% of seedlings were of good vigor, 40% were moderate, and 9% were poor.

*Spruce growth*

Five years after application, treatment had no effect on spruce diameter, height, leader length, crown width, crown length, or height: diameter ratio (p>0.05, Table 2). Leader length tended to increase (p=0.1007) and height: diameter ratio tended to decrease (p=0.1268) in the treatment relative to the control. Vegetation management method also had no effect on diameter, height, or leader length (p<0.05), but by year five, spruce tended to be larger following the glyphosate and manual methods than grazing (p<0.15, Table 2). There were significant interactions in year five between method and zone for spruce crown width and length, which were smaller in the ESSF-grazing treatment than the ICH-glyphosate and, for crown length only, the ESSF-manual treatment. Spruce were shorter following glyphosate than manual cutting in year three (data not shown), possibly as a result of herbicide damage. This difference had disappeared by year five.

Biogeoclimatic zone was by far the most influential factor on spruce growth. Within one year, spruce seedlings were taller and had longer leaders and crowns in the ICH than ESSF zone. The magnitude of this difference increased through year five. Spruce diameter was unaffected by zone, method, or treatment (p>0.05), but it tended to be larger in the ICH than ESSF zone (p=0.0659), and on glyphosate and manually treated sites than grazed sites (p=0.0651).
**Spruce competitive status**

The height of spruce relative to vegetation varied significantly with treatment, and there was also an interaction between method and zone. In the first year after treatment, treated spruce were 97% as tall as surrounding vegetation, compared to 50% for untreated spruce ($p=0.0012$). After five years, treated spruce were 108% the height of vegetation, compared with 83% for untreated spruce ($p=0.0158$). There was a significant zone $\times$ method interaction for relative height in year five due to poor spruce height growth on grazed sites. Spruce on ESSF-grazed sites averaged 39% as tall as surrounding vegetation, compared with 112% in other zone $\times$ method combinations.

Prior to brushing, 68% of spruce seedlings were overtopped by vegetation, 23% were threatened, and 9% were free-growing. Five years after application, treatment had improved competitive status more using glyphosate and manual cutting methods than grazing, and more in the ICH than the ESSF zone. On average, ICH spruce had outgrown vegetation within three years of treatment application, whereas ESSF spruce were approximately the same height as neighboring vegetation in year five (Figure 3).

**Vegetation abundance**

Vegetation management treatment reduced total vegetation and herb height for at least 5 years ($p<0.05$, Tables 3 and 4). There were significant interactions between method and treatment in year one for total vegetation cover, shrub cover, total vegetation height, and herb height, but these were no longer present by year three. In year one, total vegetation cover was reduced by glyphosate (56% cover) more than by manual and grazing (85%) treatments ($p=0.0032$). The same was true for shrub cover (14% versus 32%, $p=0.0456$) and total vegetation height (38 cm versus 89 cm, $p=0.0027$). Shrub cover differed between other method $\times$ treatment pairs, but there were no consistent trends (Table 3). Vegetation height was reduced in the grazed treatment (69 cm) and herb height was reduced in the glyphosate and grazed treatments (average 43 cm).
compared with the controls (96 cm) after one year. There were also significant interactions (p<0.05) between method and zone throughout the measurement period for shrub cover, and total vegetation, herb, and shrub heights, but there were no meaningful trends for either factor.

Plant community diversity

Species diversity was not affected by treatment, method, or zone during the five year period after treatment. Species richness was lower, however, in the glyphosate than manual cutting method after 5 years. There was an average of 42 species in the manual cutting treatment, 39 in the grazing treatment, and 33 in the glyphosate treatment in year five (p=0.0105). Species composition shifted as a result of each method (Table 5). Foliar glyphosate application had the largest effect, increasing abundance of three herb and two shrub species, and decreasing three herb and three shrub species. Manual cutting resulted in increased abundance of two herb species, while two herb species increased and two shrub species decreased following grazing.

The ICH consistently had more structural groups than the ESSF throughout the measurement period. In year five, there were 6.2 groups in the ICH versus 5.7 in the ESSF (p=0.0323). There also tended to be fewer structural groups in the treatment (5.8) than the control (6.1) in year five (p=0.0789).

