

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

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Section Eleven



Ministry of Forests
Research Program

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Mixed Broadleaf-Shrub Complex

ABSTRACT

We have fifth-year results demonstrating the effects of manual cutting, girdling, and cut stump–glyphosate treatments on the *Mixed Broadleaf-Shrub* Complex and conifers in the ICH and IDF zones. Manual cutting was applied in 5- to 8-year-old Douglas-fir and 3- to 10-year-old lodgepole pine plantations, girdling was applied in 5- to 17-year-old Douglas-fir plantations, and cut stump–glyphosate treatment was applied in 8- to 9-year-old Douglas-fir plantations.

Manual cutting: Cutting reduced broadleaf height for at least 5 years, but the effects on cover were not significant because of vigorous sprouting. After 5 years, broadleaves had recovered to about half the control height, and were taller than Douglas-fir but not lodgepole pine. The cutting treatment was not needed to ensure good survival of Douglas-fir or lodgepole pine and, to the contrary, caused an increase in pine mortality from *Armillaria* (7% in the treatment versus 2% in the control in year 3, $p = 0.07$). Five years after brushing, Douglas-fir stem diameter averaged 14% greater and leader lengths were 9.6 cm longer in the treatment than in the control, but height had not improved significantly. Lodgepole pine stem diameter increased by 37% as a result of cutting, and height:diameter ratio was significantly lower in the treatment (56.0) than in the control (68.5). Total height and leader length of pine were unaffected by the manual cutting treatment after 5 years. Manual cutting had no effect on vascular plant species richness or diversity.

Girdling: Girdling killed almost all broadleaves, but modal height was unaffected during the 5-year measurement period because treated stems died gradually and some stems were missed during

treatment. Large reductions in broadleaf cover were significant only in the first year after girdling because of great variability among sites. Girdling caused a significant reduction in Douglas-fir survival during the 5-year measurement period (90% in the treatment versus 97% in the control), mainly because *Armillaria* caused significantly more mortality in the girdling treatment than in the control (8 versus 3%, $p = 0.07$). Girdling increased Douglas-fir leader length by 56%, but had no effect on stem diameter or height. However, seedling responses may be somewhat delayed in the girdling treatment because of the gradual mortality of broadleaves. Girdling had no effect on species richness but resulted in a small, short-lived increase in diversity.

Cut stump–glyphosate: Cut stump–glyphosate treatment had a more severe effect on broadleaf abundance than either manual cutting or girdling. After 5 years, broadleaf height and cover in the treatment were less than one-half and one-quarter, respectively, of control values. Survival of Douglas-fir was excellent (average 95%) in both the cut stump–glyphosate treatment and control, and mortality caused by *Armillaria* was unaffected. However, the percentage of poor-vigour trees increased from 11 to 39% in the control while remaining constant in the girdled area. Five years after treatment, average Douglas-fir stem diameter was 52% (2.63 cm) greater in the brushed area than in the control and average height was 25% (79.9 cm) greater. Cut stump–glyphosate treatment had no effect on vascular species richness or diversity.

Competition thresholds for stem diameter of Douglas-fir, lodgepole pine, and interior spruce averaged 3664, 3367, and 2500 stems/ha for

broadleaf density, 28, 18, and 20% for broadleaf cover, and 39, 15, and 27 for CRH (broadleaf cover * broadleaf modal height)/conifer height, respectively, where all-sized broadleaves were used in the threshold estimates. Our density thresholds agree with those estimated by Simard (2001, in review).

Without treatment, our results suggest conifer stands growing in the *Mixed Broadleaf-Shrub* Complex generally will not meet all of the free-growing requirements within the recommended window (B.C. Ministry of Forests 2000). In particular the conifer:vegetation height ratio requirement is unlikely to be met.

Description of the *Mixed Broadleaf-Shrub Complex*

The *Mixed Broadleaf-Shrub Complex* is characterized by the three broadleaf species that are common in southern interior British Columbia: paper birch (*Betula papyrifera*), trembling aspen (*Populus tremuloides*), and black cottonwood (*Populus trichocarpa*). Birch is dominant, but mixtures of two or all three of the species are common. Willow (*Salix* spp.) and/or Sitka alder (*Alnus viridis*) sometimes occur in the mid-storey, and thimbleberry (*Rubus parviflorus*) and fireweed (*Epilobium angustifolium*) are common in the understorey (Figure 115). On sites where aspen dominates, the vegetation community is referred to as the *Aspen Complex* (described in Section 10), and if cottonwood is



FIGURE 115 The *Mixed Broadleaf-Shrub Complex* and Douglas-fir prior to manual cutting at Johnson Lake (Site 29) in the ICHmk1 variant in the Kamloops Forest District. Photo credit: Jean Mather.

dominant, it is classified as the *Cottonwood-Shrub Complex*. Broadleaf stands in southern interior British Columbia tend to be dominated by birch in wet climatic regions and aspen where it is drier (Lloyd et al. 1990).

The *Mixed Broadleaf-Shrub Complex* is most widespread in the ICH zone, which covers over 3 million hectares in British Columbia. In the southern interior, the complex is also common in wet-belt portions of the IDF zone, and sometimes the MS zone. Birch has an exceptionally wide distribution in British Columbia and the *Mixed Broadleaf-Shrub Complex* can be found in all biogeoclimatic zones except the MH and AT (Peterson et al. 1997).

Development of the *Mixed Broadleaf-Shrub Complex*

Birch is the dominant species associated with the *Mixed Broadleaf-Shrub Complex*, and is therefore the focus of this section. Aspen tends to occur in patches in the *Mixed Broadleaf-Shrub Complex*, particularly on sites where mature stems were present in the original stand and produced suckers following harvesting. Aspen autecology and development are discussed in detail in Section 10 of this report. Cottonwood tends to be present in the complex on sites where seed and suitable seedbeds are available; compacted skid roads and areas with moist, completely exposed mineral soil are particularly desirable (Simard and Vyse 1992).

Birch is shade-intolerant (Hosie 1969), and it expresses its best growth on open sites with moist, well-drained sandy loam or silty-textured soils, or on soils derived from limestone (Peterson et al. 1997). It has moderately high requirements for nitrogen, calcium, and magnesium, and prefers medium to rich sites (Krajina et al. 1982). Young birch trees tolerate a wide range of environmental conditions, making them efficient competitors for resources; they are moderately tolerant of drought stress (Ranney et al. 1991) and can tolerate high summer temperatures if sufficient soil water is available (Simard and Vyse 1992). They are also very frost-resistant, and can begin spring growth well before conifers, when temperatures are below freezing (Fowells 1965; Krajina et al. 1982; Peterson et al. 1997).

Paper birch reproduces mainly from seed (Fowells 1965), although it can also reproduce vegetatively from sprouting of cut or damaged stems (Hosie 1969; Klinka and Scagel 1984). It produces abundant seed, beginning at about age 15 years and peaking at age 40–70 years. Most seed falls within 100 m of parent trees, but it is light and readily blown for greater distances, especially over snow (Burns and Honkala 1990). Most birch seed germinates immediately after snowmelt in the first spring after it is shed (Haeussler et al. 1990). Germination is most abundant on moist, shady seedbeds of mineral soil or mixed mineral-organic material (Marquis et al. 1964; Marquis 1966).

In spite of germinating best in shade, birch requires abundant light for continued growth (Marquis et al. 1964) and rarely survives under established forests except in openings created by windthrow, insects, or disease (Burns and Honkala 1990). Birch reproduction is therefore most favoured by disturbances that remove the forest canopy to increase light (e.g., harvesting or wild-fire), and that expose mineral soil or mix mineral and organic materials to provide a good seedbed (e.g., intense burns, mechanical site preparation). Regeneration of cottonwood and willow are also encouraged by mineral soil exposure (Haeussler et al. 1990). Regeneration of birch from seed can be discouraged by minimizing soil disturbance and maintaining ground cover of leaf litter (Haeussler et al. 1990; Peterson et al. 1997). Birch that originates from seed has relatively slow initial growth rates (10–20 cm/yr on mesic ICH sites) but reaches a height of about 4 m by age 10 years (Simard and Vyse 1992). Birch can reproduce abundantly from seed; depending on seedbed characteristics, densities can range from 1000 to 10 000 stems/ha following moderately intense bunch-and-burn treatments to 10 000–30 000 stems/ha following severe site preparation treatments that expose mineral soil (Simard and Vyse 1992, 1994). However, birch is very shade-intolerant and self-thins rapidly. Ingress is minimal more than 2–3 years after site disturbance (Peterson et al. 1997). In the ICH zone, birch densities are typically reduced to 5000–10 000 stems/ha at age 10 years, about 1500 stems/ha at age 15 years, and 500 stems/ha at age 70 years (Simard and Vyse 1992, 1994).

Sprouting of cut or burned birch stems can also contribute substantially to birch density on sites

where there was a high component of vigorous birch in the original stand. Cut stumps sprout from adventitious buds located just below ground level (Peterson et al. 1997). Sprouts are often produced in very large numbers, especially on mature stumps; within 1–2 years of cutting, we have observed in excess of 100 sprouts on single birch stumps. Sprout growth is vigorous because of the large store of carbohydrates in the roots. Sprouts commonly increase in height at rates of 0.5–2 m/yr on mesic to subhygric sites in the ICH zone, and may reach 7 m tall by age 10 years (Simard and Vyse 1992). Sprouting is most prolific when birch are young, under high light and temperature conditions (Johansson 1985; Peterson et al. 1997).

Interactions with Conifer Seedlings

In southern interior British Columbia, the *Mixed Broadleaf-Shrub* Complex is considered a serious long-term competitor with conifers (Kimmins and Comeau 1990). Birch dominates the community, and can attain 50–100% cover 5–10 years after disturbance (Mather 1988). In the ICH zone, its juvenile height growth in full sunlight exceeds that of all conifers except western larch (Simard and Vyse 1994). In young stands, competition between broadleaves and conifers is mainly for light, although drought stress experienced by conifers can also be exacerbated by broadleaf presence on mesic and drier sites (Simard 1990a). Burton (1996) reported that conifers growing in 8- to 12-year-old birch patches in the CWHdm experienced severe light competition. As stands age, birch competition appears to lessen, and shift away from light toward soil resources (Simard and Sachs 2001, in review). Broadleaf trees can also physically damage conifers through vegetation-press and abrasion from branches (whipping) (Lees 1966; Haeussler et al. 1990; Simard 1990a). Several studies have demonstrated that vigorous, abundant birch can reduce survival and suppress growth of pine, spruce, or Douglas-fir (Gregory 1966; Andersson 1985; Simard 1990a; Simard and Heineman 1996c; Simard and Hannam 2000). Simard (2001, in review) showed that conifer species tolerate competition with paper birch in the order of western redcedar > Douglas-fir > western larch, which follows traditional interpretations of conifer shade tolerance (Krajina et al. 1982). At low to moderate densities

that are common in many ICH plantations, however, birch appears to have small effects on the growth of moderately shade tolerant conifers (Simard 2001, in review).

In spite of its competitive ability, the presence of some birch in conifer stands is beneficial to ecosystem health and productivity. For instance, paper birch foliage is high in nutrients, especially nitrogen, phosphorus, sulphur, calcium, magnesium, and potassium (Simard 1995; Wang et al. 1996), which are returned annually to the soil through leaf fall. In support of this, a modelling study showed that eliminating birch from mixed Douglas-fir–birch stands would reduce site productivity over multiple rotations (Sachs 1992). There is also a growing body of research regarding the diverse rhizosphere community associated with birch, and considerable evidence that it benefits conifers when maintained in a healthy condition. For example, nitrogen-fixing bacteria have been identified in association with birch roots (Simard 1995), and there is evidence that nutrients (in this case carbon) are transferred between birch and Douglas-fir via shared ectomycorrhizae (Simard et al. 1997a). Jones et al. (1997) found that ectomycorrhizal diversity on Douglas-fir seedling roots was greater when seedlings were grown in mixture with paper birch rather than in pure stands. Birch may also contribute to the health of conifer seedlings by reducing the spread of *Armillaria* root disease (Morrison et al. 1991), discouraging spruce weevil (*Pissodes strobi*) attack (Stiell and Berry 1985; Taylor et al. 1994), providing protection from frost damage (Andersson 1985; Stathers 1989), and reducing the incidence of ungulate browsing (Simard and Heineman 1996a). Maintaining some broadleaves in young stands also contributes to the vertical stratification and complexity that is typical of mixed ICH-zone forests (Cameron 1996).

Importance to Wildlife and Range

Paper birch, aspen, and cottonwood are all important sources of food and habitat for ungulates, small mammals, and birds in British Columbia. Thimbleberry and fireweed are also utilized by wildlife, but to a lesser degree than broadleaf trees. In this section, we focus on the importance of birch to wildlife and range, because it tends to dominate the *Mixed Broadleaf-Shrub* Complex. The importance

of thimbleberry and fireweed to wildlife and range are discussed in detail in the *Mixed Shrub* and *Fireweed* complexes, respectively.

Young paper birch stands provide year-round browse and summer cover for deer and moose, and winter browse for Rocky Mountain elk, caribou, and mountain goat (Peterson et al. 1997). It takes 3–5 years following disturbance for birch to provide an adequate supply of browse, and peak browse production occurs 10–16 years after logging, fire, or other disturbance (Burns and Honkala 1990). This coincides with the time that brushing is usually done in the *Mixed Broadleaf-Shrub* Complex. Loss of birch as a result of herbicide treatment can have a significant effect on moose food supply (Peterson et al. 1997) and can cause ungulates to switch to conifers for browse (Simard and Heineman 1996a; Mather and Simard 1998n). Mature birch has essentially no browse value, but understory plants are important food sources (Burns and Honkala 1990).

The buds, catkins, and new leaves of paper birch provide food for snowshoe hares, porcupines, beavers, squirrels, mice, and voles (Peterson et al. 1997). Snowshoe hares also feed on twigs, stems, or bark of birch, often girdling or damaging the trees. Squirrels feed on flowers and leaf buds in the spring (Haeussler et al. 1990), and voles and other rodents can consume large quantities of birch seed. Beavers sometimes use birch for dam and lodge construction, but they prefer aspen (Peterson et al. 1997). Runciman and Sullivan (1996) studied the effects of brushing treatments applied to the *Mixed Broadleaf-Shrub* Complex on small-mammal populations, and found that they were unaffected by structural changes in the vegetation that lasted up to 2 years.

Birch, cottonwood, and aspen are very important in providing snags for cavity-nesting birds, and broadleaf trees produce snags in less time than conifers (Machmer and Steeger 1995). Many birds, including woodpeckers, owls, hawks, sapsuckers, flycatchers, and vireos, nest in stem cavities or branches (Cannings et al. 1987). The buds, young twigs, and seeds of birch are an important food for several bird species (Peterson et al. 1997).

Sheep graze birch and thimbleberry minimally or erratically, but aspen and fireweed are preferred forage (Newsome et al. 1995). Cattle have low preference for fireweed, but find it most palatable when it is flowering (McLean 1979).

Common Brushing Treatments in the *Mixed Broadleaf-Shrub* Complex

The *Mixed Broadleaf-Shrub* Complex has been extensively brushed in southern interior British Columbia. Today there are few backlog (NSR) sites dominated by this complex, and few 10- to 20-year-old mixed conifer-broadleaf stands that remain unmanipulated. Brushing treatments have historically been applied to this community in a broadcast manner because it was cheaper and easier than applying selective treatments. Recently, however, some prescriptions have called for retention of 50–500 broadleaf stems/ha, or, less commonly, up to 1000 stems/ha. Brushing in the *Mixed Broadleaf-Shrub* Complex is usually done after conifers are well established, and is frequently combined with spacing.

Manual cutting using power saws or motorized brush saws has been, and remains, the most common brushing treatment applied to the *Mixed Broadleaf-Shrub* Complex. However, in older stands where broadleaves are large (>5 cm dbh), girdling is often prescribed. It is most commonly applied where aspen and/or cottonwood form a significant portion of the community. Birch stems are difficult to girdle because they are often not round. Girdling may also be combined with manual cutting where small broadleaf stems and clumps of alder and willow are growing among larger stems. Hack and squirt is essentially the same treatment as girdling,

except that herbicide is injected into the girdles. It is usually not used in the *Mixed Broadleaf-Shrub* Complex in the southern interior because girdling alone minimizes resprouting.

Glyphosate is sometimes painted on stumps immediately after cutting to control resprouting; this treatment is known as cut stump–glyphosate. A treatment with similar objectives is cut-spray glyphosate, where glyphosate is sprayed on sprouts after cut stumps have been allowed to resprout for one growing season. These treatments, while more labour-intensive than simple manual cutting treatments, can prevent resprouting broadleaves from overtopping conifers. Cut stump–glyphosate and cut-spray glyphosate are preferred over simple manual cutting in stands where conifers are relatively short at the time of brushing.

Where the *Mixed Broadleaf-Shrub* Complex is relatively short, it is sometimes treated by broadcast foliar glyphosate application. Older stands are occasionally treated by injecting glyphosate capsules into the stems. Basal application of triclopyr is also becoming popular, and has the advantage of being more selective than aerial spray treatments. In general, however, herbicide treatments have not been favoured in the *Mixed Broadleaf-Shrub* Complex because of public opposition to the use of herbicides. Details about brushing treatments applied to the *Mixed Broadleaf-Shrub* Complex are provided in Table 107.

TABLE 107 Common brushing treatments applied to the Mixed Broadleaf-Shrub Complex in the southern interior of British Columbia

Treatment	Objectives	Optimum timing	Suggested number of treatments	Tool	Average cost per ha ^a	Potential disadvantages
Manual cutting	1. Reduce light competition 2. Create a free-growing stand	May–October	1–2	1. Power saw 2. Motorized brush saw	\$538 \$538	1. Rapid resprouting of birch
Girdling	1. Reduce light competition 2. Create a free-growing stand	May–October	1	1. Chain girdler	Unknown	1. Suitable only for broadleaves >5 cm diameter 2. Birch may be difficult to girdle because it is often not round 3. Extended reductions in broadleaves may negatively affect wildlife
Cut stump–glyphosate	1. Reduce light competition 2. Create a free-growing stand	Unknown	1	1. Power saw and backpack sprayer or squirt bottle	Unknown	1. More expensive than manual cutting 2. Extended reductions in broadleaves may negatively affect wildlife 3. Difficulties obtaining herbicide permits
Cut, then spray sprouts with glyphosate	1. Reduce light competition 2. Create a free-growing stand	Unknown	1	1. Power saw and backpack sprayer or squirt bottle	Unknown	1. More expensive than manual cutting (requires two entries) 2. Extended reductions in broadleaves may negatively affect wildlife 3. Difficulties obtaining herbicide permits
Foliar glyphosate spray	1. Reduce light competition 2. Create a free-growing stand	Unknown	1	1. Backpack sprayer	\$700	1. Suitable only for young (short) stands 2. Extended reductions in broadleaves may negatively affect wildlife 3. Difficulties obtaining herbicide permits
Basal triclopyr application	1. Reduce light competition 2. Create a free-growing stand	Unknown	1	1. Sprayer 2. Roller	Unknown	1. Extended reductions in broadleaves may negatively affect wildlife 2. Difficulties obtaining herbicide permits

^a Based on average costs in the Kamloops and Nelson forest regions for single-entry treatments (B.C. Ministry of Forests 1999)

RESULTS

Manual Cutting

This section describes fifth-year conifer and vegetation responses to manual cutting of the *Mixed Broadleaf-Shrub* Complex in 5- to 8-year-old Douglas-fir plantations ($n = 3$) and 3- to 10-year-old lodgepole pine plantations ($n = 3$) in the ICH and IDF zones.

Douglas-fir in the ICH and IDF zones

Description of study sites and treatments

The response of Douglas-fir and the *Mixed Broadleaf-Shrub* Complex to manual cutting is being studied on three sites distributed throughout the Kamloops Forest Region. The sites are located at Enterprise Creek, 7 km southwest of Lillooet in the Lillooet Forest District; on the east side of Mabel Lake in the Vernon District; and at Johnson Lake, 20 km east of Barriere in the Kamloops District. The Enterprise Creek site is in the Cascade Dry Cool IDF variant (IDFdk2), the Mabel Lake site is in the Shuswap Moist Warm ICH variant (ICHmw2), and the Johnson Lake site is in the Kootenay Moist Cool ICH variant (ICHmk1).

The study areas have several similarities; all are mesic (site series 01), in mid-slope position, and of northerly aspect, and have Brunisolic sandy loam soils (Table 108). Slopes range from 10 to 45% and elevations from 450 to 1200 m. The sites were clear-cut between 1979 and 1983, 10–12 years before brushing. One site was burned, one was burned and mechanically site prepared, and the third received no site preparation. Douglas-fir were planted 4–5 years after disturbance and were 5–8 years old and 80–143 cm in height at the time of brushing. About half the Douglas-fir were overtopped and most of the remainder were threatened by vegetation. Total conifer stocking ranged from 2181 to 3659 stems/ha, of which 925–1200 stems/ha were well spaced.

Birch was the dominant broadleaf on all three study sites and was increasing in height at an average rate of 40 cm/yr, compared with 15–30 cm/yr for Douglas-fir. Distribution of birch and other broadleaf trees was patchy. Birch cover and height averaged 14% and 2.9 m, respectively, while total broadleaf cover (birch, aspen, and cottonwood) averaged 16%. At each site, all broadleaves, except

scattered stems, were cut near ground level. Treatments took place between July and October (details are in Table 109).

Conifer responses

Survival and vigour Five years after brushing, survival of 10- to 13-year-old Douglas-fir (5–8 years old at the time of treatment) averaged 88% in the manual cutting treatment and control ($p = 0.42$) (Table 110). *Armillaria ostoyae* was the major cause of conifer death in both the treatment and control, causing an average 11% mortality (2.2%/yr since brushing) ($p = 0.42$) (Figure 116). Other minor causes of mortality were cutting damage in the treatment (1%) and *Phellinus weirii* in the control (1%). The fifth-year silviculture survey, which was conducted according to the old free-growing guidelines (B.C. Ministry of Forests 1995a), indicated there were significantly more free-growing trees in the treatment (502 stem/ha) than the control (315 stems/ha) ($p = 0.04$).

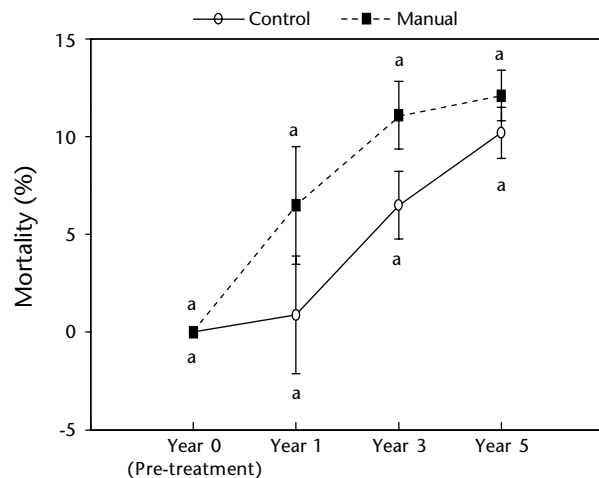


FIGURE 116 Comparison of mean Douglas-fir mortality due to *Armillaria* between the manual cutting treatment and control before, and 1, 3, and 5 years after, treatment of the ICH/IDF Mixed Broadleaf-Shrub Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_y = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance ($\alpha = 0.10$).

TABLE 108 *Characteristics and history of the three replicate study sites where the ICH/IDF Mixed Broadleaf-Shrub Complex was manually cut in Douglas-fir plantations*

Site location	Site characteristics and history							Characteristics of target conifers at PROBE initiation					Abundance of major vegetation species: cover (%) and height ^d (cm)	Conifer stocking (stems/ha)	
	BEC unit	Elev. (m)	Aspect/slope	Soil class/texture	Logging and site prep. history	Years since harvest	Years since site prep.	Est. delay ^a (yr)	Origin ^b	Stock	Age ^c (yr)	Height ^d (cm)		Total	Well spaced
Enterprise Creek PROBE 3 Lillooet District	IDFd2 01 (mesic)	950	N 45%	Brunisol/sandy loam	Clearcut 1979–1981	10	n/a	5	P 1985	PSB 313 1+0	5	87 (30)	Birch cover: 15 (15) Birch height: 307 (177) Soopolallie cover: 20 (16) Soopolallie height: 176 (133)	3659	925
Mabel Lake PROBE 12 Vernon District	ICHmw2 01 (mesic)	450	NW 35%	Brunisol/sandy loam	Clearcut 1983 Burned 1983	12	12	4	P 1985	PSB 313 1+0	8	143 (29)	Birch cover: 7 (8) Birch height: 221 (98)	3095	1200
Johnson Lake PROBE 29 Kamloops District	ICHmk1 01 (mesic)	1200	NW 10%	Brunisol/sandy loam	Clearcut 1981 Burned 1981 MSP 1983	12	10	5	P 1987	PSB 313 1+0	5	80 (24)	Birch cover: 20 (15) Birch height: 327 (91)	2181	1062

^a Establishment delay refers to the number of years between the last disturbance (e.g., harvest or site preparation) and planting^b Origin: P = planted; N = natural regeneration^c Age refers to the number of years since planting^d Values are means and one standard deviation (in parentheses)

TABLE 109 *A description of manual cutting treatments applied to the three replicate study sites to release Douglas-fir seedlings growing in the ICH/IDF Mixed Broadleaf-Shrub Complex*

Site	Treatment date	Treatment type	Broadleaf retention (stems/ha)	Treatment specification
Enterprise Creek	October 1991	Broadcast	Scattered	Vegetation within 1.5 m of seedlings was cut near ground level. All woody vegetation taller than 50 cm was cut.
Mabel Lake	August 1991	Broadcast	Scattered	All broadleaves >50 cm tall and <10 cm diameter were cut near ground level.
Johnson Lake	July 1993	Broadcast	Scattered	All broadleaves were cut near ground level except where no well-spaced conifer was present. Broadleaf stems were preserved in those spots.

TABLE 110 *Survival and growth responses of Douglas-fir seedlings to manual cutting in the ICH/IDF Mixed Broadleaf-Shrub Complex*

Response variable	Means		Standard error	p-value	Response variable	Means		Standard error	p-value
	Manual cutting	Control				Manual cutting	Control		
<i>Survival (%)</i>					<i>Height (cm)</i>				
Pre-treatment	100	100	0.000	1.00	Pre-treatment	105.3	101.5	2.530	0.40
1 yr post-treatment	93	99	2.619	0.22	1 yr post-treatment	139.0	145.2	1.198	0.07*
3 yr post-treatment	88	94	1.135	0.07*	3 yr post-treatment	200.1	201.8	5.878	0.86
5 yr post-treatment	87	89	1.311	0.42	5 yr post-treatment	271.9	257.6	4.622	0.16
<i>Mortality due to Armillaria (%)</i>					<i>Leader length (cm)</i>				
Pre-treatment	0	0	0.000	1.00	Pre-treatment	24.3	23.5	0.423	0.30
1 yr post-treatment	7	1	3.000	0.32	1 yr post-treatment	24.4	26.7	0.464	0.08*
3 yr post-treatment	11	7	1.734	0.20	3 yr post-treatment	36.0	32.0	2.573	0.38
5 yr post-treatment	12	10	1.311	0.42	5 yr post-treatment	42.6	33.0	0.346	0.00*
<i>Stem diameter (cm)</i>					<i>Height:diameter ratio</i>				
Pre-treatment	1.86	2.05	0.026	0.04*	Pre-treatment	57.0	49.2	2.084	0.12
1 yr post-treatment	2.61	2.70	0.032	0.02*	1 yr post-treatment	53.2	53.8	0.451	0.51
3 yr post-treatment	3.87	3.58	0.034	0.42	3 yr post-treatment	51.6	57.0	2.475	0.96
5 yr post-treatment	5.14	4.51	0.009	0.01*	5 yr post-treatment	53.0	57.7	1.126	0.85
<i>Diameter increment (cm)</i>									
1 yr post-treatment	0.62	0.50	0.022	0.54					
3 yr post-treatment	0.65	0.46	0.017	0.43					
5 yr post-treatment	0.66	0.48	0.005	0.12					

p-values denoted with “*” were significant at $p \leq 0.10$ according to analysis of variance; $n = 3$. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates. Analysis of covariance was applied where there were pre-treatment differences according to analysis of variance.

The vigour of Douglas-fir seedlings generally improved during the 5-year measurement period, and the improvement was somewhat greater in the brushing treatment than in the control. The percentage of good-vigour trees improved from 8 to 40% in the treatment, and from 17 to 25% in the control (Figure 117). The percentage of poor-vigour trees decreased from 16 to 8% in the treatment, and from 14 to 7% in the control.

Growth Stem diameter and leader length responded positively after brushing, but differences did not become significant ($p \leq 0.10$) (Table 110) until 5 years after treatment. There was an initial negative height response in year 1, where both leader length (Figure 118) and total height were significantly less in the brushing treatment than in the control ($p \leq 0.10$); however, these differences disappeared by year 3.

Average stem diameter was significantly less in the manual cutting treatment than in the control before treatment ($p = 0.04$), but 5 years afterward it was 14% greater in the treatment than in the control (5.14 cm versus 4.51 cm, $p = 0.01$) (Figure

119). Covariance analysis was applied to the stem diameter data in years 1 through 5. In year 5, average diameter increment was 0.18 cm greater in the manual cutting treatment than in the control (0.66 versus 0.48 cm, $p = 0.12$), and average leader length was 9.6 cm greater (42.6 cm versus 33.0 cm, $p = 0.00$). Seedling height was not affected by the treatment ($p = 0.86$ in year 3 and $p = 0.16$ in year 5). There was no difference in height:diameter ratio between the treatment and control during the 5-year measurement period.

Standardized distributions for Douglas-fir stem diameter show that, prior to treatment, there were more trees in +1 to +1.5 classes in the control than in the treatment (Figure 120). This is consistent with ANOVA, which found pre-treatment differences in stem diameter. The trend of larger diameters in the control gradually changed following manual cutting, and by year 5, the treatment distribution was skewed upward, relative to the control. This also supports ANOVA results of significantly larger stem diameters among treated control trees by year 5. The consistent nature of the

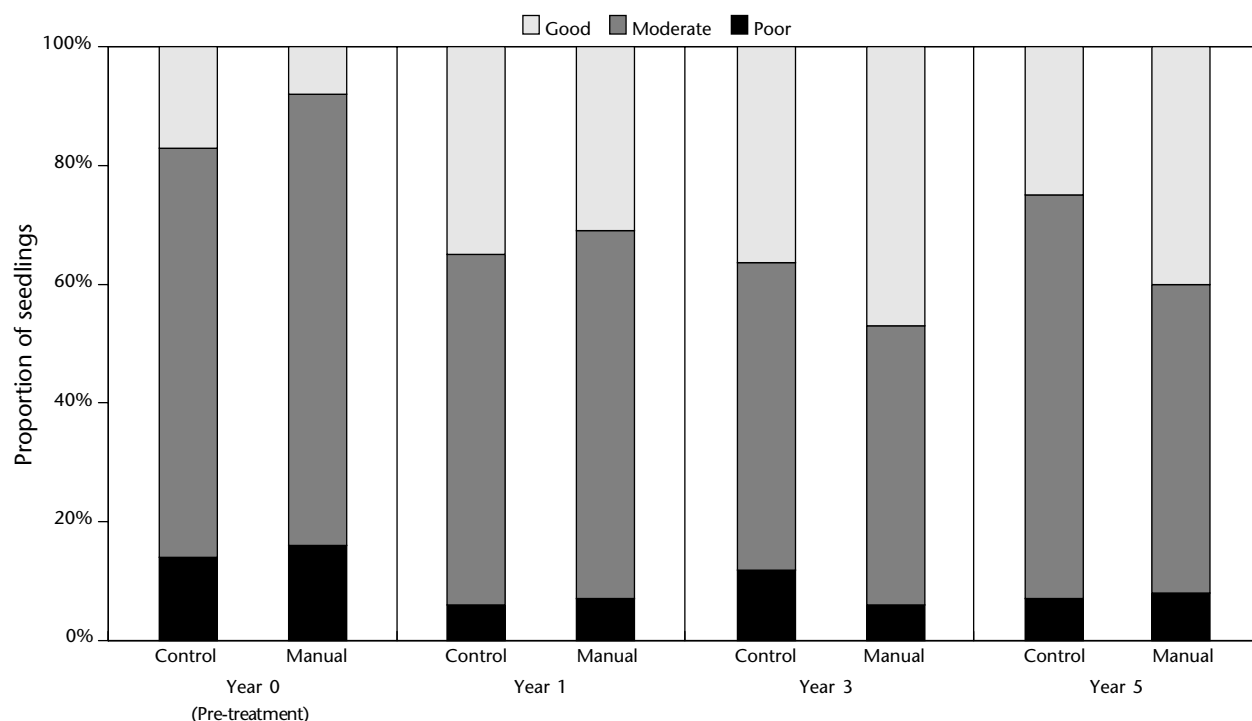


FIGURE 117 Comparison of Douglas-fir vigour between the manual cutting treatment and control before, and 1, 3, and 5 years after, treatment of the ICH/IDF Mixed Broadleaf-Shrub Complex. Good vigour seedlings had vigorous shoot growth, large leaf area, long and deep green needles, and thick caliper. Poor vigour seedlings had little or etiolated shoot growth, few and/or short needles, and small caliper. Moderate-vigour seedlings were intermediate between the good and poor classifications.

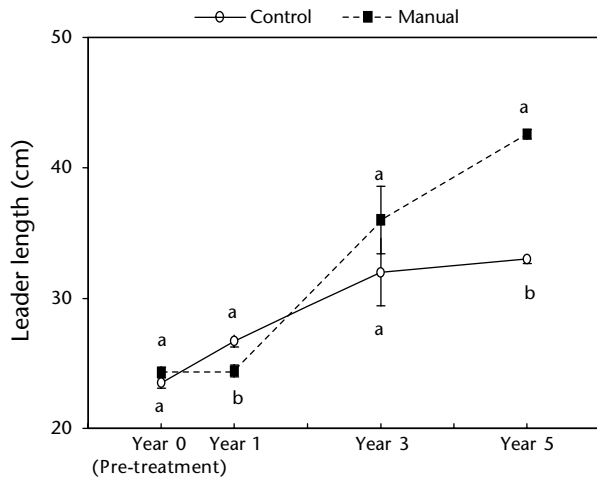


FIGURE 118 Comparison of mean Douglas-fir leader length between the manual cutting treatment and control before, and 1, 3, and 5 years after, treatment of the ICH/IDF Mixed Broadleaf-Shrub Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance ($\alpha = 0.10$).

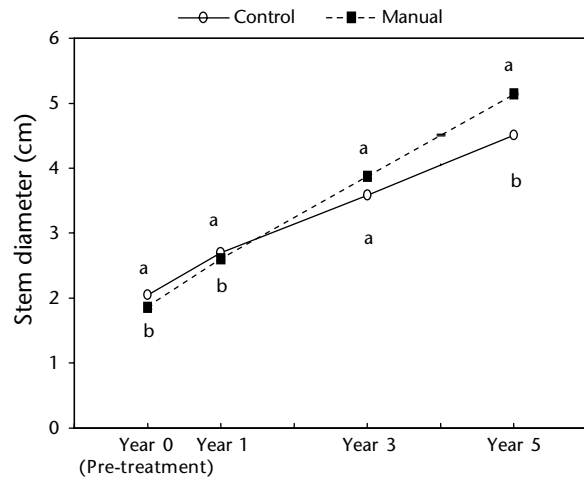


FIGURE 119 Comparison of mean Douglas-fir stem diameter between the manual cutting treatment and control before, and 1, 3, and 5 years after, treatment of the ICH/IDF Mixed Broadleaf-Shrub Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance ($\alpha = 0.10$). Analysis of covariance was applied where there were pre-treatment differences according to analysis of variance.

shift of treated trees to larger diameter classes suggests that the difference will be maintained. Standardized height distributions were similar in the treatment and control prior to brushing (Figure 121), but 1 year later, the frequencies in >0 classes had increased in the control and decreased in the treatment. This suggests a negative treatment response, but by year 5, distributions were again similar in the treatment and control, and had returned to being approximately normal. Changes in the standardized height distributions are consistent with ANOVA results.

Competitive status Manual cutting considerably increased the number of conifers that were free of vegetation, decreased overtopping by birch, and increased the average height of conifers relative to neighbouring vegetation (Figure 122). One year after treatment, the percentage of conifers that were free of vegetation had increased from 2 to 41% and the percentage of overtopped trees had decreased from 57 to 14%. Five years after treatment, the proportion of Douglas-fir that were free of vegetation had increased to 48%, while 28% continued to be overtopped, mainly by rapidly growing birch

sprouts. Meanwhile, in the control, the proportion of trees that were free of vegetation increased from 2 to 16% and the proportion overtopped increased from 45 to 63%.

Plant community responses

Abundance Birch was significantly shorter in the brushing treatment than in the control 1 year after manual cutting (106.6 versus 382.9 cm, $p = 0.03$) (Table 111), and it was still shorter after 5 years (383.4 versus 684.7 cm, $p = 0.02$) (Figure 123). Cover of birch was not significantly reduced by manual cutting in year one, but was significantly less in the treatment than in the control in years 3 (21.2 versus 17.8%, $p = 0.02$) and 5 (29.9 versus 25.6%, $p = 0.03$). Total broadleaf cover, which included aspen and cottonwood as well as birch, was significantly less in the brushing treatment (26.8%) than in the control (32.5%) 5 years after brushing ($p = 0.01$). In the control, untreated broadleaves grew vigorously during the 5-year monitoring period, increasing in

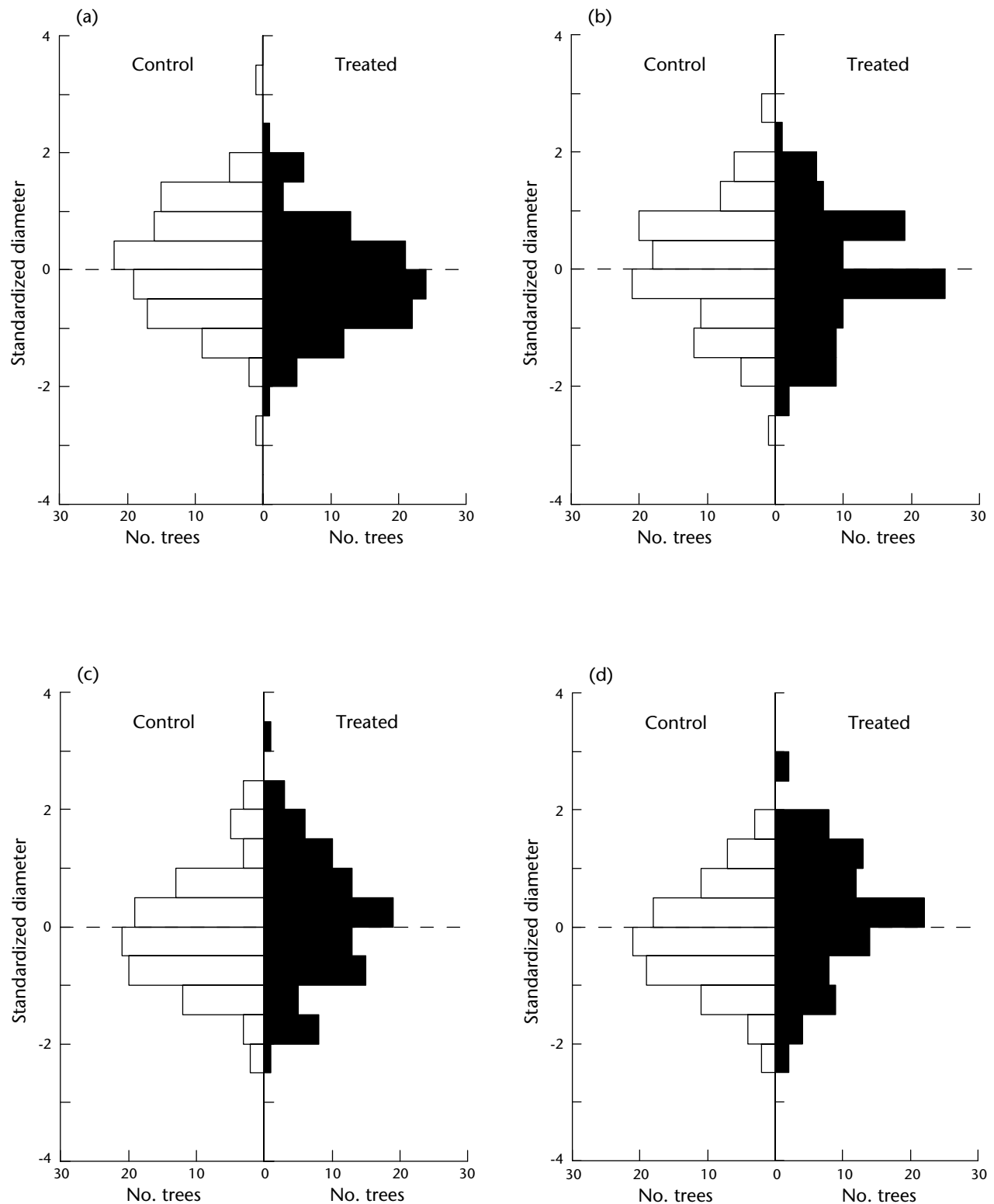


FIGURE 120 Frequency of control and treated trees in standardized diameter classes ($\mu = 0$; $s.d. = 1$; $n = 3$ for the control and treatment combined) for Douglas-fir in the ICH/IDF Mixed Broadleaf-Shrub Complex before and after manual cutting. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 3 years post-treatment; (d) 5 years post-treatment.

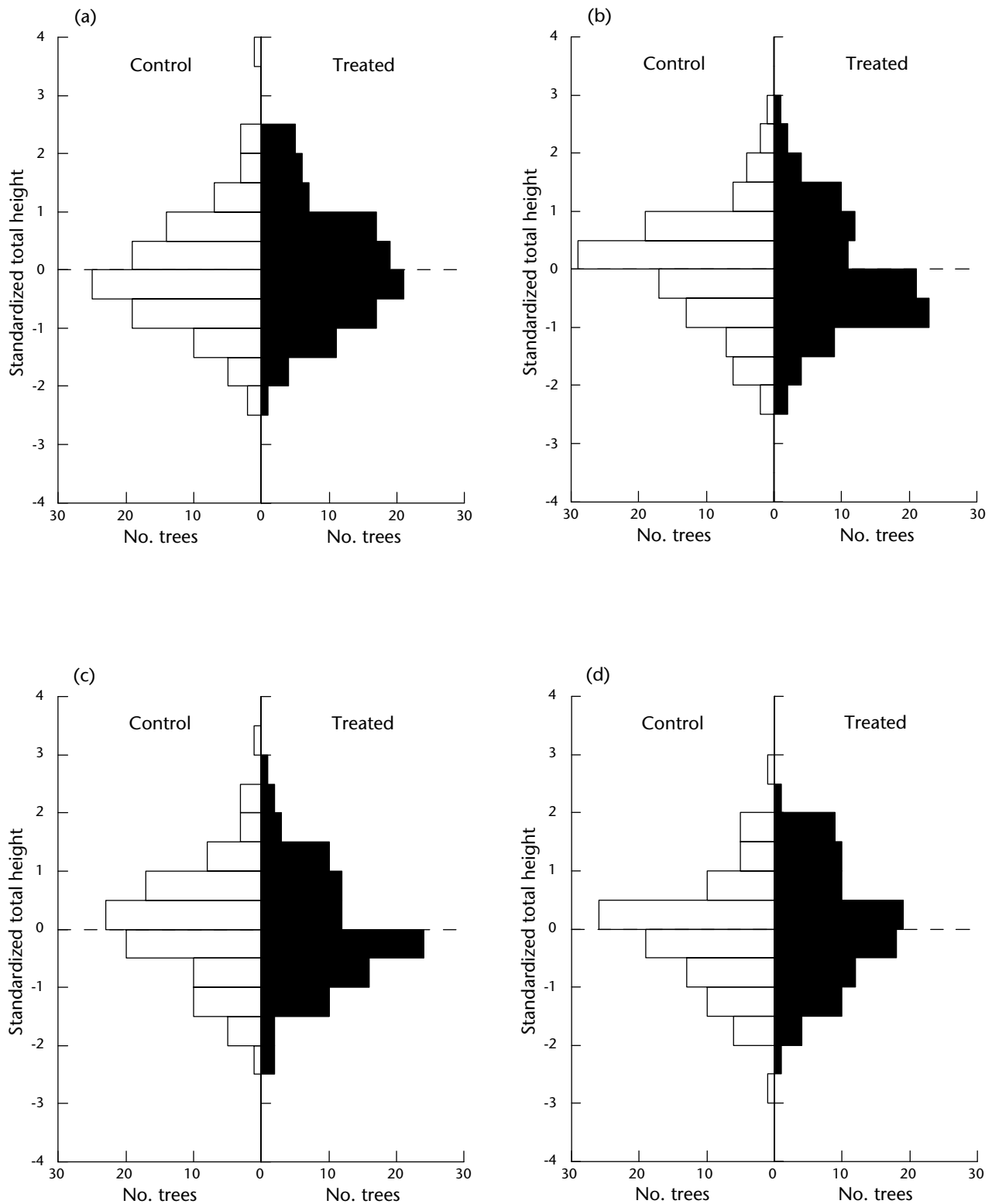


FIGURE 121 Frequency of control and treated trees in standardized total height classes ($\mu = 0$; $s.d. = 1$; $n = 3$ for the control and treatment combined) for Douglas-fir in the ICH/IDF Mixed Broadleaf-Shrub Complex before and after manual cutting. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 3 years post-treatment; (d) 5 years post-treatment.

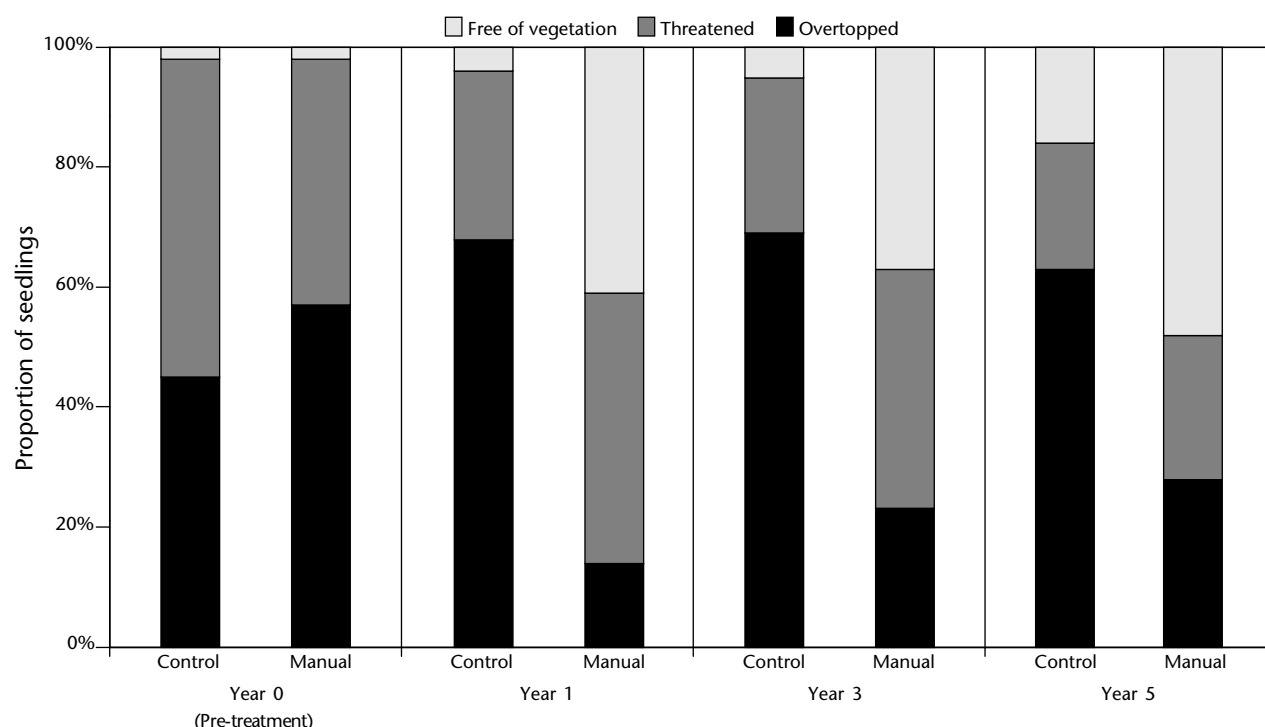


FIGURE 122 Comparison of Douglas-fir competitive status between the manual cutting treatment and control before, and 1, 3, and 5 years after, treatment of the ICH/IDF Mixed Broadleaf-Shrub Complex. Seedlings were classified as free of vegetation when the leader was well above surrounding vegetation, and classified as overtopped when the leader was overtopped. Threatened seedlings had leaders at approximately the same height as surrounding vegetation.

height from 283.3 to 688.3 cm and increasing in cover from 13.5 to 32.5%.

Cover and height of understorey herbs were not affected by the manual cutting treatment, and nor was cover of shrubs ($p > 0.10$) (Table 111). Shrub height was less in the treatment than in the control in year 3 (72.3 versus 106.8 cm, $p = 0.09$), but the difference had disappeared by year 5.

Sprouting Birch stumps sprouted vigorously after cutting. An average 93% of stumps had sprouts 1 year after treatment and, after 5 years, 86% continued to have sprouts (Table 112). The sprouts thinned and their growth rate slowed during the 5-year monitoring period. Cut stumps averaged eight sprouts that were 96 cm tall in year 1, five sprouts that were 204 cm tall in year 3, and four sprouts that were 253 cm tall in year 5.

Richness and diversity of individual species and structural vegetation groups Manual cutting of the Mixed Broadleaf-Shrub Complex had no effect on either species richness or diversity ($p > 0.10$) (Table 113). Species richness increased considerably between the pre-treatment assessment (27 species) and the

fifth-year assessment (36 species), but the increases occurred equally in the treatment and control.

Richness of structural vegetation groups did not differ between the treatment and control on any measurement date ($p > 0.10$) (Table 114). Diversity of structural groups, however, was significantly greater in the brushing treatment than in the control in year 5 ($p = 0.10$) (Table 114), probably because of reduced dominance of broadleaves.

Paper birch was the main target species, and, as expected, it decreased in cover immediately after manual cutting on all three sites. Willow cover increased within a year of manual cutting, probably because of its well-known capacity for rapid sprout growth. The cutting treatment did not affect cover of any other shrub species on more than one site.

Among herbs, one-sided wintergreen (*Orthilia secunda*) was the only species that decreased in cover following manual cutting; however, several species increased (Table 115). Fireweed increased following brushing on two of three sites, possibly in response to increased light levels. Hooker's fairy bell (*Disporum hookeri*) was not present before or 1 year after

TABLE 111 Cover and height of vegetation in the ICH/IDF Mixed Broadleaf-Shrub Complex before and after manual cutting in Douglas-fir plantations

Response variable	Means		Standard error	p-value	Response variable	Means		Standard error	p-value
	Manual cutting	Control				Manual cutting	Control		
All vegetation					Shrubs <i>(continued)</i>				
<i>Cover (%)</i>					<i>Height (cm)</i>				
Pre-treatment	70.6	70.9	1.851	0.94	Pre-treatment	90.9	83.1	7.524	0.54
1 yr post-treatment	48.2	56.1	2.043	0.11	1 yr post-treatment	72.7	98.4	12.174	0.27
3 yr post-treatment	74.1	80.2	1.673	0.13	3 yr post-treatment	72.3	106.8	8.065	0.09*
5 yr post-treatment	84.8	87.0	0.074	0.00*	5 yr post-treatment	101.7	146.4	12.331	0.12
<i>Height (cm)</i>					Herbs				
Pre-treatment	203.4	179.8	16.356	0.42	<i>Cover (%)</i>				
1 yr post-treatment	93.8	232.9	27.841	0.07*	Pre-treatment	20.8	24.5	3.279	0.51
3 yr post-treatment	138.2	395.0	59.994	0.09*	1 yr post-treatment	14.5	16.5	1.423	0.43
5 yr post-treatment	317.5	592.7	44.934	0.05*	3 yr post-treatment	22.7	22.6	1.946	0.97
Broadleaf trees					5 yr post-treatment	29.3	29.5	4.149	0.98
<i>Cover (%)</i>					<i>Height (cm)</i>				
Pre-treatment	18.8	13.5	1.261	0.10*	Pre-treatment	64.6	69.8	7.468	0.67
1 yr post-treatment	7.3	12.8	2.002	0.16	1 yr post-treatment	72.2	78.9	12.895	0.75
3 yr post-treatment	19.0	23.0	1.649	0.47	3 yr post-treatment	69.2	66.3	14.614	0.90
5 yr post-treatment	26.8	32.5	3.659	0.01*	5 yr post-treatment	57.0	47.3	5.334	0.33
<i>Height (cm)</i>					Paper birch				
Pre-treatment	299.2	283.3	4.069	0.11	<i>Cover (%)</i>				
1 yr post-treatment	109.0	388.0	38.493	0.04*	Pre-treatment	16.8	11.3	0.841	0.04*
3 yr post-treatment	229.2	512.1	68.433	0.10*	1 yr post-treatment	6.1	10.9	1.917	0.16
5 yr post-treatment	386.3	688.3	25.202	0.01*	3 yr post-treatment	17.8	21.2	1.216	0.02*
Shrubs					5 yr post-treatment	25.6	29.9	3.233	0.03*
<i>Cover (%)</i>					<i>Height (cm)</i>				
Pre-treatment	35.1	34.2	1.122	0.65	Pre-treatment	289.9	279.9	2.860	0.13
1 yr post-treatment	26.7	29.2	1.939	0.46	1 yr post-treatment	106.6	382.9	32.434	0.03*
3 yr post-treatment	39.9	39.5	1.444	0.86	3 yr post-treatment	222.0	501.4	74.073	0.12
5 yr post-treatment	45.1	45.9	3.228	0.87	5 yr post-treatment	383.4	684.7	27.331	0.02*

p-values denoted with “*” were significant at $p \leq 0.10$ according to analysis of variance; $n = 3$. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates. Analysis of covariance was applied where there were pre-treatment differences according to analysis of variance.

treatment on any of the sites, but small amounts (1–2% cover) were found in manually cut plots in years 3 and 5 on two sites. Strawberry (*Fragaria* spp.) and tiger lily (*Lilium columbianum*) either appeared or increased in cover following cutting. Dandelion (*Taraxacum officinale*) and thistle (*Cirsium arvense*), both common exotic weeds, appeared in two or three treated plots following brushing.