Competition thresholds

Competition thresholds averaged 48% cover for ESSF sites (range 5-80%) and 75% for ICH sites (50-95%). On sites where fireweed was the dominant species (i.e., fireweed was used to determine the threshold), the average threshold was 38% cover in the ESSF versus 68% in the ICH (see Figure 1 for example sites). On sites where shrubs were dominant (i.e., shrub cover was used to determine the threshold), the threshold averaged 54% in the ESSF versus 84% in the ICH
zone. The ICH sites where ferns were dominant, the threshold averaged 72% cover. On ESSF sites, 61% of untreated spruce was growing below the cover thresholds, compared to 80% on ICH sites. On both ESSF and ICH sites, 92% of treated seedlings were growing at covers below the thresholds. On ESSF sites, 10% of control and 13% of treated seedlings achieved at least 80% of the maximum 5-year diameter increment for the site, compared with 5% and 27% on ICH sites, respectively.

Discussion

Spruce growth

Biogeoclimatic zone was a stronger determinant of interior spruce growth than whether a treatment was applied, or what vegetation management method was used. Spruce had faster growth rates in the ICH than the ESSF zone, but none of the treatments improved growth, even though vegetation cover was reduced for at least one year and height for at least five years. Other studies have found that vegetation cover is well correlated with light transmission (Comeau 1988; Shropshire et al. 2001), which suggests that light availability was either not limiting to interior spruce growth on our sites, or it was not the most important limiting factor.

Spruce on our ICH sites were growing at average rates for south-central British Columbia, suggesting they were not severely constrained by vegetation competition, whereas those in the ESSF zone were growing more slowly (Coates et al. 1994). The lack of treatment effect on ESSF spruce suggests that they were unable to respond to vegetation reductions because of the over-riding influence of other limiting factors. On our ICH sites, 80% of control seedlings were already growing in neighborhoods below the cover threshold, compared with only 61% in the ESSF zone. Treatment increased the proportion of ESSF spruce below the threshold to 92% in year one, but this did not result in a growth response.
Spruce growth was slower in the ESSF than the ICH zone, but height: diameter responses did not differ between zones. This suggests the slower-growing ESSF spruce were remaining sturdy, which would enable them to withstand snow- and vegetation-press. Slower growth rates in the ESSF than the ICH zone is consistent with its harsher environment and shorter growing season (Lloyd et al. 1990). Low air temperature, cold soils, and long-lasting snowpack all contribute to poor conifer performance in the ESSF zone, and the interaction of competing vegetation with these factors may be equally as important as its effect on light availability (Farnden 1994; Balisky and Burton 1995). The relative importance of competition can vary between sites with similar levels of vegetation if the set of factors that are limiting to conifer seedling performance differ. Based on a model developed by Weldon and Slauson (1986), competition may, for example, be intense without being important (i.e., other factors are more important) or important even though it is not very intense (i.e., vegetation is the most important factor on a site with few limitations to seedling performance). It has long been debated whether competitive intensity increases (Grime 2001) or decreases (Tilman 1988) with site quality, but our results do not indicate a clear relationship between competitive intensity and site quality. Our threshold analysis suggests that competition was less intense in the more productive ICH than ESSF zone, but this is confounded by the over-riding climatic limitations in the ESSF (Lloyd et al. 1990).

The lack of spruce response to our vegetation management treatments is consistent with some, but not all, studies in mixed herb-shrub communities, illustrating the variable effects of treatment across sites. For example, manual cutting had no effect on Engelmann spruce growth after 10 years in British Columbia’s ICH zone (Whitehead and Harper 1998), whereas a similar treatment improved black spruce (Picea mariana [Mill.] B.S.P.) growth in eastern Canada (Jobidon and Charette 1997). Early improvements in spruce growth following glyphosate, multiple manual, or multiple grazing treatments disappeared after 10 years in a British Columbia
study by Biring et al. (2003), whereas glyphosate improvements in spruce height and diameter persisted for 10 years in a nearby study by Whitehead and Harper (1998).

Spruce vigor and survival

As with growth, spruce survival differed between biogeoclimatic zones but was not affected by treatment. Vigor of most spruce was moderate to good at the start of this study, but it declined to a greater extent in the ESSF than the ICH during the five year measurement period, eventually resulting in 20% higher mortality in the ESSF zone. By contrast, vigor declined similarly among treated and control seedlings during that time period, with mortality among treated and untreated seedlings attributed primarily to vegetation competition. This differs from a longer-term study in a similar ICH herb-shrub community in British Columbia, where survival of Engelmann spruce declined steeply between 4 and 10 years unless seedlings were manually or chemically brushed (Biring et al. 2003). In that study, even a single cutting treatment curbed mortality rates (Biring et al. 2003). In our study, vigor trends do not suggest there will be a similar divergence in survival between the treatment and control. As with our study, Jobidon and Charette (1997) found that black spruce survival was unaffected by manual treatment of a fireweed community in Quebec.