Lodgepole pine in the ICH zone

Only third- and fifth-year results are presented for this treatment cell. First-year analysis was not done because data were missing for one site.

Description of study sites and treatments

The response of lodgepole pine and the *Mixed Broadleaf-Shrub* Complex to manual cutting is being studied on three sites located throughout the Kamloops Forest Region. Two of the sites are in the Moist Warm ICH variant (ICHmw3) in the Clearwater Forest District; one near Spahats Creek, 18 km northwest of Clearwater, and the other on the Homestead Forest Service Road, 40 km east of Avola. The third site is near Amphitheatre Lake, 13 km southwest of Chase in the Kootenay Moist Cool ICH variant (ICHmk1) in the Kamloops District (Figure 124).



FIGURE 123 *Effects of manual cutting on the Mixed Broadleaf-Shrub Complex and Douglas-fir (a) 1 year, (b) 3 years, and (c) 5 years following treatment. The control (d) is shown 3 years post-treatment for comparison. Photo credit: Jean Mather.*

TABLE 112 *Sprouting characteristics of paper birch in the ICH/IDF Mixed Broadleaf-Shrub Complex following manual cutting in Douglas-fir plantations*

Response variable	Mean
<i>Proportion of stumps with sprouts</i>	
1 yr post-treatment	93
3 yr post-treatment	88
5 yr post-treatment	86
<i>Number of sprouts per stump</i>	
1 yr post-treatment	8
3 yr post-treatment	5
5 yr post-treatment	4
<i>Sprout length (cm)</i>	
1 yr post-treatment	96
3 yr post-treatment	204
5 yr post-treatment	253

TABLE 113 *Richness and diversity of vascular plant species in the ICH/IDF Mixed Broadleaf-Shrub Complex before and after manual cutting in Douglas-fir plantations*

Response variable	Means		Standard error	p-value
	Manual cutting	Control		
<i>Richness</i>				
Pre-treatment	27.67	26.67	0.408	0.23
1 yr post-treatment	29.67	31.67	1.780	0.51
3 yr post-treatment	29.67	32.67	2.944	0.55
5 yr post-treatment	36.33	36.00	2.014	0.92
<i>Shannon-Weaver Diversity Index</i>				
Pre-treatment	1.93	1.99	0.099	0.68
1 yr post-treatment	2.25	2.24	0.014	0.68
3 yr post-treatment	2.29	2.15	0.048	0.17
5 yr post-treatment	2.33	2.23	0.098	0.53
<i>Simpson's Diversity Index</i>				
Pre-treatment	0.76	0.79	0.016	0.34
1 yr post-treatment	0.84	0.84	0.006	0.57
3 yr post-treatment	0.86	0.82	0.018	0.26
5 yr post-treatment	0.86	0.83	0.017	0.35

The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{\text{MSE}/n}$, where MSE = Mean Square Error and n = number of replicates.

TABLE 114 *Richness and diversity of structural vegetation groups in the ICH/IDF Mixed Broadleaf-Shrub Complex before and after manual cutting in Douglas-fir plantations*

Response variable	Means		Standard error	p-value
	Manual cutting	Control		
<i>Richness</i>				
Pre-treatment	7.33	7.00	0.236	0.42
1 yr post-treatment	7.00	7.33	0.236	0.42
3 yr post-treatment	7.33	7.33	0.000	1.00
5 yr post-treatment	7.33	7.33	0.000	1.00
<i>Shannon-Weaver Diversity Index</i>				
Pre-treatment	1.32	1.35	0.058	0.71
1 yr post-treatment	1.59	1.53	0.061	0.52
3 yr post-treatment	1.66	1.50	0.063	0.23
5 yr post-treatment	1.60	1.44	0.038	0.10*
<i>Simpson's Diversity Index</i>				
Pre-treatment	0.64	0.67	0.023	0.54
1 yr post-treatment	0.76	0.73	0.023	0.43
3 yr post-treatment	0.77	0.72	0.027	0.28
5 yr post-treatment	0.76	0.69	0.017	0.10*

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; $n = 3$. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{\text{MSE}/n}$, where MSE = Mean Square Error and n = number of replicates.

The Spahats Creek and Homestead sites are submesic (site series 05) and the Amphitheatre Lake site is mesic (site series 01) (Table 116). Two sites have 25–40% slopes, northerly aspects, and Brunisolic sandy loam soils, while the third site (Spahats) has a 15% slope, southwest aspect, and a Brunisolic silt loam soil. Elevations of the sites vary from 900 to 1330 m.

The original stands were clearcut between 1982 and 1986, 10–11 years before brushing. One site was burned immediately after logging, one was mechanically site prepared 1 year following logging, and the third was not prepared. Two sites were planted with lodgepole pine 3–6 years after disturbance, and on the third site the pine were of natural origin. Pine varied in age from 3 to 10 years and from 0.9 to 3.5 m in height at the time of brushing. Only about 12% of pine seedlings were free of vegetation at that time, and the remainder were overtopped or threatened by vegetation. Total conifer stocking ranged from 2778 to 4189 stems/ha, of which 1044–1200 stems/ha were well spaced.

TABLE 115 Vascular plant species that exhibited trends of increasing cover, decreasing cover, or no change in cover following manual cutting of the ICH/IDF Mixed Broadleaf-Shrub Complex in Douglas-fir plantations. Species included in the list exhibited a common trend in the treated plots of at least two study sites, based on a subjective evaluation (see Methods, Section 3).

	Increasing cover	Decreasing cover	No change in cover
Broadleaves		<i>Betula papyrifera</i>	
Tall shrubs	<i>Salix</i> spp.		
Low shrubs			<i>Mahonia nervosa</i> <i>Pachistima myrsinites</i> <i>Rosa</i> spp. <i>Rubus parviflorus</i> <i>Symphoricarpos albus</i>
Herbs	<i>Cirsium arvense</i> <i>Disporum hookeri</i> <i>Epilobium angustifolium</i> <i>Fragaria</i> spp. <i>Lilium columbianum</i> <i>Taraxacum officinale</i>	<i>Orthilia secunda</i>	<i>Chimaphila umbellata</i> <i>Galium borealis</i> <i>Goodyera oblongifolia</i> <i>Hieracium albiflorum</i> <i>Osmorhiza chilensis</i>

Vigorous birch dominated non-coniferous vegetation before treatment, with average cover of 13% and average height of 2.6 m. Birch were increasing in height at about 35 cm/yr, and averaged one to two times the height of pine, which were increasing in height at rates of 30–50 cm/yr. Cutting treatments on the three sites were carried out between mid-August and September, and all broadleaf trees, except scattered stems, were cut near ground level. Treatment details are provided in Table 117.



FIGURE 124 The Mixed Broadleaf-Shrub Complex and lodgepole pine prior to manual cutting at Amphitheatre Lake (Site 32) in the ICHmk1 variant in the Kamloops Forest District. Photo credit: Jean Mather.

Conifer responses

Survival and vigour Survival averaged 91% in the manual cutting treatment and control 5 years after brushing ($p = 0.83$) (Table 118). *Armillaria ostoyae* caused significantly more mortality in the treatment than in the control in year 3 (7 versus 2%, $p = 0.07$) (Figure 125) and the difference tended to increase by year 5 (9% in the treatment versus 2% in the control, $p = 0.16$). However, variability between sites also increased, and the difference became statistically insignificant in year 5. *Armillaria* was the sole agent of lodgepole pine mortality in the treatment, whereas deer, competing vegetation, and weevils also caused mortality in the control. Five years after manual cutting, *Armillaria* had caused pine mortality at average rates of 1.8%/yr in the treatment and 0.4%/yr in the control. The fifth-year silviculture survey, which was conducted according to the old free-growing guidelines (B.C. Ministry of Forests 1995a), indicated there were significantly more free-growing trees in the treatment (820 stems/ha) than the control (160 stems/ha) ($p = 0.02$).

Average lodgepole pine vigour improved slightly in the manual cutting treatment from before treatment to 5 years afterward, and it declined in the control (Figure 126). The percentage of poor-vigour trees remained constant (2–4%) in the treatment, and increased from 12 to 23% in the control. The

TABLE 116 *Characteristics and history of the three replicate study sites where the ICH Mixed Broadleaf-Shrub Complex was manually cut in lodgepole pine stands*

Site location	Site characteristics and history							Characteristics of target conifers at PROBE initiation					Abundance of major vegetation species: cover (%) and height ^d (cm)	Conifer stocking (stems/ha)	
	BEC unit	Elev. (m)	Aspect/slope	Soil class/texture	Logging and site prep. history	Years since harvest	Years since site prep.	Est. delay ^a (yr)	Origin ^b	Stock	Age ^c (yr)	Height ^d (cm)		Total	Well spaced
Amphitheatre Lake PROBE 32 Kamloops District	ICHmk1 01 (mesic)	1200	NE 25%	Brunisol/ sandy loam	Clearcut 1983 Burned 1983	10	10	7	P 1984 P 1989	PSB 211 1+0	3	94 (34)	Birch cover: 17 (13) Birch height: 251 (82)	3567	1200
Homestead FSR PROBE 41 Clearwater District	ICHmw3 05 (submesic)	900	N 40%	Brunisol/ sandy loam	Clearcut 1982	11	n/a	n/a	N	n/a	10	352 (64)	Birch cover: 20 (14) Birch height: 467 (232)	4189	1044
Spahats PROBE 51 Clearwater District	ICHmw3 05 (submesic)	1330	SW 15%	Brunisol/ silt loam	Clearcut 1986 MSP 1987	10	10	3	P 1987	PSB 211 1+0	7	145 (19)	Birch cover: 3 (4) Birch height: 74 (75) Aspen cover: 5 (7) Aspen height: 120 (107) Alder cover: 10 (15) Alder height: 92 (93) Willow cover: 9 (11) Willow height: 127 (84)	2778	1200

^a Establishment delay refers to the number of years between the last disturbance (e.g., harvest or site preparation) and planting^b Origin: P = planted; N = natural regeneration^c Age refers to the number of years since planting^d Values are means and one standard deviation (in parentheses)

TABLE 117 A description of manual cutting treatments applied to the three replicate study sites to release lodgepole pine seedlings growing in the ICH Mixed Broadleaf-Shrub Complex

Site	Treatment date	Treatment type	Broadleaf retention (stems/ha)	Cutting specifications
Amphitheatre Lake	Mid-August 1993	Broadcast	Scattered	Broadleaf trees cut near ground level
Homestead FSR	September 1993	Broadcast	Scattered	Broadleaf trees cut near ground level
Spahats Creek	September 1994	1-m radius around seedlings	Scattered	All vegetation cut near ground level

percentage of good-vigour trees increased from 47 to 56% in the treatment, and declined from 43 to 6% in the control.

Growth Average stem diameter, diameter increment, and height:diameter ratio of lodgepole pine responded positively to manual cutting within 3 years, and the differences continued to be significant

in year 5 ($p < 0.10$) (Table 118). The average height of pine seedlings increased from 196.8 to 449.6 cm during the 5-year measurement period, but there were no differences between the treatment and control, and neither were there significant differences in leader length ($p > 0.10$). Five years after brushing, average stem diameter was 37% greater in the manual cutting treatment than in the control (8.42 versus 6.14 cm, $p = 0.04$) (Figure 127). Average diameter increment was 66% greater in the treatment than in the control (1.11 versus 0.67 cm, $p = 0.04$). Prior to brushing, height:diameter ratio for pine seedlings averaged 63.1. Five years later it had increased in the control (68.5) and decreased

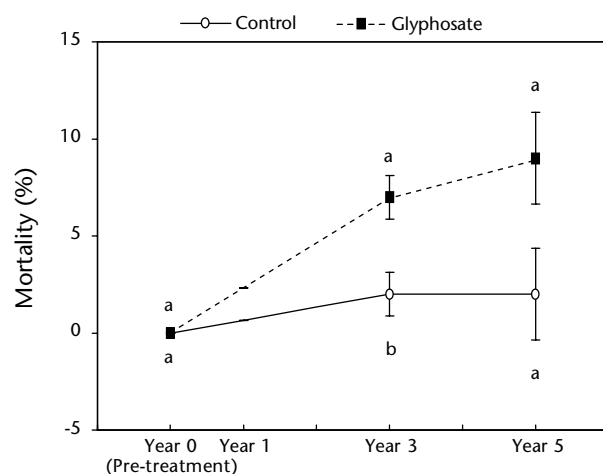


FIGURE 125 Comparison of mean lodgepole pine mortality due to *Armillaria* between the manual cutting treatment and control before, and 3 and 5 years after, treatment of the ICH Mixed Broadleaf-Shrub Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance ($\alpha = 0.10$).

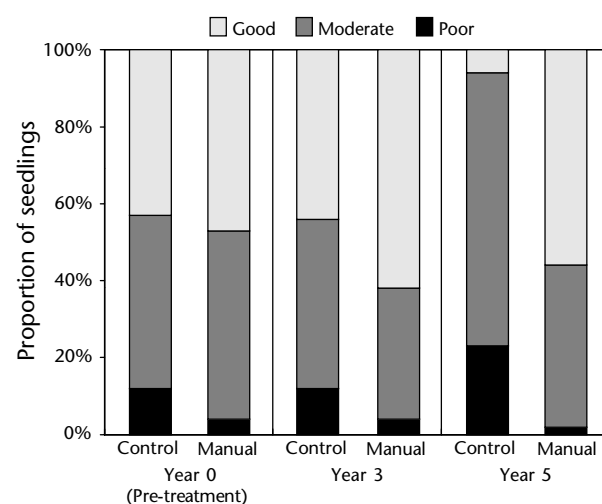


FIGURE 126 Comparison of lodgepole pine vigour between the manual cutting treatment and control before, and 3 and 5 years after, treatment of the ICH Mixed Broadleaf-Shrub Complex.

TABLE 118 *Survival and growth responses of lodgepole pine seedlings to manual cutting in the ICH Mixed Broadleaf-Shrub Complex*

Response variable	Means		Standard error	p-value
	Manual cutting	Control		
<i>Survival (%)</i>				
Pre-treatment	100	100	0.000	1.00
3 yr post-treatment	93	95	1.140	0.25
5 yr post-treatment	91	90	1.454	0.83
<i>Mortality due to Armillaria (%)</i>				
3 yr post-treatment	7	2	1.133	0.07*
5 yr post-treatment	9	2	2.363	0.16
<i>Stem diameter (cm)</i>				
Pre-treatment	3.18	2.96	0.071	0.16
3 yr post-treatment	6.25	4.80	0.226	0.05*
5 yr post-treatment	8.42	6.14	0.333	0.04*
<i>Diameter increment (cm)</i>				
3 yr post-treatment	1.01	0.64	0.045	0.03*
5 yr post-treatment	1.11	0.67	0.063	0.04*
<i>Height (cm)</i>				
Pre-treatment	205.8	187.7	11.008	0.36
3 yr post-treatment	355.8	333.1	17.312	0.45
5 yr post-treatment	476.7	422.5	28.369	0.31
<i>Leader length (cm)</i>				
Pre-treatment	39.8	36.2	1.686	0.27
3 yr post-treatment	42.9	41.6	5.343	0.88
5 yr post-treatment	52.7	39.2	6.928	0.30
<i>Height:diameter ratio</i>				
Pre-treatment	62.6	63.6	2.159	0.78
3 yr post-treatment	55.1	68.2	1.132	0.01*
5 yr post-treatment	56.0	68.5	0.309	0.00*

p-values denoted with “*” were significant at $p \leq 0.10$ according to analysis of variance; $n = 3$. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates.

in the treatment (56.0) ($p = 0.00$) (Figure 128), indicating that treated trees had become sturdier and control trees more spindly.

Standardized diameter distributions show an increase in the frequency of treated pine in larger classes relative to the control (Figure 129). This trend became pronounced in year 3 and continued into year 5, and is consistent with ANOVA results that pine stem diameter became significantly larger in the treatment than in the control following

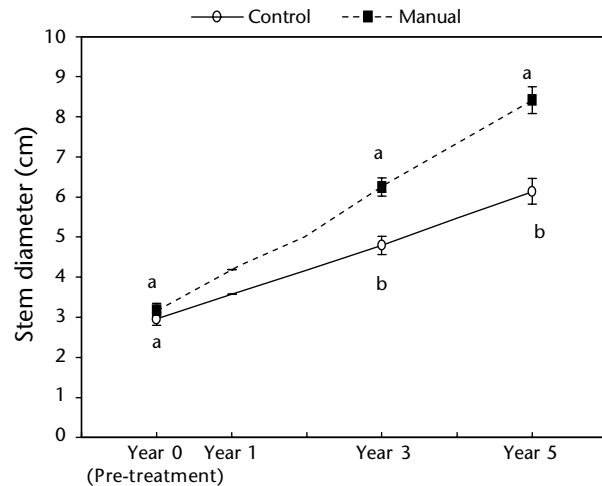


FIGURE 127 *Comparison of mean lodgepole pine stem diameter between the manual cutting treatment and control before, and 3 and 5 years after, treatment of the ICH Mixed Broadleaf-Shrub Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance ($\alpha = 0.10$).*

manual cutting. The nature of the trend suggests that most pine are responding to the cutting treatment. ANOVA showed no significant differences in pine height between the treatment and the control, but the standardized height distributions suggest that treated trees are beginning to increase in height relative to the control. Heights were distributed approximately normally prior to treatment, and the distributions were similar in the treatment and the control (Figure 130). By year 5 the frequency of treated trees had increased in larger height classes, while control trees continued to be normally distributed.

Competitive status Manual cutting immediately eliminated overtopping, resulting in a large increase in the number of pine that were free of vegetation (Figure 131). Untreated seedlings were slowly outgrowing the vegetation, but only a modest proportion (36%) were free of vegetation or threatened at the end of the 5-year measurement period. In the manual cutting treatment, the percentage of pine that were free of vegetation or threatened increased from 3 to 79%, and the percentage overtopped

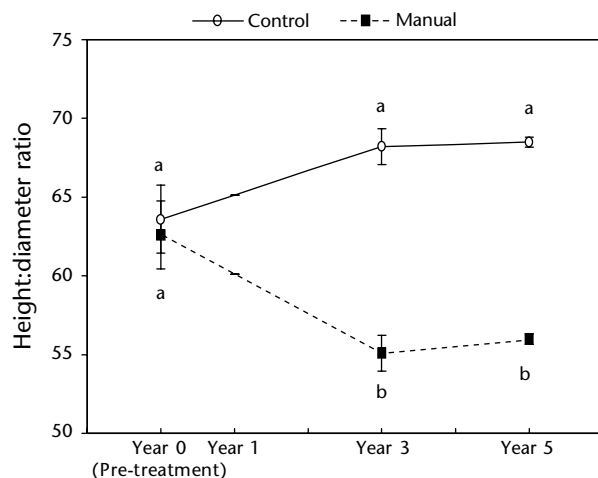


FIGURE 128 Comparison of mean lodgepole pine height:diameter ratio between the manual cutting treatment and control before, and 3 and 5 years after, treatment of the ICH Mixed Broadleaf-Shrub Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance ($\alpha = 0.10$).

decreased from 56 to 21%. In comparison, the percentage of control trees that were overtopped increased from 46 to 67%.

Plant community response

Abundance Birch height, but not cover, was significantly reduced for 5 years following manual cutting (Figure 132). Five years after treatment, birch had recovered in height to 229.8 cm in the treatment, but was still much shorter than birch in the control (485.5 cm, $p = 0.03$) (Table 119). Average birch cover was substantially lower in the brushing treatment than in the control 5 years after treatment (19.7 versus 34.4%), but due to high variability, the difference was not significant ($p = 0.23$).

Herb cover and height were not affected by manual cutting, and neither was shrub cover ($p > 0.10$) (Table 119). Shrub height was significantly less in the manual cutting treatment than in the control in year 3 (65.8 versus 115.6 cm, $p = 0.06$), but the difference disappeared by year 5.

Sprouting Birch sprouted vigorously after manual cutting, but the abundance of sprouts decreased with time and their average height did not increase. Three years after treatment, 81% of cut stumps had sprouts, and the proportion decreased to 67% within 5 years. Cut stumps averaged eight sprouts that were 207 cm tall in year 3 and five sprouts that were 200 cm tall in year 5 (Table 120).

Richness and diversity of individual species and structural vegetation groups Manual cutting of the Mixed Broadleaf-Shrub Complex had no effect on richness or diversity of vascular plant species or structural vegetation groups ($p > 0.10$) (Tables 121 and 122). As expected, paper birch, the primary target species, decreased in abundance following manual cutting. Many herb and shrub species increased or decreased in the treated plots of these study sites, but there were no obvious trends across more than one site (Table 123).

Cut Stump–Glyphosate

Douglas-fir in the ICH zone

This section describes fifth-year Douglas-fir and vegetation responses to cut stump–glyphosate treatment of the Mixed Broadleaf-Shrub Complex in the ICH zone ($n = 3$) (Figure 133). Conifers were 8–9 years old at the time of treatment.

Description of study sites and treatments

The response of Douglas-fir and the Mixed Broadleaf-Shrub Complex to cut stump–glyphosate treatment is being studied on three sites in the Kamloops Forest Region. Two are located near East Barriere Lake, 27–30 km northeast of Barriere in the Kamloops District: one in the Kootenay Moist Cool ICH variant (ICHmk1) and one in the Thompson Moist Warm ICH variant (ICHmw3). The third site is at Larch Hills, 15 km southwest of Sicamous in the Salmon Arm District, in the Shuswap Moist Warm ICH variant (ICHmw2).

The study areas have similar site characteristics; all are mesic (site series 01), in mid-slope position, of generally northerly aspect, on 25–30% slopes, and have Brunisolic sandy loam soils (Table 124). Elevations range from 870 to 1070 m.

The three sites were clearcut between 1976 and 1982. The two sites in the Kamloops District were mechanically site prepared and the site at Larch Hills was broadcast burned. Site preparation took place 1–2 years after logging and 8–13 years before

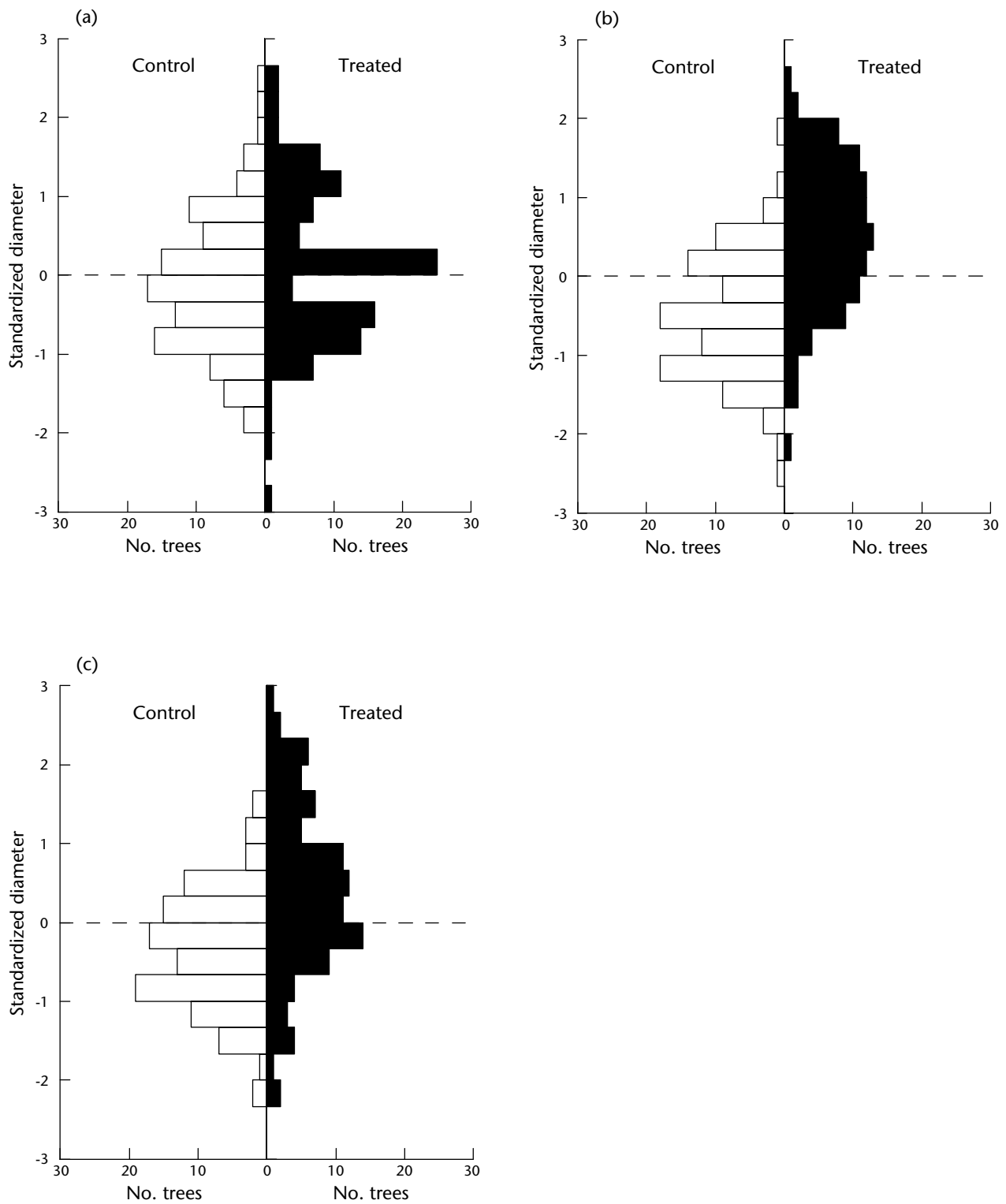


FIGURE 129 Frequency of control and treated trees in standardized diameter classes ($\mu = 0$; $s.d. = 1$; $n = 3$ for the control and treatment combined) for lodgepole pine in the ICH Mixed Broadleaf-Shrub Complex before and after manual cutting. Graphs are for: (a) pre-treatment; (b) 3 years post-treatment; (c) 5 years post-treatment.

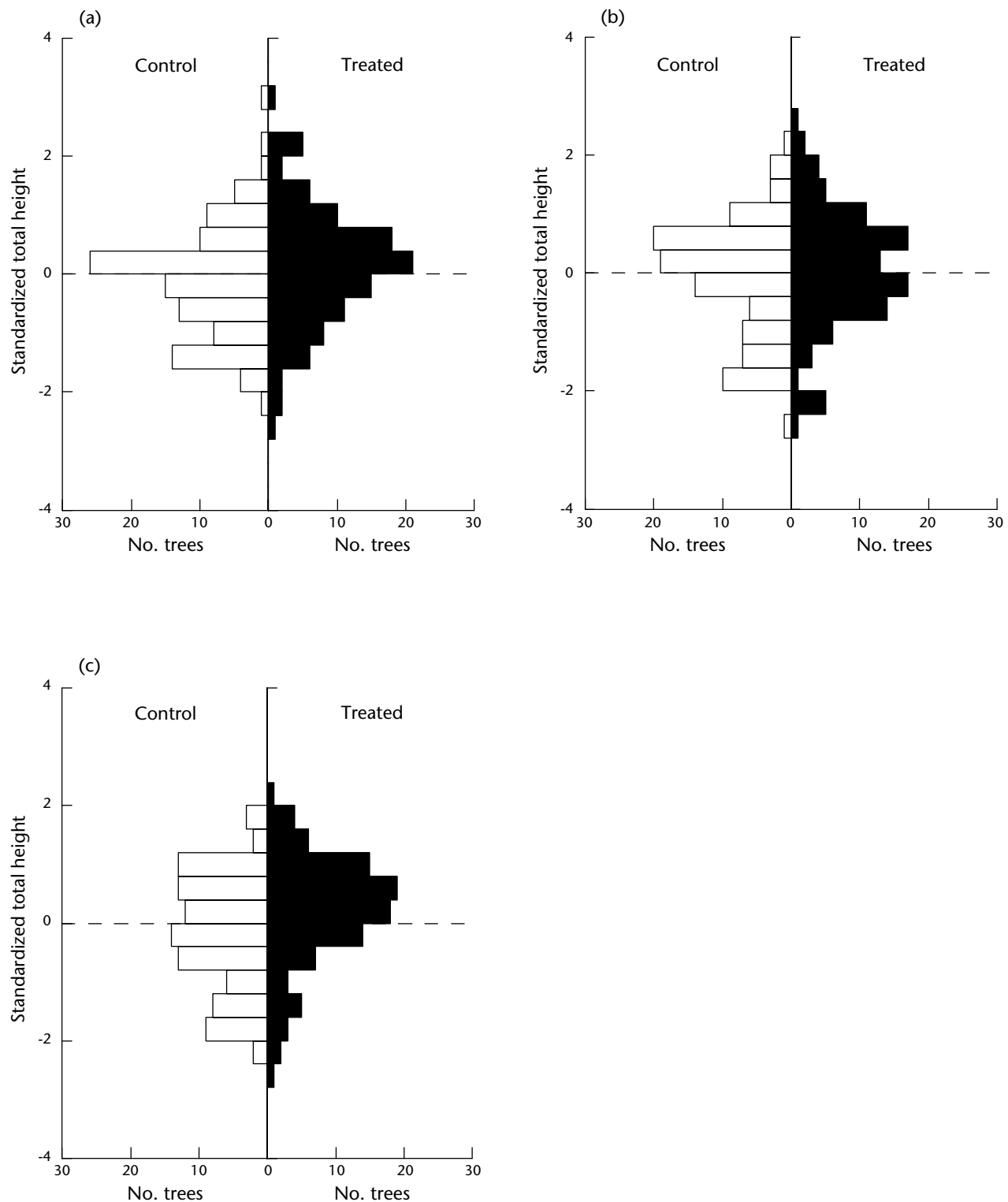


FIGURE 130 Frequency of control and treated trees in standardized total height classes ($\mu = 0$; $s.d. = 1$; $n = 3$ for the control and treatment combined) for lodgepole pine in the ICH Mixed Broadleaf-Shrub Complex before and after manual cutting. Graphs are for: (a) pre-treatment; (b) 3 years post-treatment; (c) 5 years post-treatment.

TABLE 119 Cover and height of vegetation in the ICH Mixed Broadleaf-Shrub Complex before and after manual cutting in lodgepole pine plantations

Response variable	Means		Standard error	p-value	Response variable	Means		Standard error	p-value
	Manual cutting	Control				Manual cutting	Control		
All vegetation					Shrubs (continued)				
Cover (%)					Height (cm)				
Pre-treatment	68.7	75.0	2.483	0.21	Pre-treatment	91.2	99.1	6.387	0.47
3 yr post-treatment	81.8	85.8	1.692	0.24	3 yr post-treatment	65.8	115.6	9.014	0.06*
5 yr post-treatment	89.2	94.9	4.039	0.43	5 yr post-treatment	113.6	156.4	21.316	0.29
Height (cm)					Herbs				
Pre-treatment	207.9	221.9	13.678	0.54	Cover (%)				
3 yr post-treatment	147.1	437.7	83.379	0.13	Pre-treatment	27.4	25.0	3.361	0.66
5 yr post-treatment	329.3	504.4	48.667	0.13	3 yr post-treatment	45.4	48.1	7.232	0.82
Broadleaf trees					5 yr post-treatment	54.3	49.3	7.562	0.69
Cover (%)					Height (cm)				
Pre-treatment	14.3	18.2	2.515	0.39	Pre-treatment	59.6	67.6	5.486	0.41
3 yr post-treatment	15.1	35.2	7.150	0.19	3 yr post-treatment	65.8	61.4	5.951	0.65
5 yr post-treatment	21.0	38.9	5.477	0.15	5 yr post-treatment	62.8	62.4	6.487	0.97
Height (cm)					Paper birch				
Pre-treatment	287.7	299.1	16.725	0.68	Cover (%)				
3 yr post-treatment	176.0	554.7	38.273	0.02*	Pre-treatment	12.0	15.1	2.668	0.50
5 yr post-treatment	230.1	550.3	24.572	0.01*	3 yr post-treatment	13.9	30.3	7.999	0.28
Shrubs					5 yr post-treatment	19.7	34.4	6.072	0.23
Cover (%)					Height (cm)				
Pre-treatment	39.5	41.2	2.015	0.62	Pre-treatment	271.0	256.9	26.574	0.74
3 yr post-treatment	44.1	45.6	3.145	0.76	3 yr post-treatment	170.9	495.3	58.730	0.06*
5 yr post-treatment	46.7	46.8	1.616	0.97	5 yr post-treatment	229.8	485.5	29.849	0.03*

p-values denoted with “*” were significant at $p \leq 0.10$ according to analysis of variance; $n = 3$. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates.

brushing. Douglas-fir were planted 1–2 years after site preparation and were 8–9 years old and 1.0–2.3 m tall at the time of brushing. About 60% of the Douglas-fir were overtopped and few were free of vegetation. Trees averaged half the height of neighbouring vegetation.

Birch was the dominant deciduous species on the sites before cut stump–glyphosate application. Its abundance varied among the sites, but cover averaged 50% (range of 40–56%) and height averaged 4.3 m (range of 2.7–5.9 m). Birch density varied from 3100 to 7800 stems/ha and most stems were vigorous. At the time of treatment, annual height growth of birch averaged 30–70 cm/yr, compared with 25–35 cm/yr for Douglas-fir. Total conifer density on these sites was 3159–7045

stems/ha, of which 1095–1200 stems/ha were well spaced.

At each site, broadleaf trees were cut near ground level and glyphosate was painted on the stumps at a rate of 0.74–3.20 kg ai/ha (Table 125). Work quality was good at two sites, but many stumps were missed during glyphosate application at the third site (John Creek). Treatments were applied between mid-June and mid-October.

Conifer responses

Survival and vigour Survival of Douglas-fir averaged 95% in the cut stump–glyphosate treatment and control 5 years after brushing ($p = 0.23$) (Table 126). *Armillaria ostoyae* caused almost all the mortality, but affected the treatment and control

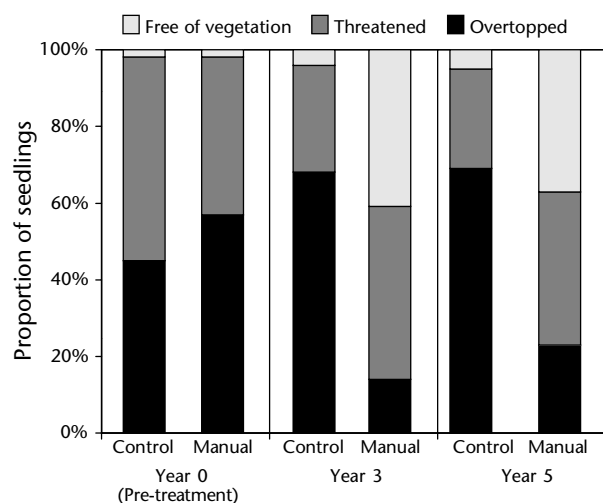


FIGURE 131 Comparison of lodgepole pine competitive status between the manual cutting treatment and control before, and 3 and 5 years after, treatment of the ICH Mixed Broadleaf-Shrub Complex. Seedlings were classified as free of vegetation when the leader was well above surrounding vegetation, and classified as overtopped when the leader was overtopped. Threatened seedlings had leaders at approximately the same height as surrounding vegetation.

TABLE 120 Sprouting characteristics of paper birch in the ICH Mixed Broadleaf-Shrub Complex following manual cutting in lodgepole pine stands

Response variable	Mean
<i>Proportion of stumps with sprouts</i>	
3 yr post-treatment	81
5 yr post-treatment	67
<i>Number of sprouts per stump</i>	
3 yr post-treatment	8
5 yr post-treatment	5
<i>Sprout length (cm)</i>	
3 yr post-treatment	207
5 yr post-treatment	200

TABLE 121 Richness and diversity of vascular plant species in the ICH Mixed Broadleaf-Shrub Complex before and after manual cutting in lodgepole pine stands

Response variable	Means		Standard error	p-value
	Manual cutting	Control		
<i>Richness</i>				
Pre-treatment	35.67	36.67	4.320	0.89
3 yr post-treatment	35.00	35.50	1.061	0.80
5 yr post-treatment	38.00	39.00	2.273	0.79
<i>Shannon-Weaver Diversity Index</i>				
Pre-treatment	2.42	2.34	0.093	0.58
3 yr post-treatment	2.33	2.22	0.162	0.71
5 yr post-treatment	2.42	2.48	0.057	0.59
<i>Simpson's Diversity Index</i>				
Pre-treatment	0.86	0.83	0.023	0.42
3 yr post-treatment	0.86	0.81	0.045	0.58
5 yr post-treatment	0.85	0.87	0.026	0.57

The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

TABLE 122 Richness and diversity of structural vegetation groups in the ICH Mixed Broadleaf-Shrub Complex before and after manual cutting in lodgepole pine stands

Response variable	Means		Standard error	p-value
	Manual cutting	Control		
<i>Richness</i>				
Pre-treatment	7.00	7.00	0.000	1.00
3 yr post-treatment	7.00	7.50	0.354	0.50
5 yr post-treatment	7.00	7.00	0.000	1.00
<i>Shannon-Weaver Diversity Index</i>				
Pre-treatment	1.54	1.57	0.088	0.86
3 yr post-treatment	1.65	1.59	0.124	0.81
5 yr post-treatment	1.62	1.64	0.069	0.90
<i>Simpson's Diversity Index</i>				
Pre-treatment	0.74	0.73	0.033	0.83
3 yr post-treatment	0.78	0.74	0.044	0.70
5 yr post-treatment	0.76	0.77	0.029	0.72

The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.



FIGURE 132 Effects of manual cutting on the Mixed Broadleaf-Shrub Complex and lodgepole pine (a) 1 year, (b) 3 years, and (c) 5 years following treatment. The control (d) is shown 5 years post-treatment for comparison. Photo credit: Jean Mather.

TABLE 123 Vascular plant species that exhibited trends of increasing cover, decreasing cover, or no change in cover following manual cutting of the ICH Mixed Broadleaf-Shrub Complex in lodgepole pine plantations. Species included in the list exhibited a common trend in the treated plots of at least two study sites, based on a subjective evaluation (see Methods, Section 3).

	Increasing cover	Decreasing cover	No change in cover
Broadleaves		<i>Betula papyrifera</i>	
Low shrubs			<i>Lonicera involucrata</i> <i>Ribes lacustre</i> <i>Rubus parviflorus</i>
Herbs			<i>Chimaphila umbellata</i> <i>Lilium columbianum</i> <i>Linnaea borealis</i> <i>Smilacina racemosa</i>

TABLE 124 *Characteristics and history of the three replicate study sites where a cut stump–glyphosate treatment was applied to the ICH Mixed Broadleaf-Shrub Complex in Douglas-fir plantations*

Site location	Site characteristics and history							Characteristics of target conifers at PROBE initiation					Abundance of major vegetation species: cover (%) and height ^d (cm)	Conifer stocking (stems/ha)	
	BEC unit	Elev. (m)	Aspect/slope	Soil class/texture	Logging and site prep. history	Years since harvest	Years since site prep.	Est. delay ^a (yr)	Origin ^b	Stock	Age ^c (yr)	Height ^d (cm)		Total	Well spaced
John Creek PROBE 1 Kamloops District	ICHmk1 01 (mesic)	870	NE 25%	Brunisol/sandy loam	Clearcut 1982 Piled and burned 1983	9	8	0	P 1984	PSB 313 1+0	8	98 (39)	Birch cover: 52 (17) Birch height: 266 (64)	7045	1200
Upper John Creek PROBE 2 Kamloops District	ICHmw3 01 (mesic)	920	NW 30%	Brunisol/sandy loam	Clearcut 1976 MSP 1978 Grass seeded 1981	15	13	4	P 1979	2+1 BR	9	218 (67)	Birch cover: 40 (28) Birch height: 589 (184)	3159	1095
Larch Hills PROBE 7 Salmon Arm District	ICHmw2 01 (mesic)	1070	NW 25%	Brunisol/silt loam	Clearcut 1980 Burned 1981–1982	11	9	1	P 1984	2+0 BR	8	228 (68)	Birch cover: 56 (15) Birch height: 447 (102)	4775	1200

^a Establishment delay refers to the number of years between the last disturbance (e.g., harvest or site preparation) and planting^b Origin: P = planted; N = natural regeneration^c Age refers to the number of years since planting^d Values are means and one standard deviation (in parentheses)



FIGURE 133 *The Mixed Broadleaf-Shrub Complex prior to cut stump–glyphosate treatment at Upper John Creek (Site 2) in the ICHmw3 variant in the Kamloops Forest District. Photo credit: Jean Mather.*

similarly ($p = 0.42$) (Figure 134). The fifth-year silviculture survey, which was conducted according to the old free-growing guidelines (B.C. Ministry of Forests 1995a), indicated there were significantly more free-growing trees in the treatment (745 stems/ha) than the control (128 stems/ha) ($p = 0.04$).

Although survival was high in both the treatment and control, the average vigour of Douglas-fir declined considerably in the control while remaining constant in the brushing treatment during the 5-year measurement period (Figure 135). The proportion of poor-vigour trees increased from 11 to 39% in the control but remained constant at 6–7%

TABLE 125 *A description of cut stump–glyphosate treatments applied to the three replicate study sites to release Douglas-fir seedlings growing in the ICH Mixed Broadleaf-Shrub Complex*

Site	Initial treatment date	Treatment type	Application rate (kg ai/ha)
John Creek	Mid-July 1991	Broadcast	0.91
Upper John Creek	Mid-June 1991	Broadcast	0.74
Larch Hills	Mid-October 1991	Broadcast; broadleaf stems >10 cm diameter retained	3.20

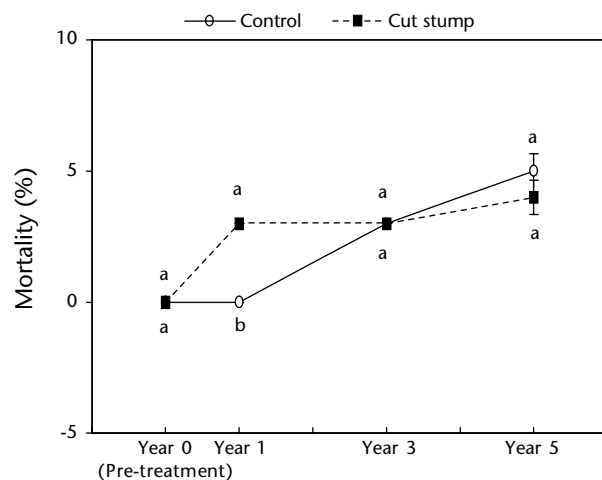


FIGURE 134 *Comparison of mean Douglas-fir mortality due to Armillaria between the cut stump–glyphosate treatment and control before, and 1, 3, and 5 years after, treatment of the ICH Mixed Broadleaf-Shrub Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where $MSE = \text{Mean Square Error}$ and $n = \text{number of replicates}$. Means with different letters within a single year are significantly different according to analysis of variance ($\alpha = 0.10$).*

TABLE 126 *Survival and growth responses of Douglas-fir seedlings to cut stump-glyphosate treatment in the ICH Mixed Broadleaf-Shrub Complex*

Response variable	Means		Standard error	p-value
	Cut stump– glyphosate	Control		
<i>Survival (%)</i>				
Pre-treatment	100	100	0.000	1.00
1 yr post-treatment	97	100	0.000	1.00
3 yr post-treatment	97	97	0.000	1.00
5 yr post-treatment	96	94	1.135	0.23
<i>Mortality due to Armillaria (%)</i>				
Pre-treatment	0	0	0.000	1.00
1 yr post-treatment	3	0	0.000	0.00
3 yr post-treatment	3	3	0.000	1.00
5 yr post-treatment	4	5	0.655	0.42
<i>Stem diameter (cm)</i>				
Pre-treatment	3.93	3.37	0.343	0.33
1 yr post-treatment	4.86	3.81	0.495	0.27
3 yr post-treatment	6.70	4.53	0.658	0.14
5 yr post-treatment	7.69	5.06	0.641	0.10*
<i>Diameter increment (cm)</i>				
1 yr post-treatment	1.03	0.50	0.173	0.16
3 yr post-treatment	0.92	0.37	0.093	0.05*
5 yr post-treatment	0.58	0.29	0.020	0.01*
<i>Height (cm)</i>				
Pre-treatment	187.7	174.8	6.636	0.30
1 yr post-treatment	237.9	220.8	16.048	0.53
3 yr post-treatment	309.9	274.7	20.831	0.35
5 yr post-treatment	398.4	318.5	17.854	0.09*
<i>Leader length (cm)</i>				
Pre-treatment	33.9	33.3	0.784	0.51
1 yr post-treatment	25.2	30.1	5.577	0.15
3 yr post-treatment	42.1	31.2	2.583	0.10*
5 yr post-treatment	45.3	23.0	2.773	0.03*
<i>Height:diameter ratio</i>				
Pre-treatment	49.3	51.4	1.978	0.61
1 yr post-treatment	50.9	58.5	2.316	0.14
3 yr post-treatment	47.4	61.5	3.352	0.10*
5 yr post-treatment	52.7	63.1	2.058	0.07*

p-values denoted with “*” were significant at $p \leq 0.10$ according to analysis of variance; $n = 3$. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates.

in the brushed treatment. In addition, the proportion of good-vigour trees decreased from 24 to 2% in the control but remained constant at 29–32% in the treated plots. Poor-vigour trees tended to be spindly with thinning foliage.

Growth Diameter increment and leader length of Douglas-fir seedlings increased in the treatment relative to the control 3 years after cut stump-glyphosate application ($p < 0.10$), but significant differences in stem diameter ($p = 0.10$) (Figure 136) and height ($p = 0.09$) (Figure 137) did not appear until year 5 (Table 126). In the fifth-year assessment, average stem diameter, diameter increment, and leader length of Douglas-fir were all approximately twice as great in the treatment as in the control, and seedlings were about 25% taller. Seedlings were 13–15 years old in year 5, and were 398.4 cm tall with 7.69 cm stem diameter in the treatment, compared to 318.5 cm tall with 5.06 cm stem diameter in the control. Treated seedlings were increasing in height at approximately twice the rate of control seedlings in year 5 (leaders were 45.3 cm in the treatment versus 23.0 cm in the control). Height:diameter ratio of Douglas-fir also decreased within 3 years of the cut stump-glyphosate treatment. Before treatment, height:diameter ratio averaged 50.4 ($p = 0.61$), but 5 years later it had increased to 63.1 in the control and remained essentially unchanged (52.7) in the treatment ($p = 0.07$) (Figure 138).

Standardized diameter distributions for Douglas-fir were normal in the treatment prior to brushing, but in the control there were a comparatively large number of seedlings in the -1 to -1.5 diameter classes (Figure 139). In the control, the frequency of trees in smaller diameter classes increased further through year 5, while in the cut stump-glyphosate treatment, frequencies increased in the larger diameter classes. The difference between the control and treatment was not large enough to be statistically significant prior to treatment, but by year 5, ANOVA showed that stem diameter was larger in the treatment than in the control. The standardized height distributions were approximately normal in both the treatment and control prior to the cut stump-glyphosate treatment (Figure 140). The distribution of control heights changed very little during the 5-year measurement period, but in the treatment, frequencies increased slightly in the +1 height class. These results agree with ANOVA findings that Douglas-fir were significantly taller in the treatment than in the control by year 5. The trend of

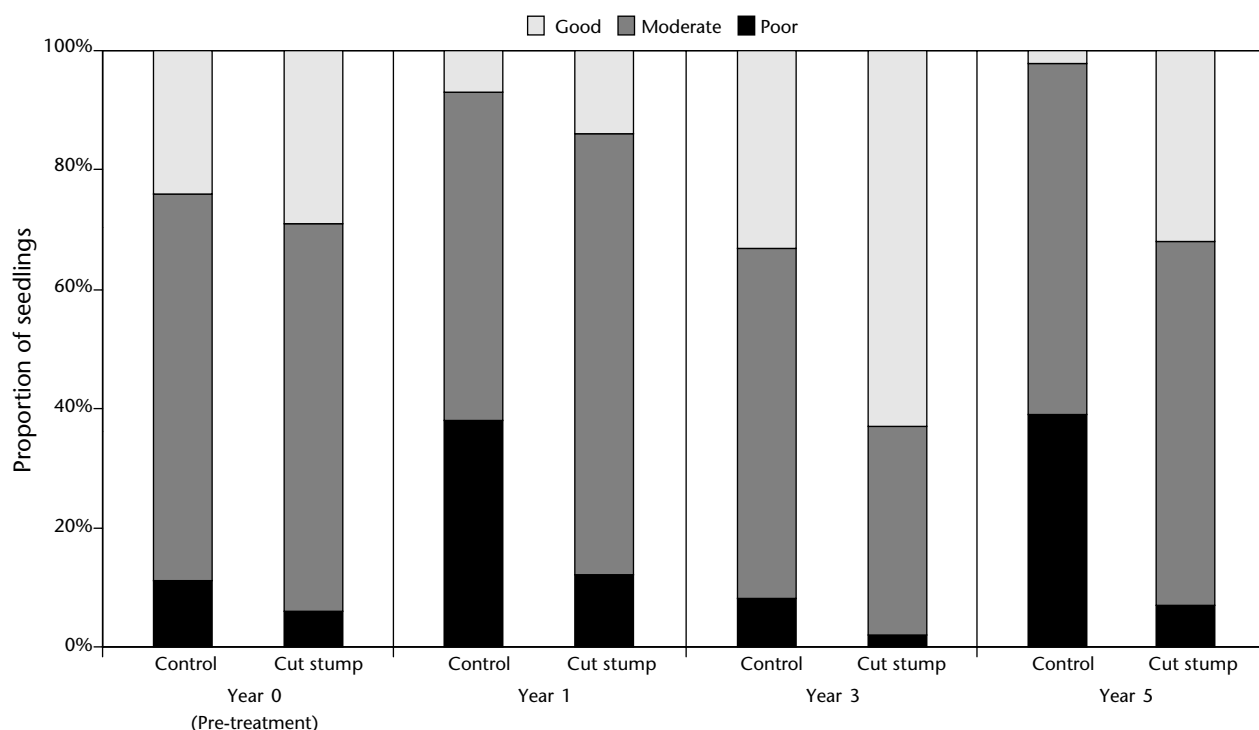


FIGURE 135 Comparison of Douglas-fir vigour between the cut stump–glyphosate treatment and control before, and 1, 3, and 5 years after, treatment of the ICH Mixed Broadleaf-Shrub Complex.