Fewer trees survived on our grazed than manually cut or glyphosate-treated ESSF sites, or on any of the ICH sites regardless of treatment method. The poorer spruce performance following grazing than the other treatments may be related to the higher average elevation and colder climate of the grazed sites. Physiological functioning of spruce is inhibited at low soil temperatures (Carter et al. 1988; Grossnickle 1988; Örlander 1990), and a dense vegetation canopy can further restrict soil and air warming in the seedling microenvironment (Spittlehouse and Stathers 1990). Manipulation of vegetation structure and composition can alter the soil thermal regime and increase seedling growth to some extent (Coates et al. 1991 and 1994; Wood and von Althen 1993), but this did not occur following grazing of our ESSF sites.
The average delay between the last disturbance (i.e., harvesting or site preparation) and planting was also considerably longer for grazed sites than manually cut or glyphosate-treated ESSF sites. Wagner et al. (1999) identified a critical period of 1-3 years after planting when competing herbs should be treated to improve black spruce performance. If we assume a similar critical period for release of interior spruce, glyphosate and manual treatments were applied at an appropriate time in our study, whereas grazing treatments were applied too late. Prompt application of brushing treatments is known to contribute to successful seedling establishment, particularly where the vegetation community develops quickly (Boateng and Comeau 1997).

Vegetation responses

Treatments reduced vegetation cover for 1-5 years, even though spruce survival and growth did not improve. Glyphosate was more effective than the other treatments at reducing vegetation cover, while both glyphosate and grazing were more effective than manual cutting at reducing vegetation height. The ineffectiveness of our single manual treatment at reducing vegetation abundance agrees with other studies in British Columbia (LePage et al. 1991; Harper et al. 1997; Whitehead and Harper 1998; Comeau et al. 2000). More than one grazing pass has also been required to release conifer seedlings from vigorous herbs for longer than one year (Newsome et al. 1995), even though grazing effects lasted slightly longer than cutting effects in our study. Disappearance of our glyphosate effects after three years is consistent with previous studies using similar herbicide application rates (Simard et al. 2001; Simard and Heineman 1996).

Plant community diversity

Plant species richness and diversity were affected by vegetation management method, but they did not vary with biogeoclimatic zone or treatment. Sites treated with glyphosate had nine fewer species after five years than those that were manually cut. Others have also reported short-term
decreases in species richness following herbicide application (Santillo et al. 1989; Freedman et al. 1993; Sullivan et al. 1998), whereas a longer-term study found no effect of glyphosate after 10-12 years (Boateng et al. 2000). By contrast, medium and high severity mechanical site preparation treatments have affected plant community structure, composition, and diversity for at least 10 years (Haeussler et al. 1999).

Glyphosate reduced the relative abundance of six species, of which three (fireweed, ladyfern, and thimbleberry) were the primary species targeted by our vegetation management treatments. Oval-leaf blueberry (*Vaccinium ovalifolium* Sm. in Rees) also decreased following chemical application, as did thimbleberry and black gooseberry (*Ribes lacustre* (Pers.) Poir. in Lam.). Berry-producing shrubs are important to wildlife, and have been shown to decrease following herbicide and site preparation treatments (Moola and Mallik 1998; Haeussler et al. 1999). Glyphosate also caused five species to increase. Three of the increasers are commonly associated with disturbed sites (MacKinnon et al. 1992; Parish et al. 1996), and may have responded to the increased growing space created by the chemical treatment. Only one non-indigenous species increased following glyphosate treatment, whereas Haeussler et al. (1999) found that non-native species increased 10-16-fold following high-severity mechanical site preparation. Herb species that increased following manual cutting and grazing were of low stature and may have responded to reductions of taller species (Small and McCarthy 2002). Two shrub species decreased following grazing, but this was unlikely related to treatment because neither was a preferred forage species for sheep (Newsome et al. 1995).