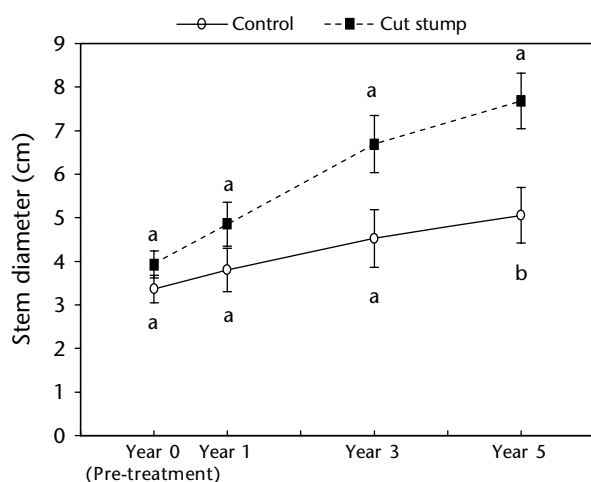


FIGURE 136 Comparison of mean Douglas-fir stem diameter between the cut stump–glyphosate treatment and control before, and 1, 3, and 5 years after, treatment of the ICH Mixed Broadleaf-Shrub Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance ($\alpha = 0.10$).

increase is less pronounced for height than for diameter, and it is difficult to predict whether it will continue into future assessments.

Competitive status Cut stump–glyphosate application resulted in a large increase in the percentage of Douglas-fir that were free of vegetation and nearly eliminated overtopping (Figure 141). Within one year of treatment, the percentage of trees that were free of vegetation in the treatment increased from 3 to 63%, and the percentage overtopped decreased from 64 to 13%. These improvements remained relatively constant through year 5. Meanwhile, competitive status worsened in the control during the 5-year monitoring period; the percentage of trees free of vegetation decreased from 6 to 0%, and the percentage overtopped increased from 57 to 76%.

Plant community responses

Abundance Cut stump–glyphosate treatment reduced birch height for at least 5 years ($p < 0.10$) (Table 127, Figures 142 and 143). One year after treatment, birch averaged 123.0 cm tall in the treatment compared with 543.0 cm tall in the control. By year 5, treated birch had grown about 250 cm to 376.8 cm tall, while those in the control had grown

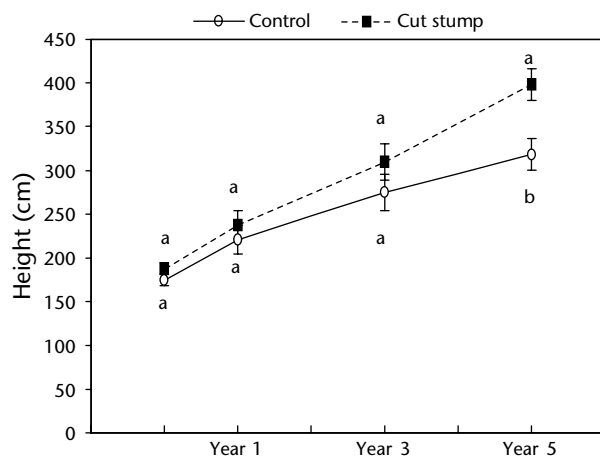


FIGURE 137 Comparison of mean Douglas-fir height between the cut stump-glyphosate treatment and control before, and 1, 3, and 5 years after, treatment of the ICH Mixed Broadleaf-Shrub Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance ($\alpha = 0.10$).

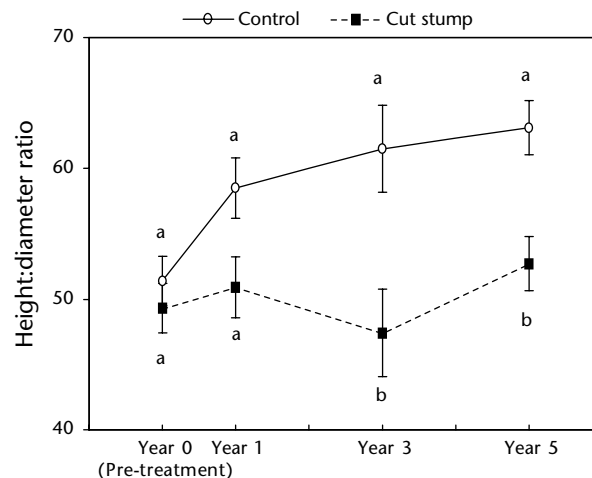


FIGURE 138 Comparison of mean Douglas-fir height:diameter ratio between the cut stump-glyphosate treatment and control before, and 1, 3, and 5 years after, treatment of the ICH Mixed Broadleaf-Shrub Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance ($\alpha = 0.10$).

almost 500 cm to 932.2 cm tall. The brushing treatment also substantially reduced birch cover for at least 5 years (15.3% in the treatment compared to 64.8% in the control in year 5, $p = 0.05$). Birch cover in the control increased gradually from 50.1 to 64.8% during the 5-year measurement period.

Herb cover and height and shrub cover were unaffected by cut stump-glyphosate treatment of broadleaf trees. Shrub height was significantly less in the treatment than in the control 1 and 3 years after brushing ($p = 0.04$).

Sprouting Twenty-eight percent of birch stumps had sprouts 1 year after treatment and the proportion was about the same (24%) in year 5 (Table 128). One year after treatment, stumps averaged six sprouts each, but after 3 years these had thinned to an average of two per stump. Average sprout height was 50 cm 1 year after treatment and 273 cm by year 5. Sprouting was highly variable among sites, depending on the completeness of the glyphosate treatment. Where glyphosate was applied to all cut stumps, there was virtually no sprouting, whereas on the site where many stumps missed

glyphosate treatment, about 70% of cut stumps had sprouts.

Richness and diversity of individual species and structural vegetation groups Cut stump-glyphosate treatment of the Mixed Broadleaf-Shrub Complex had no effect on either species richness or diversity ($p > 0.10$) (Table 129). Species richness increased considerably between the pre-treatment (18 species) and the third-year assessment (31 species), but increases occurred equally in the treatment and control.

Richness of structural vegetation groups did not differ between the treatment and control on any measurement date ($p > 0.10$) (Table 130). However, diversity of structural groups was significantly greater in the brushing treatment than in the control 3–5 years after cut stump-glyphosate application ($p < 0.10$) (Table 130), likely because of reduced broadleaf dominance in the treatment.

Paper birch was the primary target species on these sites, and its presence decreased dramatically on all three sites following treatment. Reductions in cover persisted for at least 5 years on two of the study sites. On the third site, where treatment was

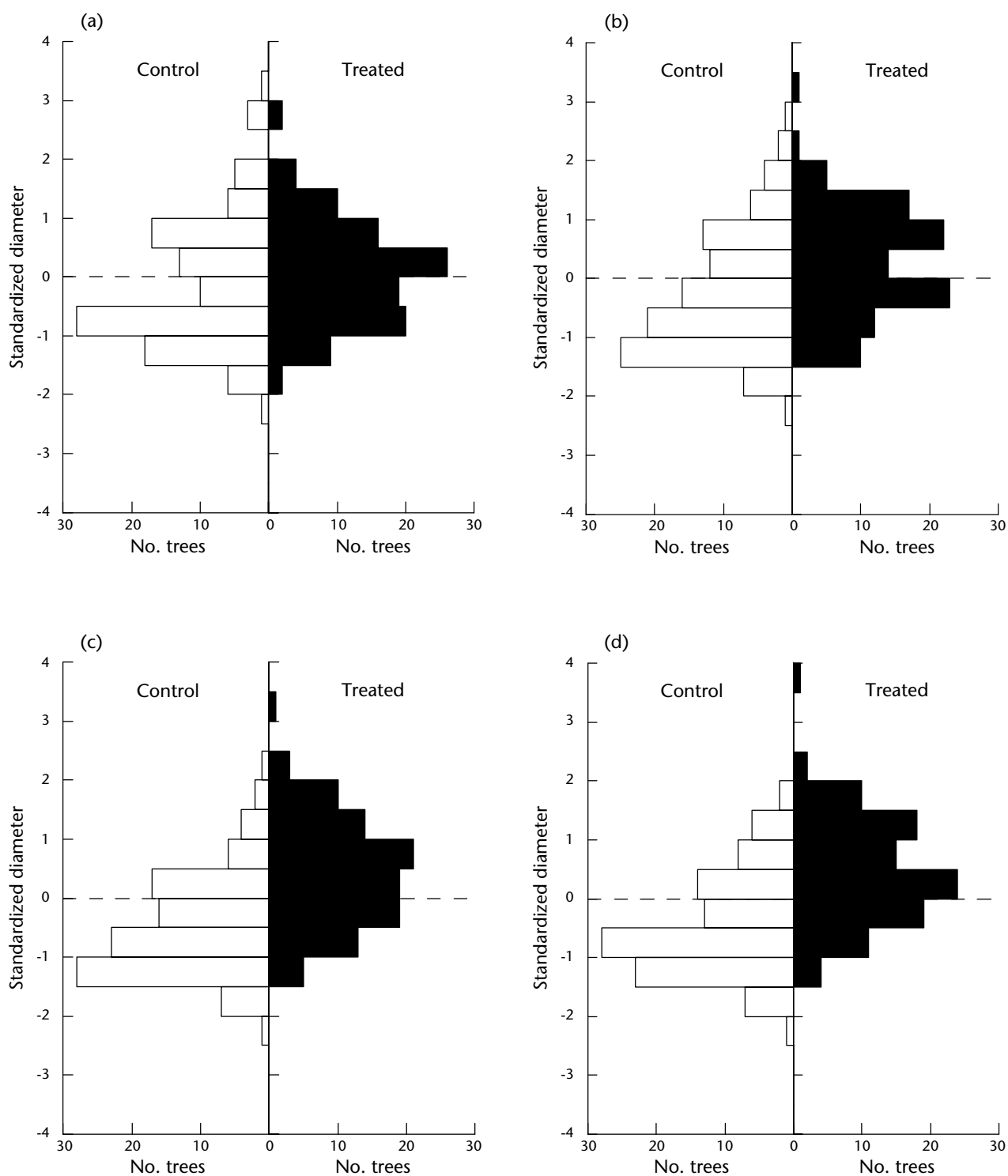


FIGURE 139 Frequency of control and treated trees in standardized diameter classes ($\mu = 0$; $s.d. = 1$; $n = 3$ for the control and treatment combined) for Douglas-fir in the ICH Mixed Broadleaf-Shrub Complex before and after cut stump-glyphosate treatment. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 3 years post-treatment; (d) 5 years post-treatment.

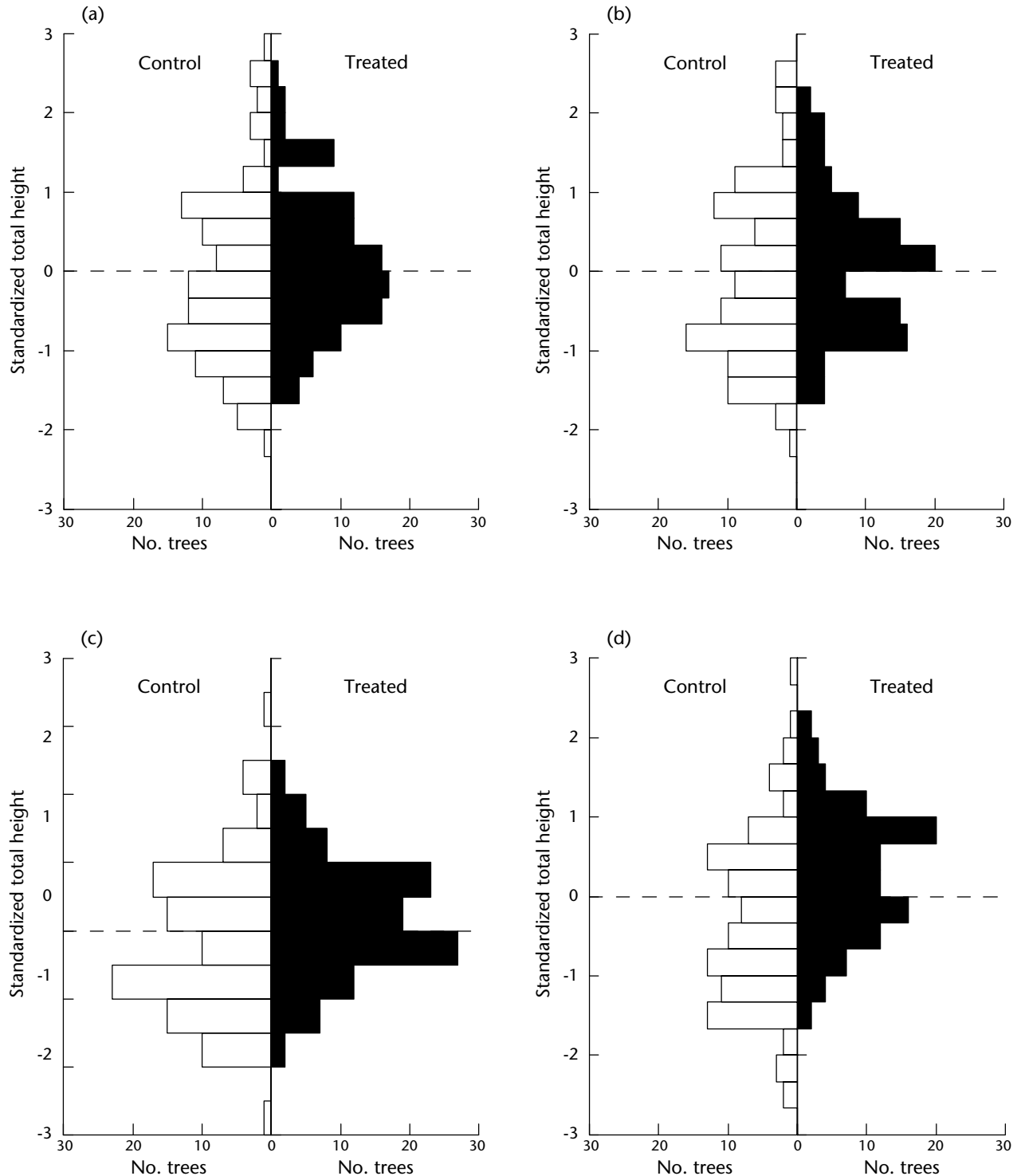


FIGURE 140 Frequency of control and treated trees in standardized total height classes ($\mu = 0$; $s.d. = 1$; $n = 3$ for the control and treatment combined) for Douglas-fir in the ICH Mixed Broadleaf-Shrub Complex before and after cut stump-glyphosate treatment. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 3 years post-treatment; (d) 5 years post-treatment.

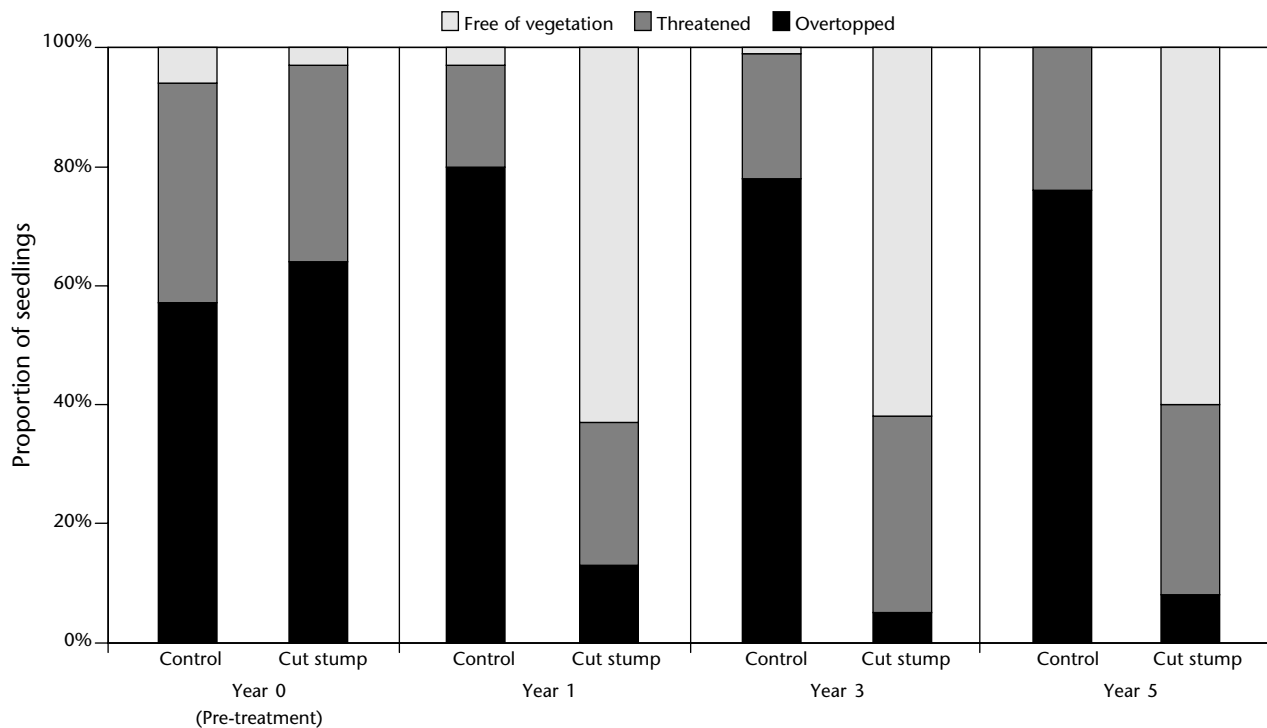


FIGURE 141 Comparison of Douglas-fir competitive status between the cut stump–glyphosate treatment and control before, and 1, 3, and 5 years after, treatment of the ICH Mixed Broadleaf-Shrub Complex. Seedlings were classified as free of vegetation when the leader was well above surrounding vegetation, and classified as overtopped when the leader was overtopped. Threatened seedlings had leaders at approximately the same height as surrounding vegetation.

poorly applied, birch partially recovered, increasing in cover by the fifth-year assessment. Willow either appeared or gradually increased during the 5 years of monitoring in the treated plots but not in the controls.

Herbs showed no tendency to decrease following the cut stump–glyphosate treatment, but several species became more abundant following treatment, likely in response to increased light availability (Table 131). The following herbs increased in abundance in treatment but not control plots on at least two of three sites: fireweed cover gradually increased during the 5-year monitoring period, dandelion appeared or increased in abundance, and strawberry and rattlesnake plantain (*Goodyera oblongifolia*) appeared within 3 years of brushing.

Girdling

Douglas-fir in the ICH zone

This section describes fifth-year Douglas-fir and vegetation responses to girdling of broadleaf stems

in the ICH zone *Mixed Broadleaf-Shrub Complex* ($n = 3$) (Figure 144). Conifers were 5–17 years old at the time of treatment.

Description of study sites and treatments

The three sites in this treatment cell are located throughout the Kamloops Forest Region: at Russell Creek, 22 km northeast of Barriere in the Kamloops District; at Gordon Bay, on the west side of Adams Lake in the Clearwater District; and at Scotch Creek, 20 km north of Sorrento on the north side of Shuswap Lake in the Salmon Arm District. All three sites are in the Thompson Moist Warm ICH variant (ICHmw3).

Two of the sites are mesic (site series 01) in mid- and lower slope positions, and one is mesic–submesic (site series 05) in mid-slope position (Table 132). The sites have southeasterly to easterly aspects with gentle to moderate slopes (5–35%). Soils are loamy (loam to sandy loam) Brunisols. Elevations of the sites range from 520 to 1200 m.

The original stands were clearcut between 1972

TABLE 127 *Cover and height of vegetation in the ICH Mixed Broadleaf-Shrub Complex before and after cut stump-glyphosate treatment in Douglas-fir plantations*

Response variable	Means		Standard error	p-value	Response variable	Means		Standard error	p-value
	Cut stump– glyphosate	Control				Cut stump– glyphosate	Control		
All vegetation					Shrubs (<i>continued</i>)				
<i>Cover (%)</i>					<i>Height (cm)</i>				
Pre-treatment	87.3	87.5	1.177	0.90	Pre-treatment	77.6	92.4	7.276	0.29
1 yr post-treatment	39.8	57.0	7.909	0.26	1 yr post-treatment	75.8	98.4	3.231	0.04*
3 yr post-treatment	70.9	80.3	1.277	0.04*	3 yr post-treatment	91.3	113.2	3.101	0.04*
5 yr post-treatment	78.0	90.5	6.491	0.31	5 yr post-treatment	112.0	117.9	7.330	0.63
<i>Height (cm)</i>					Herbs				
Pre-treatment	219.8	363.6	67.881	0.27	<i>Cover (%)</i>				
1 yr post-treatment	104.3	495.5	45.110	0.03*	Pre-treatment	34.0	25.9	4.748	0.35
3 yr post-treatment	155.7	578.1	73.264	0.06*	1 yr post-treatment	9.4	5.4	2.204	0.33
5 yr post-treatment	193.9	933.6	155.545	0.08*	3 yr post-treatment	17.8	7.7	4.924	0.28
Broadleaf trees					5 yr post-treatment	18.4	7.6	6.754	0.38
<i>Cover (%)</i>					<i>Height (cm)</i>				
Pre-treatment	52.6	54.9	1.663	0.42	Pre-treatment	65.5	65.1	2.128	0.92
1 yr post-treatment	2.7	34.6	12.522	0.21	1 yr post-treatment	94.3	77.5	12.453	0.44
3 yr post-treatment	9.4	50.3	10.206	0.10*	3 yr post-treatment	124.9	90.1	12.905	0.20
5 yr post-treatment	15.4	69.6	7.493	0.04*	5 yr post-treatment	148.4	87.9	21.400	0.18
<i>Height (cm)</i>					Paper birch				
Pre-treatment	427.2	448.0	17.731	0.42	<i>Cover (%)</i>				
1 yr post-treatment	107.5	556.7	72.320	0.05*	Pre-treatment	48.2	50.1	1.342	0.42
3 yr post-treatment	218.0	692.2	94.518	0.07*	1 yr post-treatment	2.5	32.8	13.175	0.25
5 yr post-treatment	384.6	952.3	78.360	0.04*	3 yr post-treatment	9.3	46.8	11.162	0.14
Shrubs					5 yr post-treatment	15.3	64.8	8.354	0.05*
<i>Cover (%)</i>					<i>Height (cm)</i>				
Pre-treatment	41.9	50.2	4.267	0.30	Pre-treatment	423.3	444.2	14.731	0.42
1 yr post-treatment	27.0	29.5	0.550	0.08*	1 yr post-treatment	123.0	543.0	77.824	0.06*
3 yr post-treatment	43.7	51.2	2.505	0.17	3 yr post-treatment	227.0	679.7	97.110	0.08*
5 yr post-treatment	48.1	58.7	2.714	0.11	5 yr post-treatment	376.8	932.2	93.385	0.05*

p-values denoted with “*” were significant at $p \leq 0.10$ according to analysis of variance; $n = 3$. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates.

and 1978 and each site was prepared within 3 years of harvest. Two sites were mechanically site prepared and one was broadcast burned. Douglas-fir were planted on the sites 1–7 years after site preparation, and the planted trees were 5–17 years old and 1.1–6.5 m tall at the time of brushing. About half the Douglas-fir were overtopped and 17% were free of vegetation. Total conifer stocking ranged from 1125 to 3909 stems/ha, of which 795–1200 stems/ha were well spaced.

Birch, aspen, and cottonwood were present in

varying abundances on the three sites. The broadleaf composition varied from pure birch on one site, to a mixture of birch and cottonwood on the second site, to a mixture of aspen and cottonwood with a minor birch component on the third site. The broadleaves tended to be vigorous, and on all sites they were increasing in height at a greater rate (30–75 cm/yr) than the Douglas-fir (20–50 cm/yr). Total broadleaf cover and height averaged 25% and 603 cm, respectively, but ranged from 9 to 41% and 374 to 803 cm. Density of broadleaf trees varied from

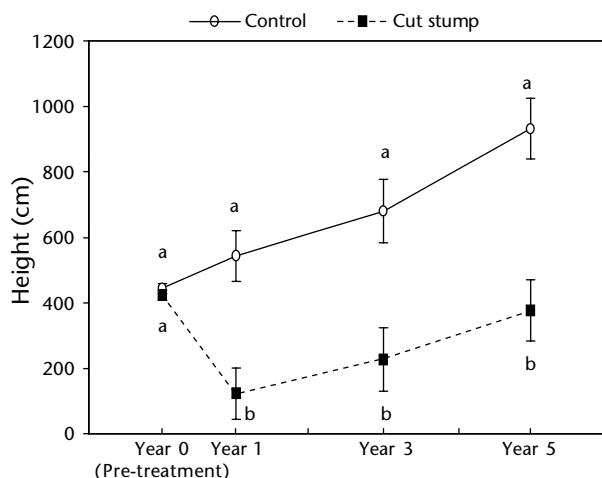


FIGURE 142 Comparison of mean birch height between the cut stump–glyphosate treatment and control before, and 1, 3, and 5 years after, treatment of the ICH Mixed Broadleaf-Shrub Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance ($\alpha = 0.10$).

TABLE 128 Sprouting characteristics of paper birch in the ICH Mixed Broadleaf-Shrub Complex following cut stump–glyphosate treatment in Douglas-fir plantations

Response variable	Mean
<i>Proportion of stumps with sprouts</i>	
1 yr post-treatment	28
3 yr post-treatment	24
5 yr post-treatment	24
<i>Number of sprouts per stump</i>	
1 yr post-treatment	6
3 yr post-treatment	2
5 yr post-treatment	2
<i>Sprout length (cm)</i>	
1 yr post-treatment	50
3 yr post-treatment	134
5 yr post-treatment	273

TABLE 129 Richness and diversity of vascular plant species in the ICH Mixed Broadleaf-Shrub Complex following cut stump–glyphosate treatment in Douglas-fir plantations

Response variable	Means		Standard error	p-value
	Cut stump–glyphosate	Control		
<i>Richness</i>				
Pre-treatment	16.00	20.00	1.225	0.15
1 yr post-treatment	21.33	24.00	1.247	0.27
3 yr post-treatment	25.00	31.67	2.494	0.20
5 yr post-treatment	28.50	33.00	1.768	0.32
<i>Shannon-Weaver Diversity Index</i>				
Pre-treatment	1.48	1.56	0.030	0.20
1 yr post-treatment	1.82	1.71	0.088	0.47
3 yr post-treatment	1.93	1.73	0.110	0.33
5 yr post-treatment	1.58	1.52	0.068	0.65
<i>Simpson's Diversity Index</i>				
Pre-treatment	0.67	0.69	0.008	0.21
1 yr post-treatment	0.75	0.72	0.011	0.21
3 yr post-treatment	0.77	0.72	0.024	0.26
5 yr post-treatment	0.68	0.65	0.020	0.52

The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

1600 to 31 000 stems/ha. The lowest density occurred at Russell Creek, where the trees were larger (8 m tall) than on the other two sites (3–6 m tall).

Brushing took place 14–20 years after harvest and 12–19 years after site preparation. At Russell Creek and Gordon Bay, broadleaves were girdled and smaller vegetation was manually cut (Table 133). At Russell Creek, 350 broadleaves stems/ha were retained, while at Gordon Bay all broadleaves were treated. At Scotch Creek, broadleaves were injected with glyphosate, which had an effect similar to that of girdling.

Conifer response

Survival and vigour Survival of 10- to 22-year-old Douglas-fir (5–17 years old at the time of treatment) was significantly lower in the girdling treatment (90%) than in the control (97%) 5 years after treatment ($p = 0.02$) (Table 134). *Armillaria ostoyae* was the main mortality agent, and it caused significantly more mortality in the treatment than in the control (8 versus 3%, $p = 0.07$) (Figure 145). Annual



FIGURE 143 *Effects of cut stump-glyphosate treatment on the Mixed Broadleaf-Shrub Complex and Douglas-fir (a) 1 year, (b) 3 years and (c) 5 years following treatment. The control (d) is shown 5 years post- treatment for comparison. Photo credit: Jean Mather.*



FIGURE 144 The Mixed Broadleaf-Shrub Complex and Douglas-fir prior to girdling at Gordon Bay (Site 15) in the ICHmw3 variant in the Clearwater Forest District. Photo credit: Silver Ring Forestry Ltd.

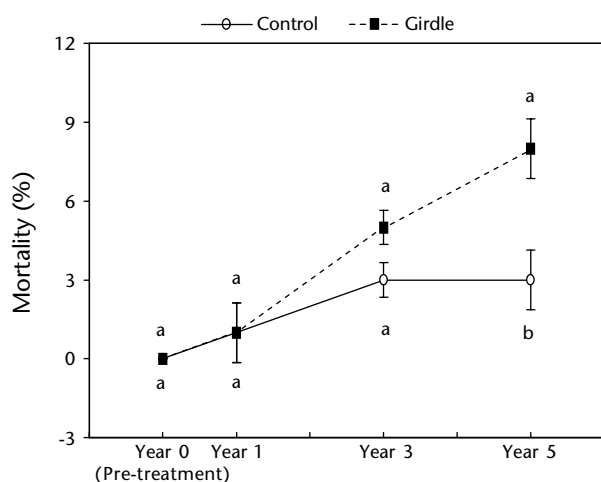


FIGURE 145 Comparison of mean Douglas-fir mortality due to *Armillaria* between the girdling treatment and control before, and 1, 3, and 5 years after, treatment of the ICH Mixed Broadleaf-Shrub Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance ($\alpha = 0.10$).

TABLE 130 Richness and diversity of structural vegetation groups in the ICH Mixed Broadleaf-Shrub Complex following cut stump-glyphosate treatment in Douglas-fir plantations

Response variable	Means		Standard error	p-value
	Cut stump-glyphosate	Control		
<i>Richness</i>				
Pre-treatment	7.00	7.67	0.471	0.42
1 yr post-treatment	8.00	7.67	0.236	0.42
3 yr post-treatment	7.67	7.67	0.000	1.00
5 yr post-treatment	7.50	7.50	0.707	1.00
<i>Shannon-Weaver Diversity Index</i>				
Pre-treatment	1.20	1.30	0.019	0.06*
1 yr post-treatment	1.45	1.36	0.035	0.20
3 yr post-treatment	1.49	1.37	0.036	0.14
5 yr post-treatment	1.32	1.25	0.007	0.09*
<i>Simpson's Diversity Index</i>				
Pre-treatment	0.61	0.65	0.016	0.26
1 yr post-treatment	0.69	0.67	0.009	0.20
3 yr post-treatment	0.70	0.67	0.001	0.00*
5 yr post-treatment	0.69	0.61	0.002	0.06*

p-values denoted with “*” were significant at $p \leq 0.10$ according to analysis of variance; $n = 3$. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Analysis of covariance was applied where there were pre-treatment differences according to analysis of variance.

rates of mortality from *Armillaria* since brushing were 1.6%/yr in the girdling treatment and 0.6%/yr in the control. The fifth-year silviculture survey, which was conducted according to the old free-growing guidelines (B.C. Ministry of Forests 1995a), indicated there were significantly more free-growing trees in the girdling treatment (370 stems/ha) than the control (166 stems/ha) ($p = 0.05$).

During the 5-year monitoring period, average vigour of Douglas-fir improved in the girdling treatment and remained constant in the control (Figure 146). The proportion of poor-vigour trees decreased from 24 to 4% in the treatment but remained constant (17–18%) in the control. By year 5, 52% of treated Douglas-fir were of good vigour, compared to 28% of control trees. At one site (Scotch Creek), there was a large decrease in the vigour of Douglas-fir in the first year after treatment because damage from deer and rabbit browsing increased

after birch were killed. However, most trees recovered within 2 years.

Growth One year after girdling, Douglas-fir growth did not differ between the girdling treatment and the control ($p>0.10$) (Table 134). Three years after treatment, diameter increment was greater (0.67 versus 0.43 cm, $p = 0.03$) and height:diameter ratio lower (50.2 versus 60.3, $p = 0.08$) (Figure 147) in the treatment than in the control, but there were

still no differences in diameter, height, or leader length ($p>0.10$). Five years after girdling, the diameter increment and height:diameter ratio differences had disappeared, and there still were no differences in total height. Leader length was greater in the treatment than in the control in the fifth-year assessment (34.9 versus 22.3 cm, $p = 0.02$) (Figure 148), but the difference was not large enough to significantly affect overall height.

TABLE 131 Vascular plant species that exhibited trends of increasing cover, decreasing cover, or no change in cover following cut stump–glyphosate treatment of the ICH Mixed Broadleaf-Shrub Complex in Douglas-fir plantations. Species included in the list exhibited a common trend in the treated plots of at least two study sites, based on a subjective evaluation (see Methods, Section 3).

	Increasing cover	Decreasing cover	No change in cover
Broadleaves		<i>Betula papyrifera</i>	
Low shrubs	<i>Ribes lacustre</i> <i>Salix</i> spp.		<i>Pachistima myrsinites</i> <i>Rubus parviflorus</i>
Herbs	<i>Epilobium angustifolium</i> <i>Fragaria</i> spp. <i>Goodyera oblongifolia</i> <i>Taraxacum officinale</i>		

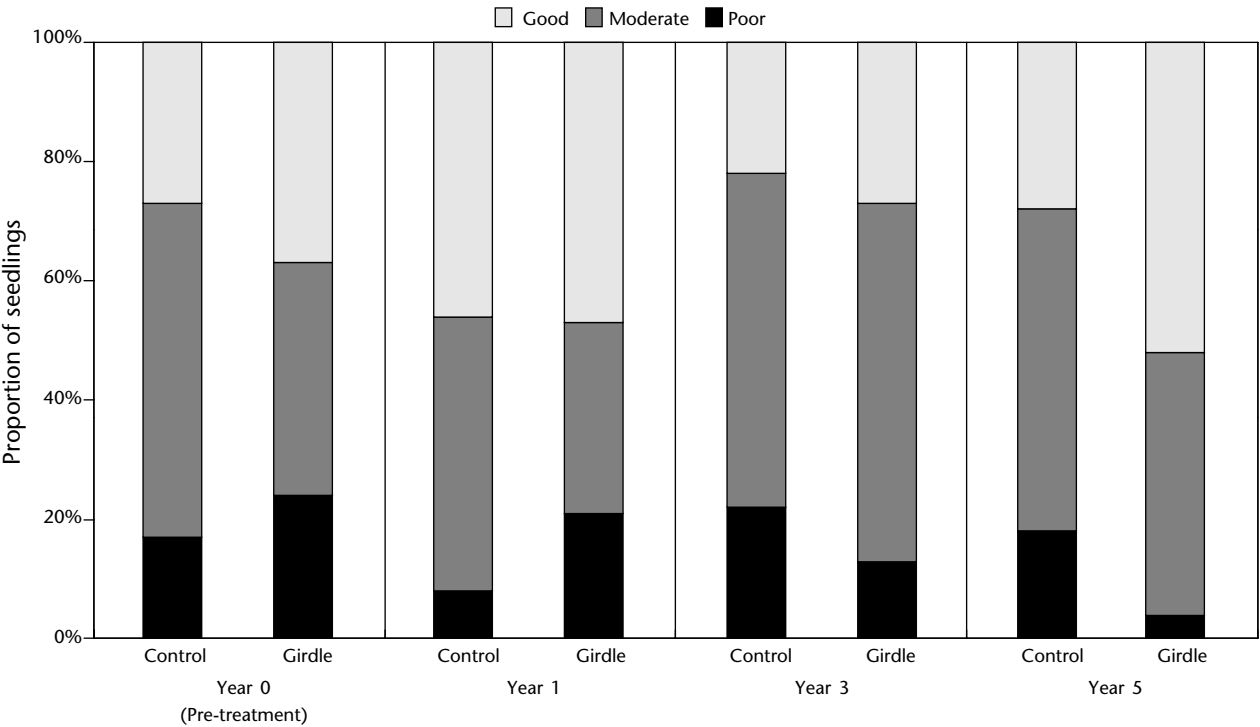


FIGURE 146 Comparison of Douglas-fir vigour between the girdling treatment and control before, and 1, 3, and 5 years after, treatment of the ICH Mixed Broadleaf-Shrub Complex.

TABLE 132 *Characteristics and history of the three replicate study sites where the ICH Mixed Broadleaf-Shrub Complex was girdled in Douglas-fir plantations*

Site location	Site characteristics and history							Characteristics of target conifers at PROBE initiation					Abundance of major vegetation species: cover (%) and height ^d (cm)	Conifer stocking (stems/ha)	
	BEC unit	Elev. (m)	Aspect/slope	Soil class/texture	Logging and site prep. history	Years since harvest	Years since site prep.	Est. delay ^a (yr)	Origin ^b	Stock	Age ^c (yr)	Height ^d (cm)		Total	Well spaced
Russell Creek PROBE 30 Kamloops District	ICHmw3 05 (mesic-submesic)	1200	E 5%	Brunisol/sandy loam	Clearcut 1972 Burned 1973	21	20	3	P 1974	1+0 plug	17	654 (147)	Aspen cover: 5 (3) Aspen height: 823 (260) Cottonwood cover: 3 (3) Cottonwood ht: 555 (271) Willow cover: 4 (2) Willow height: 486 (567)	1125	795
Gordon Bay PROBE 15 Clearwater District	ICHmw3 01 (mesic)	520	SE 15%	Brunisol/sandy loam	Clearcut 1977 MSP 1980	14	12	5	P 1985	PSB 313 1+0	7	116 (47)	Birch cover: 39 (22) Birch height: 663 (209)	2499	798
Scotch Creek PROBE 21 Salmon Arm District	ICHmw3 01 (mesic)	880	SE 35%	Brunisol/loam	Clearcut 1978 MSP 1980	14	12	7	P 1987	PSB 313 1+0	5	107 (38)	Birch cover: 17 (10) Birch height: 470 (794) Cottonwood cover: 6 (5) Cottonwood ht: 241 (115)	3909	1200

^a Establishment delay refers to the number of years between the last disturbance (e.g., harvest or site preparation) and planting^b Origin: P = planted; N = natural regeneration^c Age refers to the number of years since planting^d Values are means and one standard deviation (in parentheses)

TABLE 133 A description of girdling treatments applied to the three replicate study sites to release Douglas-fir seedlings growing in the ICH Mixed Broadleaf-Shrub Complex

Site	Treatment date	Broadleaf retention (stems/ha)	Treatment tool	Treatment specification
Russell Creek	August 1993	350	Chain girdler	Broadleaves >5 cm diameter girdled; smaller broadleaves and willow cut near ground level. Treatment done within 2-m radius of healthy conifers (not done around conifers with <i>Armillaria</i> symptoms). Girdling was the dominant treatment.
Gordon Bay	August 1993	0	Chain girdler	All birch girdled; cottonwood, aspen, cherry, willow, and other large shrubs cut near ground level.
Scotch Creek	Mid-October 1992	0	E-Z-JECT injector	Broadleaves >1 cm diameter injected with glyphosate (0.15 g per 5-cm stem). Stems <1 cm diameter not treated.

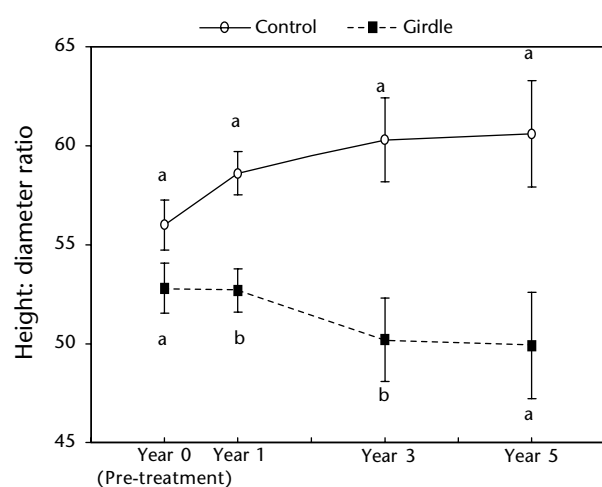


FIGURE 147 Comparison of mean Douglas-fir height:diameter ratio between the girdling treatment and control before, and 1, 3, and 5 years after, treatment of the ICH Mixed Broadleaf-Shrub Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance ($\alpha = 0.10$).

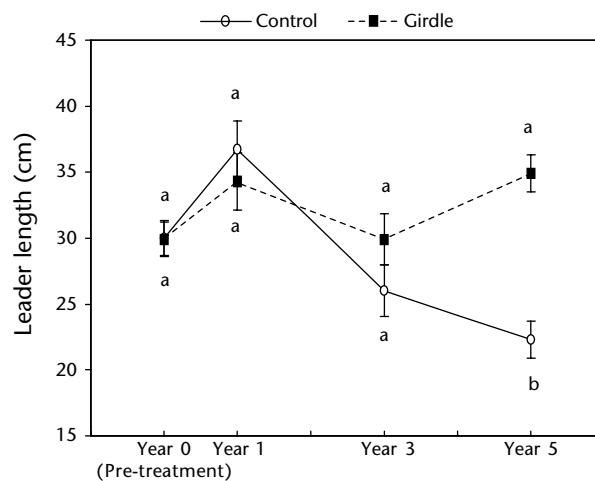


FIGURE 148 Comparison of mean Douglas-fir leader length between the girdling treatment and control before, and 1, 3, and 5 years after, treatment of the ICH Mixed Broadleaf-Shrub Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance ($\alpha = 0.10$).

TABLE 134 *Survival and growth responses of Douglas-fir seedlings to girdling in the ICH Mixed Broadleaf-Shrub Complex*

Response variable	Means		Standard error	p-value
	Girdling	Control		
<i>Survival (%)</i>				
Pre-treatment	100	100	0.000	1.00
1 yr post-treatment	99	99	1.135	1.00
3 yr post-treatment	95	97	0.000	0.00*
5 yr post-treatment	90	97	0.653	0.02*
<i>Mortality due to Armillaria (%)</i>				
Pre-treatment	0	0	0.000	1.00
1 yr post-treatment	1	1	1.135	1.00
3 yr post-treatment	5	3	0.654	0.18
5 yr post-treatment	8	3	1.133	0.07*
<i>Stem diameter (cm)</i>				
Pre-treatment	6.55	5.93	0.468	0.44
1 yr post-treatment	7.98	6.84	0.697	0.37
3 yr post-treatment	9.28	7.65	0.665	0.22
5 yr post-treatment	10.71	8.68	0.518	0.11
<i>Diameter increment (cm)</i>				
1 yr post-treatment	0.97	0.67	0.099	0.14
3 yr post-treatment	0.67	0.43	0.027	0.03*
5 yr post-treatment	0.71	0.54	0.058	0.18
<i>Height (cm)</i>				
Pre-treatment	297.9	286.3	13.250	0.62
1 yr post-treatment	361.3	351.4	12.726	0.64
3 yr post-treatment	427.6	406.9	13.064	0.38
5 yr post-treatment	495.8	451.9	14.580	0.17
<i>Leader length (cm)</i>				
Pre-treatment	29.9	30.0	1.341	0.96
1 yr post-treatment	34.3	36.7	2.201	0.52
3 yr post-treatment	29.9	26.0	1.949	0.29
5 yr post-treatment	34.9	22.3	1.388	0.02*
<i>Height:diameter ratio</i>				
Pre-treatment	52.8	56.0	1.277	0.21
1 yr post-treatment	52.7	58.6	1.094	0.06*
3 yr post-treatment	50.2	60.3	2.118	0.08*
5 yr post-treatment	49.9	60.6	2.678	0.11

p-values denoted with “*” were significant at $p \leq 0.10$ according to analysis of variance; $n = 3$. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates.

Standardized stem diameter distributions for Douglas-fir were more or less normal in both the treatment and control prior to the girdling treatment, but by year 5, there was a noticeable increase in the frequency of treated trees in larger diameter classes (Figure 149). ANOVA showed that differences between the treatment and the control were not statistically significant during the 5-year measurement period, but the distributions suggest that the difference may become more pronounced in future assessments. Standardized height distributions were approximately normal in the treatment and control, and they changed very little during the 5-year assessment period (Figure 150). This is consistent with ANOVA results showing that Douglas-fir did not become taller as a result of broadleaf girdling.

Competitive status Girdling gradually decreased overtopping of Douglas-fir seedlings, but, after 5 years, only half of the treated trees were free of vegetation and one-quarter were still overtopped (Figure 151). The percentage of trees in the treatment that were free of vegetation increased from 15% before treatment to 24% in year 1 and 48% in year 5. The percentage that were overtopped decreased from 50% before treatment to 21% in year 1, and that proportion remained constant through year 5. In the control, the competitive status of Douglas-fir did not change during the 5-year monitoring period (roughly one-fifth were free of vegetation, one-fifth were threatened, and three-fifths were overtopped).

Plant community response

Abundance Girdling killed almost all (>95%) treated broadleaf trees, greatly reducing broadleaf cover in comparison with the control (28.4 versus 9.2, $p = 0.09$ in year 1) (Table 135). The effects on cover were highly variable, however, and differences between the treatment and control were not significant in years 3 and 5, even though the average cover values in the treatment and control changed very little between the two assessments. By year 5, broadleaf cover was 9.7% in the girdling treatment compared with 34.5% in the control ($p = 0.18$) (Table 135, Figures 153 and 154).

Girdling did not have a large effect on modal broadleaf height because a few trees escaped treatment and because girdled trees died slowly. After 1 year, broadleaf height was 610.2 cm in the treatment compared with 621.2 cm in the control ($p > 0.10$). Although broadleaf height increased to 843.7 cm in

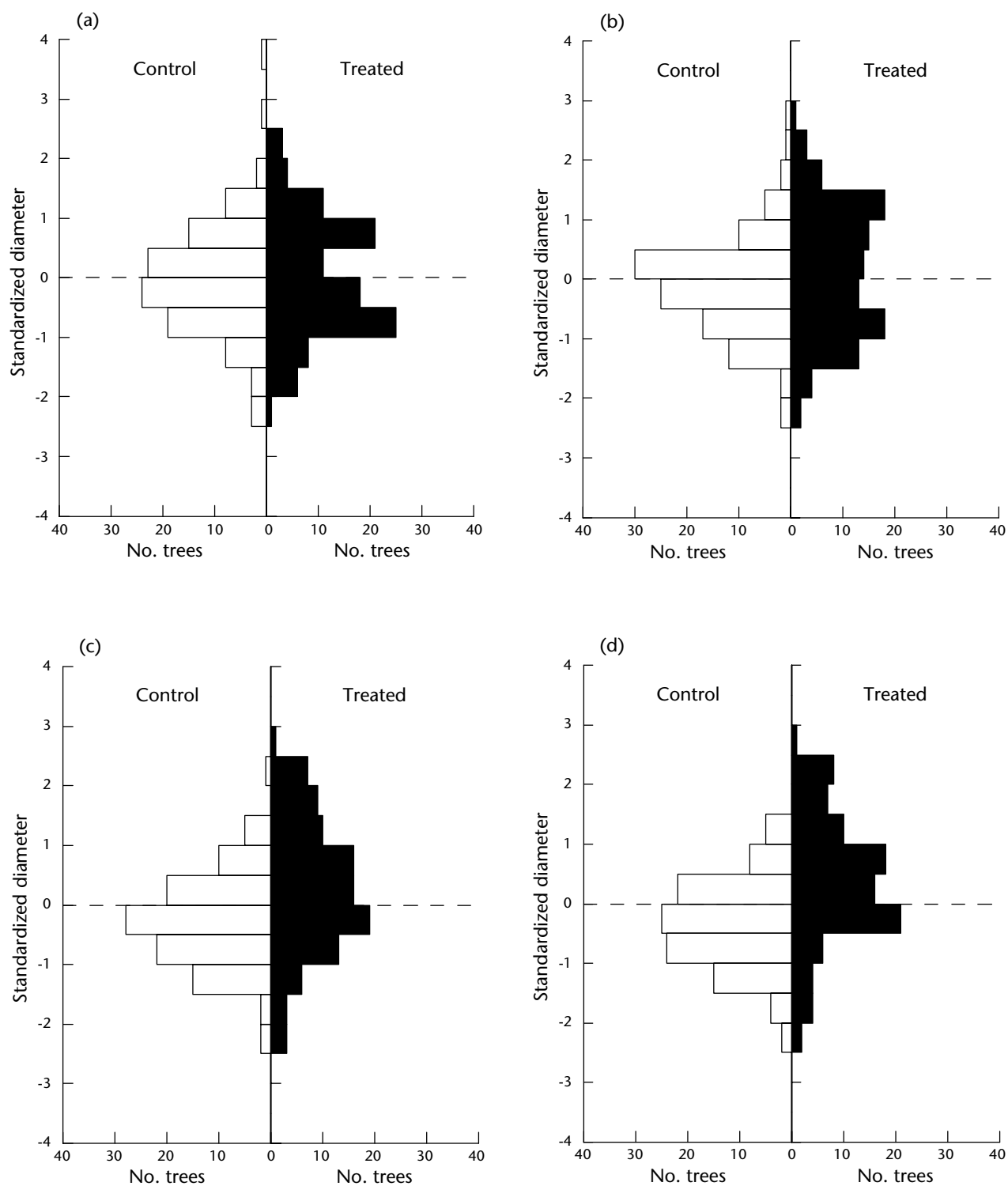


FIGURE 149 Frequency of control and treated trees in standardized diameter classes ($\mu = 0$; $s.d. = 1$; $n = 3$ for the control and treatment combined) for Douglas-fir in the ICH Mixed Broadleaf-Shrub Complex before and after girdling treatment. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 3 years post-treatment; (d) 5 years post-treatment.

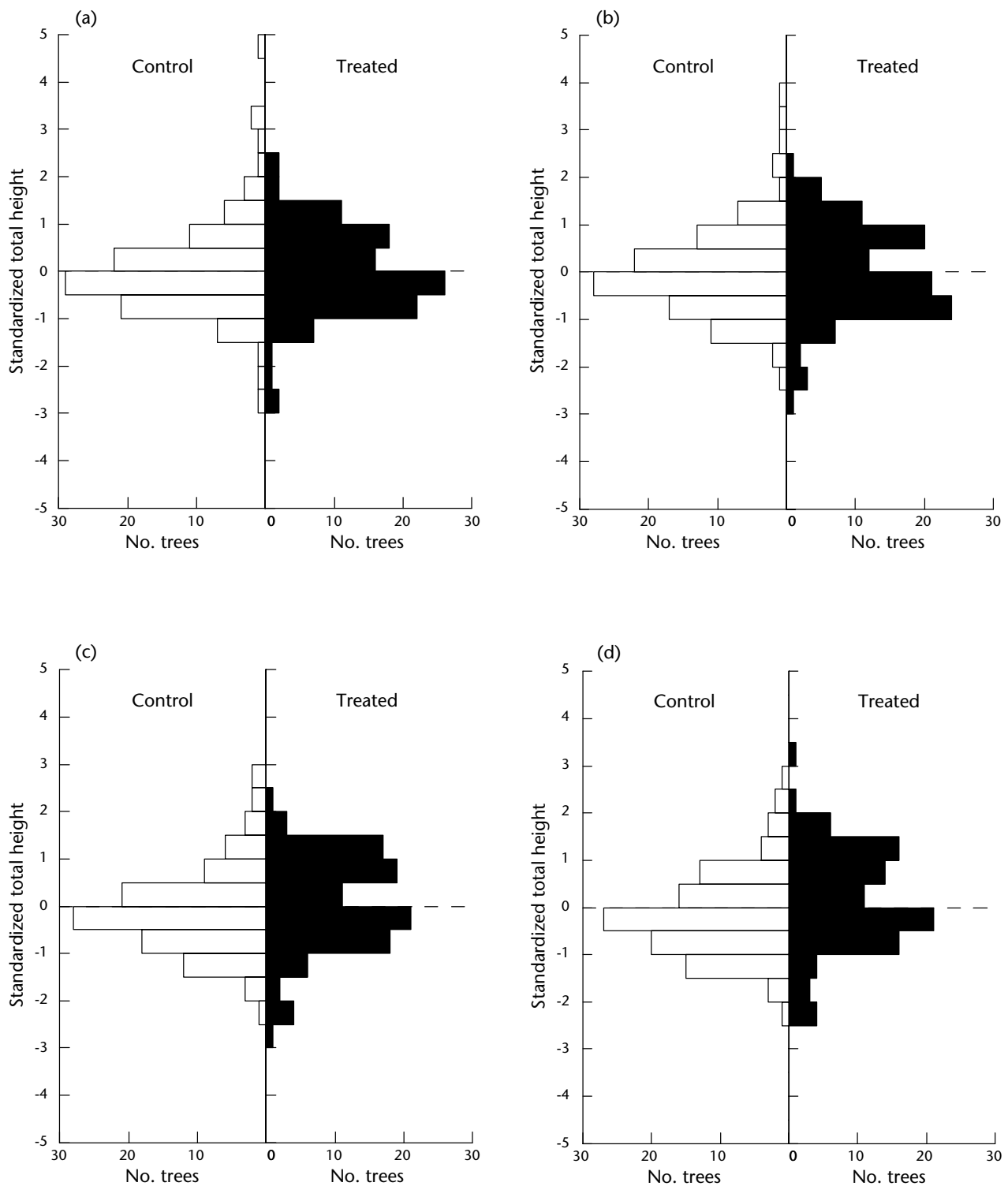


FIGURE 150 Frequency of control and treated trees in standardized total height classes ($\mu = 0$; $s.d. = 1$; $n = 3$ for the control and treatment combined) for Douglas-fir in the ICH Mixed Broadleaf-Shrub Complex before and after girdling treatment. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 3 years post-treatment; (d) 5 years post-treatment.