None of the factors examined in this study affected structural diversity of the vegetation community, which contradicts results from other studies where diversity of structural groups increased following silviculture treatments (Haeussler et al. 1999; Boateng et al. 2000). There were more structural groups in the ICH than the ESSF zone, although the magnitude of the difference (less than one group) was small, and was due mainly to the presence of shade tolerant
conifers on ICH sites. There was also a slight reduction in structural group richness as a result of

 treatment, which was primarily caused by mortality of the few broadleaf trees following

glyphosate application. Although this change is minor, birch and aspen trees are considered

keystone species in these ecosystems because of their importance for cavity nesting birds and

other wildlife species (Enns et al. 1993; Aitken et al. 2002).

Competition thresholds

We identified competition thresholds based on the concept that competition is a constraint rather

than a determinant of conifer performance, particularly on sites where vegetation is patchy and

topography or soils are heterogeneous (Goldberg 1987; Wagner et al. 1994; Burton 1993). We

found that spruce diameter varied widely at neighborhoods with low to moderate vegetation

cover, reflecting the secondary importance of competition to other limiting factors at these levels

(Wagner 2000). Only where vegetation was highly abundant did spruce diameter growth appear

constrained by competition. We found that cover thresholds were approximately one-third lower

in the ESSF than the ICH zone, presumably because the smaller and less vigorous conifers

growing in the harsher, high elevation environment were less tolerant of competition. Our

thresholds were greater than those identified earlier on the same sites by Simard et al. (2001),

particularly in the ICH zone. This suggests that vegetation competition was decreasing in

importance as stands aged and as spruce gradually outgrew the overtopping vegetation. The zone

difference in threshold increases reflects the fact that spruce outgrew the vegetation canopy

approximately two years earlier in the ICH than ESSF zone following brushing (Figure 2).

The higher threshold in communities with more ferns and shrubs than fireweed suggests

spruce was less tolerant of fireweed than of the other species. Fireweed is a particularly strong

competitor for light because its canopy develops earlier in the growing season than many other

species (Spittlehouse and Stathers 1990; DeLong 1991). Herb species generally establish earlier
and reach maximum competitiveness sooner than shrub or woody species (Eis 1981). The relative competitiveness of individual species is linked more to their size, growth rate, and ability to pre-empt growing space than to intrinsic species differences in resource uptake processes (Harper 1977; Goldberg 1987; Bell et al. 2000).

The competition thresholds identified in our study correspond with the maximum response threshold for growth described by Wagner (2000). Survival thresholds, where competition increases the likelihood of mortality, occur at higher vegetation levels than growth thresholds. Five years after our study was initiated, 31% of ESSF spruce had died and a further 39% were at risk of future mortality because they were growing in neighborhoods well above the growth threshold. In the ICH zone, by contrast, the growth threshold was higher, with only 11% of spruce dead after 5 years and 20% more in neighborhoods that could threaten survival.

Conclusions and forest management implications

Our study suggests that the glyphosate, manual, and grazing treatments that have commonly been applied in ICH and ESSF herb-shrub communities in southern interior British Columbia have been ineffective at improving interior spruce performance. This is for different reasons in the ESSF than the ICH, suggesting different management strategies and expectations are appropriate for the two biogeoclimatic zones. On circum-mesic ICH sites, our results suggest that treating herb-shrub communities is generally not required because spruce survival, growth and free-growing objectives are being met without treatment (BC Ministry of Forests 2000; Simard et al. 2001). We found that most untreated seedlings on our ICH sites were growing in neighborhoods below the response threshold.

By contrast, spruce survival and vigor gradually declined on circum-mesic ESSF sites, and growth rates were lower than in the ICH zone. Although treatment reduced vegetation abundance for 1-5 years in the ESSF, it did not relieve the primary constraints on seedling
performance, which appear more related to the cold environment than vegetation competition. Alternative treatments that relieve the harsh environmental conditions, such as improving the soil thermal regime, may be more appropriate before and during the seedling establishment period. Other studies suggest that mechanical or chemical site preparation, early and repeated vegetation management treatments, and the selection of large stock types can contribute to successful seedling establishment on these sites (Brand 1990; Wood and von Althen 1993; Farnden 1994; Thiffault et al. 2003).

Many plantations in British Columbia have been brushed unnecessarily during the past two decades because foresters lacked ecosystem-specific information on factors that primarily limit conifer survival and growth. In this study, we identified sites that do not benefit from brushing, which should free up resources for more appropriate treatment of plantations that are under-performing.

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