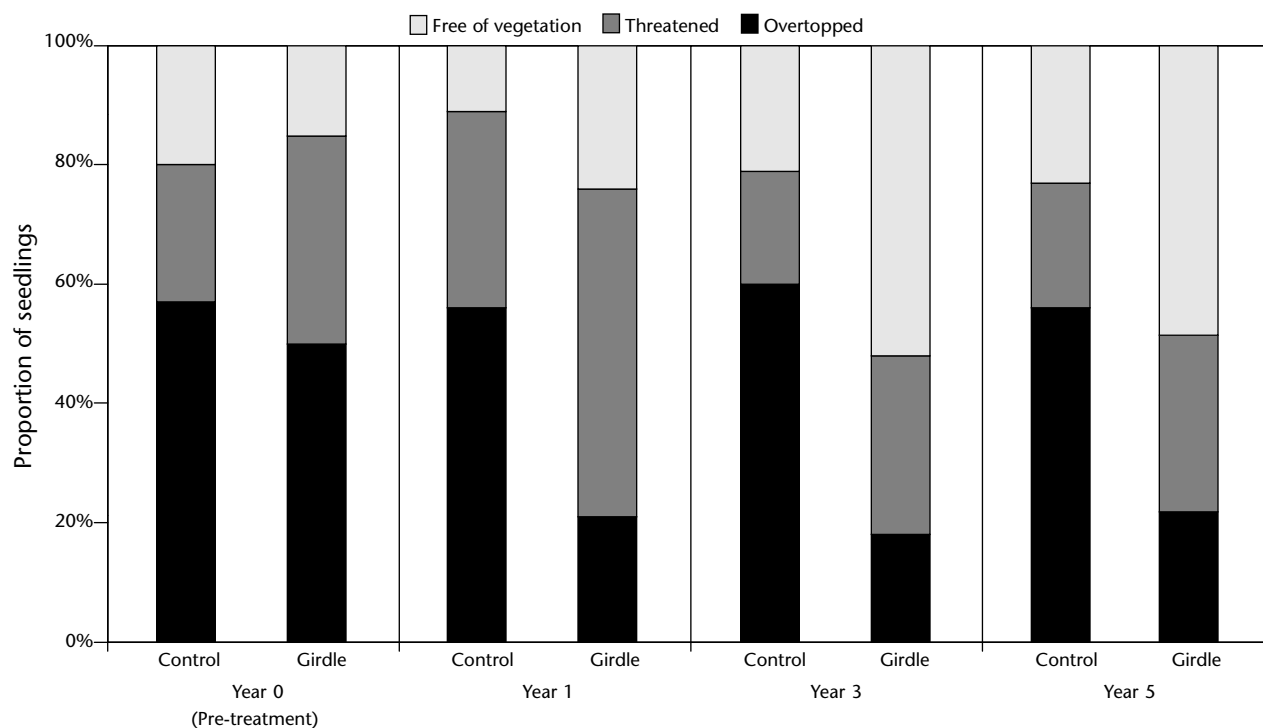


FIGURE 151 Comparison of Douglas-fir competitive status between the girdling treatment and control before, and 1, 3, and 5 years after, treatment of the ICH Mixed Broadleaf-Shrub Complex. Seedlings were classified as free of vegetation when the leader was well above surrounding vegetation, and classified as overtopped when the leader was overtopped. Threatened seedlings had leaders at approximately the same height as surrounding vegetation.

the control and decreased slightly to 569.1 cm in the treatment during the 5-year monitoring period, large variability between sites prevented the differences from being statistically significant ($p > 0.10$) (Figure 153). Brushing did not affect height or cover of understorey herbs and shrubs ($p > 0.10$).

Sprouting Few stems sprouted following girdling or injection of broadleaf trees with glyphosate. Three percent of treated stems had sprouts after 1 year and 11% had sprouts after 5 years. The stems that sprouted had an average of five sprouts that averaged 8 cm tall in year 1 and these thinned to two sprouts that averaged 205 cm tall by year 5 (Table 136).

Richness and diversity of individual species and structural vegetation groups Girdling of broadleaf stems had no effect on species richness in the *Mixed Broadleaf-Shrub Complex* ($p > 0.10$) (Table 137). The number of species increased between the pre-treatment (38 species) and fifth-year assessments (49 species), but the increase occurred equally in the girdling treatment and control. Girdling resulted in slightly greater species diversity compared with the control 1 year after brushing

($p = 0.07$ for H, $p = 0.03$ for SDI), but the difference had disappeared by year 3 ($p > 0.10$).

The richness of structural vegetation groups was similar in the girdling treatment and control throughout the 5-year monitoring period ($p > 0.10$) (Table 138), but diversity of structural groups was slightly greater in the control than in the girdling treatment 1 and 5 years after treatment ($p < 0.10$).

Girdling caused large decreases in the cover of paper birch, which was the main brushing target, on two of the three study sites. Partial reductions were apparent 1 year after treatment, but girdled stems died gradually, and the full impact on birch cover was not expressed until the third year after treatment. Trembling aspen and black cottonwood were also present on two of the three sites, and their cover decreased in a similar manner to birch over the 5-year monitoring period (Table 139). Cover of individual shrub and herb species did not decrease on more than one site, and although total herb cover increased on all sites following girdling, dandelion was the only species that increased on more than one site.



FIGURE 152 Effects of girdling on the Mixed Broadleaf-Shrub Complex and Douglas-fir (a) 1 year and (b) 5 years following treatment. The control (c) is shown 5 years post-treatment for comparison. Photo credit: Silver Ring Forestry Ltd.

Competition Thresholds for Douglas-fir, Lodgepole Pine, and Hybrid Spruce

Competition thresholds were derived for stem diameter of Douglas-fir, lodgepole pine, and interior spruce using all PROBE plantations dominated by the *Mixed Broadleaf-Shrub* Complex. For Douglas-fir, four sites were manually cut, three were treated with cut stump–glyphosate, three were girdled, and four were treated with other chemical applications ($n = 14$). For lodgepole pine, the analysis included two sites that were manually brushed and one that received a glyphosate spray treatment ($n = 3$). For interior spruce, two sites were manually cut and one was sprayed with glyphosate ($n = 3$). Almost all sites occurred in the ICH zone, and a few occurred in wetter subzones of the IDF zone (see site descriptions in this section and in Appendix 2). The range in plantation ages was 2–17 years for Douglas-fir (Table 140), 3–11 years for lodgepole pine (Table 141), and 1–13 years

for interior spruce (Table 142). Thresholds were based on broadleaf density (stems/ha), percent cover, and the index CRH, where $CRH = (\text{broadleaf cover} * \text{modal broadleaf height}) / \text{seedling height}$. The dominant broadleaf species was paper birch.

The density thresholds for Douglas-fir (Table 140), lodgepole pine (Table 141), and interior spruce (Table 142) stem diameter averaged 3664, 3367, and 2500 stems/ha, respectively. Cover thresholds averaged 28, 18, and 20%, and CRH thresholds averaged 39, 15, and 27, for Douglas-fir, lodgepole pine, and interior spruce, respectively. There were no clear trends in threshold changes with plantation age. Density and cover thresholds for all conifer species were diffuse on most sites and sharp on a few; however, conifer stem diameter consistently decreased above the threshold values. In contrast, CRH thresholds were sharp on most sites. Below all thresholds, conifer diameter was highly variable (e.g., Figure 155).

The proportion of conifers that occurred above

TABLE 135 *Cover and height of vegetation in the ICH Mixed Broadleaf-Shrub Complex before and after girdling in Douglas-fir plantations*

Response variable	Means		Standard error	p-value	Response variable	Means		Standard error	p-value
	Girdling	Control				Girdling	Control		
All vegetation					Shrubs				
Cover (%)					Cover (%)				
Pre-treatment	77.7	79.9	2.182	0.54	Pre-treatment	27.4	30.0	3.073	0.61
1 yr post-treatment	85.8	88.6	0.665	0.10*	1 yr post-treatment	43.9	54.7	6.015	0.33
3 yr post-treatment	86.7	90.0	1.987	0.36	3 yr post-treatment	54.9	58.7	3.352	0.51
5 yr post-treatment	87.8	91.7	1.017	0.11	5 yr post-treatment	no data	no data		
Height (cm)					Height (cm)				
Pre-treatment	547.1	511.7	51.110	0.67	Pre-treatment	103.2	117.2	17.730	0.63
1 yr post-treatment	214.1	494.0	57.205	0.07*	1 yr post-treatment	82.4	130.9	22.493	0.27
3 yr post-treatment	137.9	597.8	107.307	0.09*	3 yr post-treatment	83.2	108.8	11.192	0.25
5 yr post-treatment	456.9	736.7	73.414	0.11	5 yr post-treatment	no data	no data		
Broadleaf trees					Herbs				
Cover (%)					Cover (%)				
Pre-treatment	22.7	26.3	1.893	0.32	Pre-treatment	34.8	32.7	2.266	0.59
1 yr post-treatment	9.2	28.4	4.499	0.09*	1 yr post-treatment	44.6	27.1	4.494	0.11
3 yr post-treatment	7.9	32.9	6.545	0.11	3 yr post-treatment	47.9	30.4	2.568	0.04*
5 yr post-treatment	9.7	34.5	8.828	0.18	5 yr post-treatment	45.2	36.1	7.639	0.49
Height (cm)					Height (cm)				
Pre-treatment	648.6	559.4	24.463	0.12	Pre-treatment	83.8	104.8	18.860	0.51
1 yr post-treatment	610.2	621.2	92.878	0.94	1 yr post-treatment	56.9	48.9	6.870	0.50
3 yr post-treatment	544.6	803.8	123.279	0.28	3 yr post-treatment	51.4	69.3	11.937	0.40
5 yr post-treatment	569.1	843.7	121.244	0.25	5 yr post-treatment	56.2	42.0	6.919	0.28

p-values denoted with “*” were significant at $p \leq 0.10$ according to analysis of variance; $n = 3$. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates.

TABLE 136 *Sprouting characteristics of paper birch in the ICH Mixed Broadleaf-Shrub Complex following girdling in Douglas-fir plantations*

Response variable	Mean
<i>Proportion of stumps with sprouts</i>	
1 yr post-treatment	3
3 yr post-treatment	14
5 yr post-treatment	11
<i>Number of sprouts per stump</i>	
1 yr post-treatment	5
3 yr post-treatment	7
5 yr post-treatment	2
<i>Sprout length (cm)</i>	
1 yr post-treatment	8
3 yr post-treatment	78
5 yr post-treatment	205

the density thresholds (stems/ha) was 19–37% of all trees (treated and control), 20–39% of control trees, and 15–51% of treated trees. More than half the treated trees (45–85%) and half the control trees (49–80%) fell below the density thresholds. For cover and CRH indices, 29–39% of all trees, 51–62% of control trees, and 2–20% of treated trees occurred above the thresholds. Most treated trees fell below the cover and CRH thresholds (82–98%), whereas less than half the control trees (37–49%) fell below them. These results suggest that conifer response was more sensitive to overall broadleaf cover and height relations than to numbers of individual broadleaf neighbours (i.e., conifer diameter declined at relatively low levels of broadleaf cover and CRH, but was insensitive to a wide range in broadleaf densities). The higher density

thresholds did not reflect the increase in number of individual broadleaf stems following manual cutting because density thresholds were derived using control plots only.

Brushing was successful at reducing broadleaf cover and CRH below the thresholds for most treated conifers. Most untreated conifers occurred above the cover and CRH thresholds, although many also naturally occurred in competitive environments below the thresholds. In contrast, only half the treated trees fell below the density thresholds. Cut stump–glyphosate and, to a much lesser degree, manual treatments significantly improved mean diameter as well as diameter distributions of Douglas-fir, whereas girdling had no significant effect. Manual cutting improved lodgepole pine mean diameter and diameter distributions to a greater degree than it did for Douglas-fir. On average, 9% of treated pine and 6% of treated Douglas-fir that were growing in neighbourhoods below the thresholds achieved $\geq 80\%$ of the maximum diameter measured on the sites. The effects of manual cutting and glyphosate spray on spruce diameter distributions appeared variable, and effects on mean diameter could not be statistically evaluated because of inadequate replication. Approximately 10% of treated spruce growing in neighbourhoods below the thresholds achieved $\geq 80\%$ of the maximum diameter measured on the sites.

Linear regressions of Douglas-fir diameter versus competition index were statistically significant on nine of 14 sites for broadleaf cover, seven of 14 sites for broadleaf density, and all sites for CRH ($p < 0.10$) (Table 140). The range in adjusted r^2 values was 0.04–0.43 for broadleaf density, 0.03–0.46 for broadleaf cover, and 0.05–0.46 for CRH (significant regressions only). The slopes of the regressions (β_1) were moderately steep for broadleaf cover (–0.001 to –0.094), very shallow for broadleaf density (0 to –0.002), and shallow to steep for CRH (–0.003 to –0.137) compared with other complexes.

Regressions were similar for lodgepole pine and interior spruce. Linear regressions were statistically significant on two-thirds of the sites for broadleaf cover and density, and all sites for CRH ($p < 0.10$). The range in adjusted r^2 values was 0.02–0.31 for broadleaf cover, 0.01–0.18 for broadleaf density, and 0.06–0.36 for CRH (significant regressions only). The slopes of the regressions (β_1) were moderately steep for broadleaf cover (–0.016 to –0.049), flat for broadleaf density (0), and shallow to moderate for

CRH (–0.006 to –0.040) compared with other complexes. Fitting a negative exponential function to the diameter–CRH relationships did not improve the adjusted r^2 values. These results suggest that broadleaf competition, as measured by all of the indices, is moderately important and moderately intense for Douglas-fir, lodgepole pine, and interior spruce.

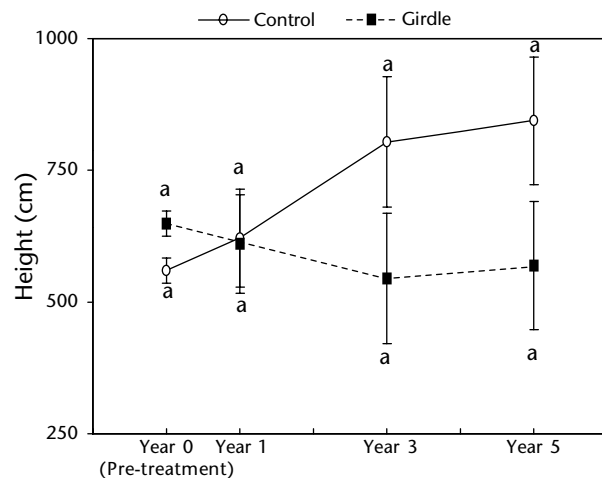


FIGURE 153 Comparison of mean broadleaf height between the girdling treatment and control before, and 1, 3, and 5 years after, treatment of the ICH Mixed Broadleaf-Shrub Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance ($\alpha = 0.10$).



FIGURE 154 Canopy of Mixed Broadleaf-Shrub in (a) the treatment and (b) the control 5 years following girdling. Photo credit: Silver Ring Forestry Ltd.

TABLE 137 Richness and diversity of vascular plant species in the ICH Mixed Broadleaf-Shrub Complex before and after girdling in Douglas-fir plantations

Response variable	Means		Standard error	p-value
	Girdling	Control		
<i>Richness</i>				
Pre-treatment	36.00	40.33	1.312	0.14
1 yr post-treatment	47.33	48.00	2.321	0.86
3 yr post-treatment	49.67	43.67	5.888	0.55
5 yr post-treatment	46.50	52.50	0.707	0.11
<i>Shannon-Weaver Diversity Index</i>				
Pre-treatment	2.43	2.37	0.053	0.52
1 yr post-treatment	2.44	2.34	0.021	0.07*
3 yr post-treatment	2.33	2.28	0.148	0.82
5 yr post-treatment	2.37	2.47	0.086	0.55
<i>Simpson's Diversity Index</i>				
Pre-treatment	0.86	0.84	0.013	0.29
1 yr post-treatment	0.85	0.82	0.004	0.03*
3 yr post-treatment	0.83	0.82	0.022	0.80
5 yr post-treatment	0.84	0.86	0.008	0.42

p-values denoted with “*” were significant at $p \leq 0.10$ according to analysis of variance; $n = 3$. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates.

TABLE 138 Richness and diversity of structural vegetation groups in the ICH Mixed Broadleaf-Shrub Complex before and after girdling in Douglas-fir plantations

Response variable	Means		Standard error	p-value
	Girdling	Control		
<i>Richness</i>				
Pre-treatment	7.67	8.00	0.236	0.42
1 yr post-treatment	7.67	8.00	0.236	0.42
3 yr post-treatment	7.67	8.00	0.236	0.42
5 yr post-treatment	7.50	8.00	0.354	0.50
<i>Shannon-Weaver Diversity Index</i>				
Pre-treatment	1.63	1.64	0.030	0.81
1 yr post-treatment	1.57	1.59	0.002	0.02*
3 yr post-treatment	1.50	1.59	0.051	0.36
5 yr post-treatment	1.55	1.68	0.010	0.07*
<i>Simpson's Diversity Index</i>				
Pre-treatment	0.77	0.76	0.011	0.80
1 yr post-treatment	0.75	0.74	0.003	0.19
3 yr post-treatment	0.72	0.75	0.020	0.43
5 yr post-treatment	0.74	0.78	0.001	0.04*

p-values denoted with “*” were significant at $p \leq 0.10$ according to analysis of variance; $n = 3$. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates.

TABLE 139 Vascular plant species that exhibited trends of increasing cover, decreasing cover, or no change in cover following girdling of the ICH Mixed Broadleaf-Shrub Complex in Douglas-fir plantations. Species included in the list exhibited a common trend in the treated plots of at least two study sites, based on a subjective evaluation (see Methods, Section 3).

	Increasing cover	Decreasing cover	No change in cover
Broadleaves		<i>Betula papyrifera</i> <i>Populus tremuloides</i> <i>Populus trichocarpa</i>	
Tall shrubs			<i>Salix</i> spp.
Low shrubs			<i>Ribes lacustre</i> <i>Spirea betulifolia</i>
Herbs	<i>Taraxacum officinale</i>		<i>Anaphalis margaritacea</i> <i>Cornus canadensis</i> <i>Disporum hookeri</i> <i>Galium triflorum</i> <i>Hieracium albiflorum</i> <i>Orthilia secunda</i>

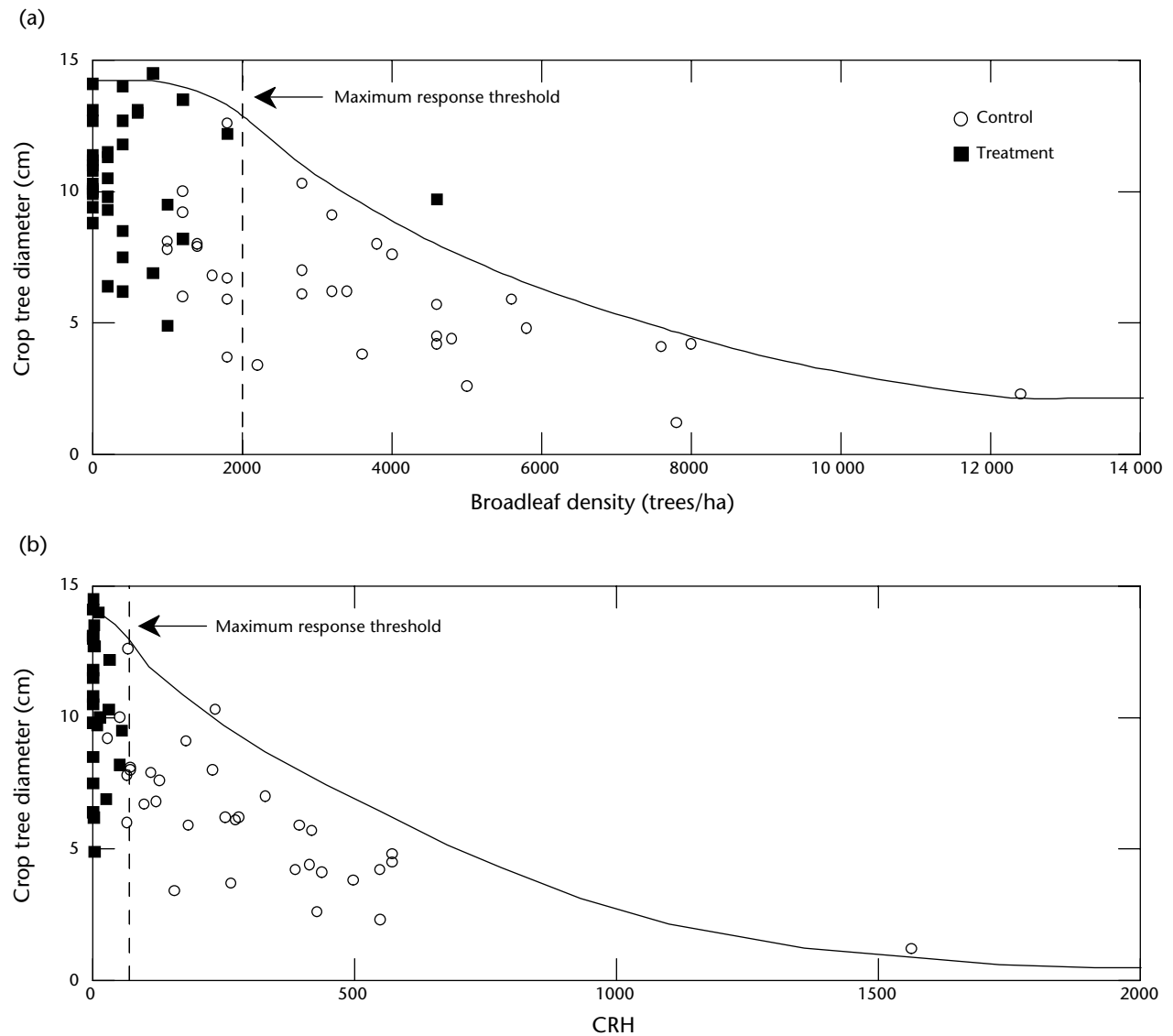


FIGURE 155 Relationship between stem diameter of Douglas-fir growing amongst the ICH Mixed Broadleaf-Shrub Complex and (a) broadleaf density or (b) CRH, where $CRH = (\text{broadleaf cover} * \text{broadleaf modal height}) / \text{Douglas-fir height}$. Data points include both treatment and control subplots for PROBE site 2 ($n = 68$). Similar relationships were found for lodgepole pine and hybrid spruce. Maximum response threshold is the point below which conifer diameter is independent of decreasing neighbourhood abundance, and above which conifer performance declines sharply in response to increasing neighbourhood abundance (after Wagner et al. 1989).

TABLE 140 Competition thresholds, regression equation parameter estimates, p-values, and adjusted r^2 values for predicting Douglas-fir stem diameter from the competition indices, broadleaf density, broadleaf cover, and CRH, in the Mixed Broadleaf-Shrub Complex in the ICH zone

Site	# of trees in the regression (n)	Conifer age (years)	Density threshold (stems/ha)	Linear regression equation predicting diameter from broadleaf density ^a	Adjusted r^2 for linear regression predicting diameter from broadleaf density ^a	p-value for linear regression predicting diameter from broadleaf density ^a	Cover threshold (%)	Linear regression equation predicting diameter from broadleaf cover ^a
1	70	7	12000	$y = 5.301 - 0.000 x$	0.08	0.01	35	$y = 5.776 - 0.022 x$
2	68	12	2000	$y = 10.237 - 0.001 x$	0.43	0.00	10	$y = 10.538 - 0.065 x$
3	70	6	2000	$y = 3.983 - 0.000 x$	0.00	0.95	15	$y = 4.294 - 0.019 x$
7	68	7	3500	$y = 6.888 - 0.000 x$	0.10	0.01	20	$y = 7.211 - 0.026 x$
12	50	6	3200	$y = 6.502 - 0.000 x$	0.00	0.37	25	$y = 7.271 - 0.032 x$
15	65	7	1700	$y = 3.987 - 0.000 x$	0.05	0.05	15	$y = 4.451 - 0.024 x$
21	70	5	2300	$y = 4.172 - 0.000 x$	0.00	0.41	25	$y = 4.607 - 0.029 x$
29	70	6	5000	$y = 4.252 - 0.000 x$	0.00	0.91	50	$y = 5.399 - 0.026 x$
30	67	17	3200	$y = 22.932 - 0.002 x$	0.07	0.02	20	$y = 22.475 - 0.094 x$
62	70	2	2700	$y = 1.450 - 0.000 x$	0.00	0.37	10	$y = 1.520 - 0.002 x$
68	72	8	2900	$y = 3.155 - 0.000 x$	0.00	0.69	50	$y = 3.197 - 0.001 x$
69	106	9	2000	$y = 4.956 - 0.000 x$	0.00	0.32	50	$y = 4.970 - 0.024 x$
86	107	3	7000	$y = 6.291 - 0.000 x$	0.04	0.02	45	$y = 7.267 - 0.035 x$
126	70	7	1800	$y = 3.112 - 0.000 x$	0.06	0.03	15	$y = 3.049 - 0.033 x$
mean			3664				28 (4)	
(s.e.)			(748)					

^a General form of linear equation is: $y = a + b x$, where y is Douglas-fir stem diameter, x is broadleaf cover or density, a is the intercept, and b is the slope.

^b General form of linear equation is: $y = a + b x$, where y is Douglas-fir stem diameter, x is CRH, a is the intercept, and b is the slope. CRH = (broadleaf cover * broadleaf modal height)/Douglas-fir total height.

^c General form of non-linear equation is $y = a e^{(b/x)}$, where y is Douglas-fir stem diameter, x is CRH, a is the intercept, and b is the asymptote at high CRH.

TABLE 140 *Continued*

Adjusted r^2 for linear regression predicting diameter from broadleaf cover ^a	p-value for linear regression predicting diameter from broadleaf cover ^a	CRH threshold	Linear regression equation predicting diameter from CRH ^b	Adjusted r^2 for linear regression predicting diameter from CRH ^b	p-value for linear regression predicting diameter from CRH ^b	Non-linear regression equation predicting diameter from CRH ^c	Adjusted r^2 for non-linear regression predicting diameter from CRH ^c
0.03	0.07	20	$y = 5.995 - 0.009 x$	0.33	0.00		
0.46	0.00	30	$y = 9.702 - 0.009 x$	0.46	0.00		
0.01	0.23	45	$y = 4.407 - 0.006 x$	0.19	0.00		
0.17	0.00	41	$y = 7.049 - 0.009 x$	0.34	0.00		
0.11	0.01	20	$y = 7.258 - 0.019 x$	0.29	0.00	$y = 7.439 e^{(-0.003 \cdot x)}$	0.31
0.20	0.00	16	$y = 4.312 - 0.005 x$	0.30	0.00		
0.08	0.01	36	$y = 4.496 - 0.007 x$	0.17	0.00		
0.06	0.02	50	$y = 5.362 - 0.009 x$	0.38	0.00		
0.00	0.33	30	$y = 23.851 - 0.137 x$	0.09	0.00		
0.00	0.85	24	$y = 1.667 - 0.003 x$	0.05	0.07		
0.00	0.91	110	$y = 3.531 - 0.003 x$	0.06	0.01		
0.01	0.18	58	$y = 5.045 - 0.024 x$	0.12	0.00		
0.14	0.00	50	$y = 6.955 - 0.011 x$	0.46	0.02		
0.09	0.01	14	$y = 2.905 - 0.003 x$	0.18	0.00		
		39 (6)					

TABLE 141 *Competition thresholds, regression equation parameter estimates, p-values, and adjusted r² values for predicting lodgepole pine stem diameter from the competition indices, broadleaf density, broadleaf cover, and CRH, in the Mixed Broadleaf-Shrub Complex in the ICH zone*

Site	# of trees in the regression (n)	Conifer age (years)	Density threshold (stems/ha)	Linear regression equation predicting diameter from broadleaf density ^a	Adjusted r ² for linear regression predicting diameter from broadleaf density ^a	p-value for linear regression predicting diameter from broadleaf density ^a	Cover threshold (%)	Linear regression equation predicting diameter from broadleaf cover ^a
46	70	3	6000	$y = 4.414 - 0.000 x$	0.10	0.02	22	$y = 4.382 - 0.017 x$
41	67	11	1300	$y = 9.310 - 0.000 x$	0.01	0.21	15	$y = 11.013 - 0.049 x$
51	68	5	2800	$y = 5.207 - 0.000 x$	0.18	0.00	16	$y = 5.875 - 0.024 x$
mean			3367				18 (2)	
(s.e.)			(1386)					

^a General form of linear equation is: $y = a + b x$, where y is pine stem diameter, x is broadleaf cover or density, a is the intercept, and b is the slope.

^b General form of linear equation is: $y = a + b x$, where y is pine stem diameter, x is CRH, a is the intercept, and b is the slope. $CRH = (\text{broadleaf cover} * \text{broadleaf modal height}) / \text{pine total height}$.

^c General form of non-linear equation is $y = a e^{(b x)}$, where y is pine stem diameter, x is CRH, a is the intercept, and b is the asymptote at high CRH.

TABLE 142 *Competition thresholds, regression equation parameter estimates, p-values, and adjusted r² values for predicting hybrid spruce stem diameter from the competition indices, broadleaf density, broadleaf cover, and CRH, in the Mixed Broadleaf-Shrub Complex in the ICH zone*

Site	# of trees in the regression (n)	Conifer age (years)	Density threshold (stems/ha)	Linear regression equation predicting diameter from broadleaf density ^a	Adjusted r ² for linear regression predicting diameter from broadleaf density ^a	p-value for linear regression predicting diameter from broadleaf density ^a	Cover threshold (%)	Linear regression equation predicting diameter from broadleaf cover ^a
5	70	13	2900	$y = 7.922 - 0.000 x$	0.00	0.40	3	$y = 7.823 - 0.019 x$
9	67	1	2000	$y = 3.440 - 0.000 x$	0.12	0.02	3	$y = 3.666 - 0.033 x$
39	72	13	2500	$y = 8.907 - 0.000 x$	0.07	0.01	54	$y = 10.272 - 0.016 x$
mean			2500				20 (17)	
(s.e.)			(260)					

^a General form of linear equation is: $y = a + b x$, where y is spruce stem diameter, x is broadleaf cover or density, a is the intercept, and b is the slope.

^b General form of linear equation is: $y = a + b x$, where y is spruce stem diameter, x is CRH, a is the intercept, and b is the slope. $CRH = (\text{broadleaf cover} * \text{broadleaf modal height}) / \text{spruce total height}$.

^c General form of non-linear equation is: $y = a e^{(b x)}$, where y is spruce stem diameter, x is CRH, a is the intercept, and b is the asymptote at high CRH.

TABLE 141 *Continued*

Adjusted r^2 for linear regression predicting diameter from broadleaf cover ^a	p-value for linear regression predicting diameter from broadleaf cover ^a	CRH threshold	Linear regression equation predicting diameter from CRH ^b	Adjusted r^2 for linear regression predicting diameter from CRH ^b	p-value for linear regression predicting diameter from CRH ^b	Non-linear regression equation predicting diameter from CRH ^c	Adjusted r^2 for non-linear regression predicting diameter from CRH ^c
0.20	0.00	15	$y = 4.428 - 0.021 x$	0.32	0.00	$y = 4.451 e^{(-0.006^*x)}$	0.34
0.09	0.01	25	$y = 10.791 - 0.040 x$	0.21	0.00		
0.05	0.04	5	$y = 5.799 - 0.015 x$	0.09	0.01		
		15 (6)					

TABLE 142 *Continued*

Adjusted r^2 for linear regression predicting diameter from broadleaf cover ^a	p-value for linear regression predicting diameter from broadleaf cover ^a	CRH threshold	Linear regression equation predicting diameter from CRH ^b	Adjusted r^2 for linear regression predicting diameter from CRH ^b	p-value for linear regression predicting diameter from CRH ^b	Non-linear regression equation predicting diameter from CRH ^c	Adjusted r^2 for non-linear regression predicting diameter from CRH ^c
0.00	0.51	37	$y = 8.089 - 0.023 x$	0.06	0.02	$y = 8.120 e^{(-0.003^*x)}$	0.07
0.31	0.00	0	$y = 3.534 - 0.006 x$	0.36	0.00		
0.02	0.11	45	$y = 10.256 - 0.012 x$	0.12	0.00		
		27 (14)					

The *Mixed Broadleaf-Shrub* Complex is widespread in the ICH and IDF zones of the southern interior, particularly on areas affected by logging and wild-fire. The vast majority of sites dominated by broadleaves receive brushing treatments within a decade of planting, both to increase light availability to seedlings and to ensure that free-growing requirements are met (B.C. Ministry of Forests 1995a, 2000). A variety of brushing methods have been applied to this community, including manual cutting, girdling, cut stump–glyphosate, cut–spray glyphosate, foliar glyphosate spray, injection of broadleaves with glyphosate capsules, and basal application of triclopyr. Here we discuss fifth-year responses of Douglas-fir and vegetation to manual cutting, girdling, and cut stump–glyphosate treatment, and fifth-year responses of lodgepole pine and vegetation to manual cutting. These results focus on broadcast application of treatments because partial removal of broadleaf stems was uncommon at the time our studies were initiated.

Conifer Response

Survival

Survival of Douglas-fir and lodgepole pine seedlings growing amongst the *Mixed Broadleaf-Shrub* Complex was good to excellent (85–97%) during the 5-year measurement period, which we had anticipated because the majority of seedlings were well established (ranging in age from 3 to 17 years old) and healthy at the time of brushing. Seedling vigour generally improved in response to brushing, but survival was not increased any of the brushing treatments (manual cutting, girdling, cut stump–glyphosate). However, mortality from *Armillaria* root disease increased among Douglas-fir in the girdling treatment and among lodgepole pine in the manual cutting treatment in comparison with the controls. Eight percent of Douglas-fir in the girdling treatment died from *Armillaria*, compared with 3% of control seedlings. This translated into a significant difference in overall survival (90% in the girdling treatment versus 97% in the control) because *Armillaria* was virtually the only mortality agent. A greater proportion of lodge-pole pine also died from *Armillaria* root disease in the manual cutting treatment than in its control (9 versus 2%

in year 5), but overall survival was not significantly affected because a greater proportion of control than treatment seedlings died from other causes (deer damage, weevils, and vegetation competition).

Greater incidence of *Armillaria* root disease following brushing has also been observed in other studies. For example, 3 years after manual and chemical brushing on a southern interior ICH site, Simard and Heineman (1996c) found 3–5% *Armillaria*-related mortality among Douglas-fir in control and chemical treatments and 15% in the cutting treatment. After 9 years, when seedlings were 13 years old, *Armillaria* had caused 20–23% mortality in the two brushing treatments, compared to 15% in the control. In another study, the incidence of *Armillaria* infection in 25-year-old ICH zone Douglas-fir plantations was twice as high on manually brushed as on unbrushed cutblocks (Woods 1994). Brushing the *Mixed Broadleaf-Shrub* Complex has not consistently increased the incidence of *Armillaria*-related seedling mortality, however. For instance, in our study, applying manual cutting and cut stump–glyphosate treatments in Douglas-fir plantations did not affect rates of mortality from *Armillaria* or overall seedling survival. Simard and Hannam (2000) likewise found that *Armillaria*-related mortality did not increase among spruce within 5 years of manual thinning or cut stump–glyphosate treatment (spruce were 13 years old at the time of assessment). Manual treatments may facilitate the spread of *Armillaria* root disease among conifers to a greater extent than chemical treatments (H. Merler, pers. comm., 2000). A possible explanation is that, although broadleaves are generally tolerant of *Armillaria*, the spread of the fungus through their root systems may be stimulated by treatments such as manual cutting, which stress but do not kill stems. Herbicide treatments, on the other hand, may induce chemical changes that make broadleaf roots less desirable hosts for the fungus. *Armillaria* can function as either a pathogen or a saprophyte; however, it is not a particularly competitive saprophyte, and is likely to be outcompeted by other, more aggressive species. Our results are compatible with this theory because increases in *Armillaria*-related mortality occurred in the manual cutting and girdling

treatments, but not in the cut stump–glyphosate treatment. We did not find that mortality caused by *Armillaria* had increased among Douglas-fir following manual cutting, possibly because seedlings were relatively young and small during the assessment period.

There are several possible mechanisms by which brushing may increase the spread of *Armillaria* in brushed birch stands (Simard 1998). These are: (1) increased inoculum loads through the creation of dead, dying, or stressed birch stumps, (2) increased continuity of susceptible conifer inoculum, (3) higher probability of infection of remaining susceptible conifer stems, (4) increased growth rates of remaining susceptible trees, resulting in faster root-to-root contact, and (5) negative effect on the health of the below ground microbial community, reducing the stand's overall resistance to infection. For example, DeLong (1999) found that the *Armillaria*-antagonistic rhizosphere bacterium *Pseudomonas fluorescens* was significantly less abundant in pure Douglas-fir stands than in mixed stands with paper birch. In our study, manual cutting increased the incidence of mortality from *Armillaria* among lodgepole pine but not among Douglas-fir. Pine exhibited a more pronounced growth response following brushing than did Douglas-fir, which because of pine's larger stature, suggests that greater root-to-root contact may have contributed to increased spread of the root disease. The various brushing treatments in our study also differed in their effects on the incidence of *Armillaria*-related mortality among Douglas-fir seedlings. Girdling increased the proportion of Douglas-fir that died from the root disease, but manual cutting and cut stump–glyphosate treatment had no effect. This is possibly related to the greater age and size of Douglas-fir in the girdling treatment (10–22 years old at the fifth-year assessment), since root spread and root-to-root contact would presumably be greater in older conifers and provide a more continuous pathway for *Armillaria* to spread from dying broadleaves.

Further monitoring is required to evaluate the relationship between brushing treatments and the incidence of *Armillaria*-related conifer mortality. Rates of mortality due to *Armillaria* in our study ranged from 0.4 to 2.2%/yr, which is similar to rates of 1–2%/yr reported by Morrison et al. (1991) for 5- to 10-year-old Douglas-fir stands. According to Woods (1994), rates of infection are likely to be

higher in the ICH than the IDF zone. There are insufficient long-term data to determine how *Armillaria* mortality rates change with stand age. However, the dynamics of the disease and infected stands suggest that rates may decrease once stands have outgrown the sapling stage (B. Van der Kamp, pers. comm., 1999).

Growth

Douglas-fir and lodgepole pine growth increased in response to all the brushing treatments applied to the *Mixed Broadleaf-Shrub* Complex in our study, but they required more than a single year to do so. Stem diameter responded in advance of height, which is consistent with the literature (e.g., Lanner 1985; Lanini and Radosevich 1986; Simard and Heineman 1996a, 1996c). As of year 5, conifer height had increased only in response to the cut stump–glyphosate treatment.

Douglas-fir

Douglas-fir growing among the *Mixed Broadleaf-Shrub* Complex exhibited a larger growth response following the cut stump–glyphosate treatment than following girdling or manual cutting. In general, the magnitude of the growth response corresponded with efficacy of the brushing treatment at reducing broadleaf abundance, which is consistent with observations from several of our unreplicated treatments (Mather and Simard 1998a, 1998f, 1998k, 1998p; Appendix 1). Five years after cut stump–glyphosate application, Douglas-fir stem diameter, stem diameter increment, height, leader length, and height:diameter ratio had all improved. Stem diameter and height were 52 and 25% greater, respectively, among treated than control seedlings. The girdling treatment also improved growth of Douglas-fir, but more slowly and to a lesser degree than the cut stump–glyphosate treatment. This is likely related to the more advanced age of seedlings, and to the fact that girdling reduced broadleaf abundance gradually. After 5 years, Douglas-fir leaders were 56% longer in the girdling treatment and stem diameter was on the verge of responding (10.71 cm in the treatment versus 8.68 cm in the control, $p = 0.11$). A similar Douglas-fir growth response occurred as a result of manual cutting, where there was a 14% increase in stem diameter and a 29% increase in leader length, and no improvement in height:diameter ratio. Figures 156, 157, and 158 illustrate the extent to which the various treatments

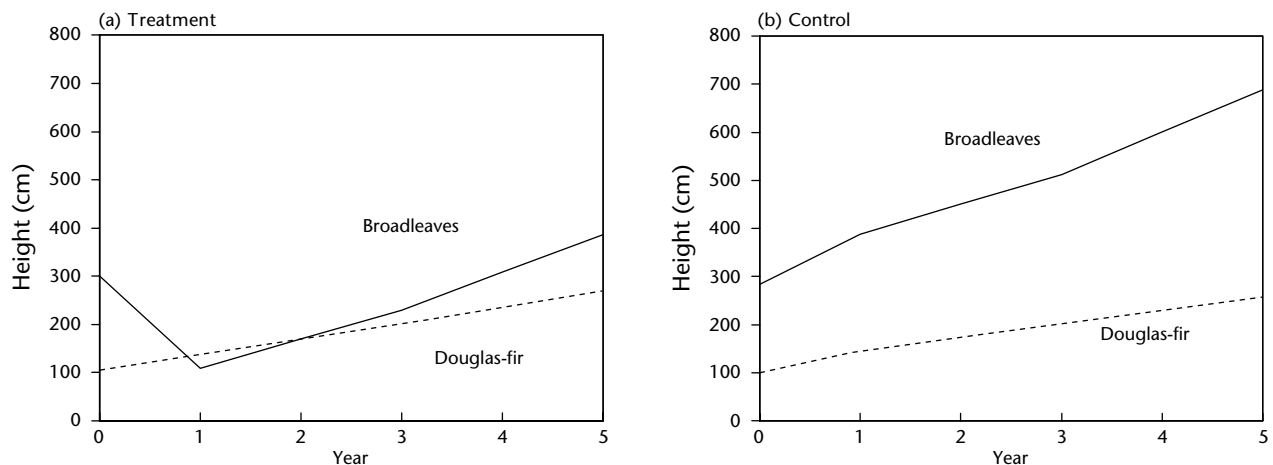


FIGURE 156 Comparison of average Douglas-fir and broadleaf height profiles in (a) the brushing treatment and (b) the control in the years following manual cutting in the ICH/IDF Mixed Broadleaf-Shrub Complex. Heights for years 2 and 4 were interpolated from actual data. Both treated and control Douglas-fir are expected to remain below the broadleaf canopy through the free-growing window.

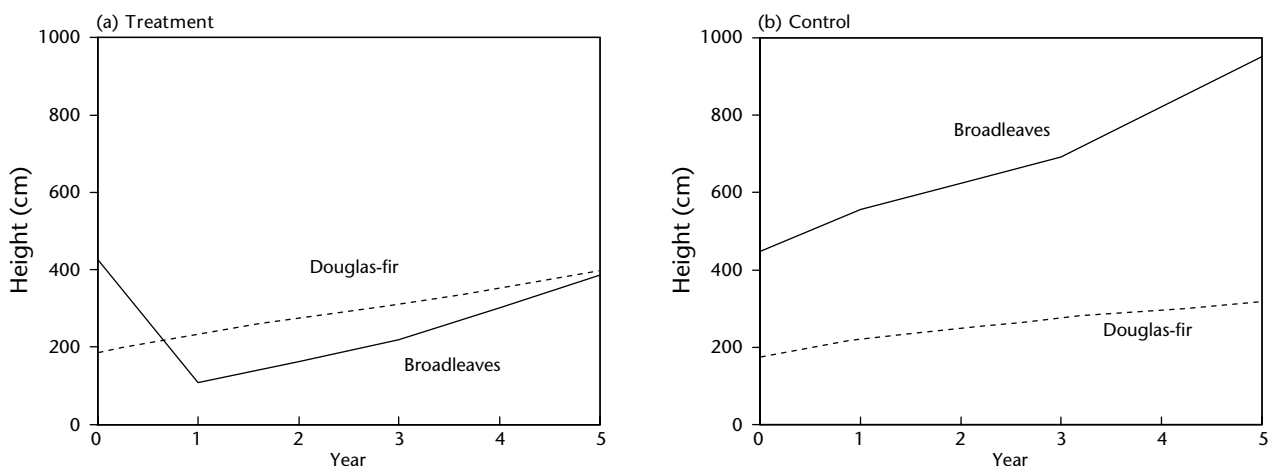


FIGURE 157 Comparison of average Douglas-fir and broadleaf height profiles in (a) the brushing treatment and (b) the control in the years following cut stump-glyphosate treatment in the ICH Mixed Broadleaf-Shrub Complex. Heights for years 2 and 4 were interpolated from actual data. Control Douglas-fir are expected to remain below the broadleaf canopy through the free-growing assessment period.

reduced the height of broadleaves relative to Douglas-fir, and help explain the difference in seedling responses to the cut stump-glyphosate and manual treatments. Figure 158 is somewhat misleading regarding girdling, however, because it illustrates the average height of the few broadleaf stems missed by girdling and does not show that broadleaf cover was substantially reduced.

Simard and Heineman (1996a) also found that Douglas-fir growth increased following chemical, but not manual, treatments. In that study, manual

cutting did not successfully reduce vegetation height below that of Douglas-fir, which may explain why seedlings did not respond to treatment. In comparison, broadcast glyphosate application reduced vegetation height well below that of conifers and resulted in a 31% increase in average stem diameter, but had no effect on height. Harper et al. (1998) studied the effects of multiple manual cutting treatments on an ICH *Mixed Broadleaf-Shrub* community, and found that average Douglas-fir stem diameter increased in response to treatment by

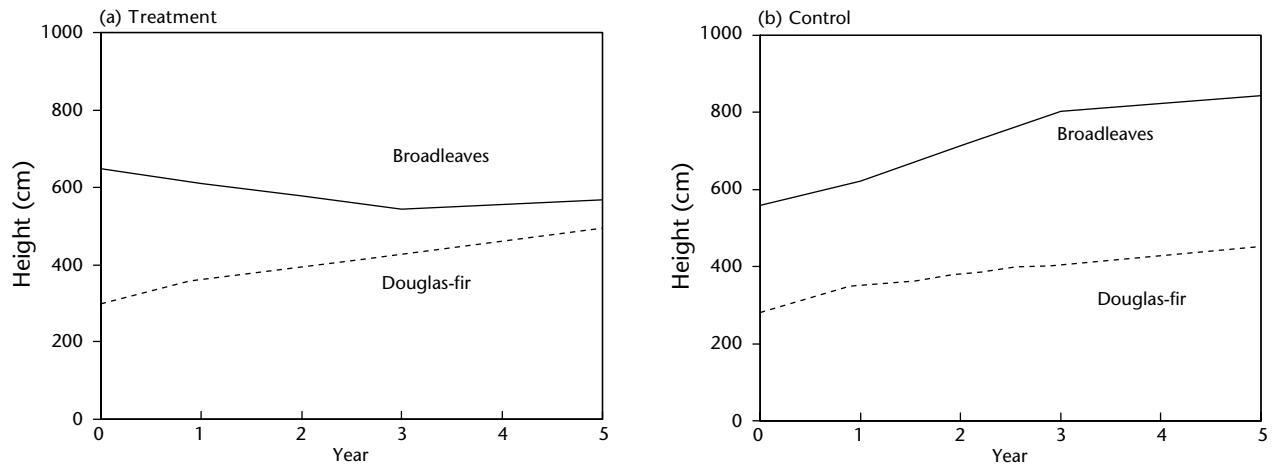


FIGURE 158 Comparison of average Douglas-fir and broadleaf height profiles in (a) the brushing treatment and (b) the control in the years following girdling in the ICH Mixed Broadleaf-Shrub Complex. Heights for years 2 and 4 were interpolated from actual data. Control Douglas-fir will remain below the broadleaf canopy through the free-growing assessment period.

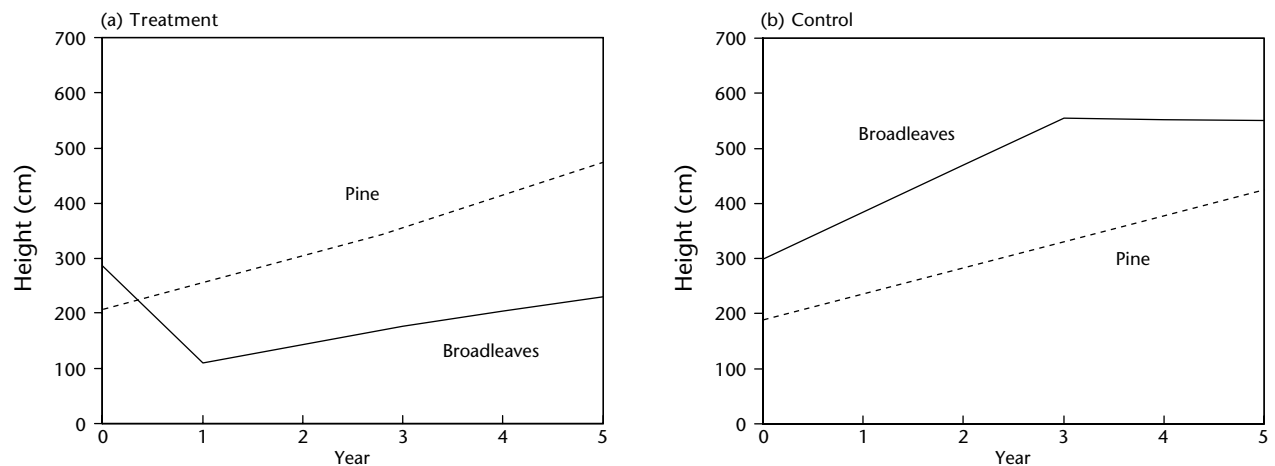


FIGURE 159 Comparison of average lodgepole pine and broadleaf height profiles in (a) the brushing treatment and (b) the control in the years following manual cutting in the ICH Mixed Broadleaf-Shrub Complex. Heights for years 2 and 4 were interpolated from actual data. Treated broadleaves remained shorter than pine during the 5-year measurement period, and are expected to remain shorter through the free-growing assessment period.

52–182% after 10 years, but differences between one, two, and three cutting passes were not significant. Cutting also improved stocking of Douglas-fir and reduced birch density. In yet another ICH study, average spruce diameter growth improved following cut stump-glyphosate and manual treatments that reduced birch abundance to 0 and 50 stems/ha, respectively, but not following a manual treatment that reduced birch density to 1000 stems/ha. None of the treatments affected average spruce leader

length or total height within 5 years of treatment (Simard and Hannam 2000). These studies, as well as ours, indicate that brushing treatments that reduce birch density and height for sustained periods of time result in the largest conifer diameter responses, but that height responses do not always occur.

Both cut stump-glyphosate and girdling resulted in decreased height:diameter ratios among Douglas-fir in our study. Regardless, ratios in the controls

were similar (slightly less than 60) to those reported by Cole and Newton (1987) in their least competitive treatment, and are not considered to reflect serious competitive stress. Cole and Newton's work took place in Oregon, where seedlings were only 5 years old, compared to a range of 8–22 years in our study.

Lodgepole pine

Stem diameter, diameter increment, and height:diameter ratio of lodgepole pine significantly increased within 3 years of manual cutting. There were no significant improvements in height by year 5, but the difference between treated and control trees was widening. Pine stem diameter was 37% greater in the treatment than in the control in year 5, which contributed to the difference in height:diameter ratio (56.0 in the treatment versus 68.5 in the control). Trees in the control were becoming increasingly spindly and their vigour was declining relative to those in the cutting treatment. Seedling growth responses following manual cutting were more pronounced among pine than Douglas-fir, probably because pine trees were able to maintain a height advantage over cut broadleaves (Figure 159), while Douglas-fir trees were overtaken within 2 years of cutting (Figure 156). In the northwestern interior ICH, young lodgepole pine growth exceeded that of several other conifer species when light levels were above 70% relative irradiance (Douglas-fir was not part of the study) (Coates and Burton 1999).

Plant Community Responses

Manual cutting

In both Douglas-fir and lodgepole pine plantations, manual cutting significantly reduced broadleaf abundance for at least 5 years. However, birch resprouted vigorously, and recovered to heights of 230 and 386 cm (approximately half the control heights) during that period. Nearly all cut stumps sprouted, and 67–85% of them still had an average of four to five sprouts after 5 years. Sprouts increased in height at average rates of 40–50 cm/yr during the measurement period, which was faster than Douglas-fir and approximately the same as lodgepole pine. The rapid recovery of the *Mixed Broadleaf-Shrub* Complex observed in our study corresponds with operational information summarized by others (Haeussler et al. 1990; Hart and

Comeau 1992). Simard and Heineman (1996a) found that birch on a mesic ICH site sprouted even more vigorously, reaching heights of more than 2 m within 3 years of manual cutting. On a nearby site, birch sprouted far less vigorously, however, recovering to less than 1 m tall after 5 years (Simard and Hannam 2000). Peterson et al. (1997) suggest that birch sprouting can be minimized if manual cutting is applied in June through August, possibly because carbohydrate reserves are lower than during the dormant season (Haeussler et al. 1990). In our study, cutting took place on dates in July through October.

Manual cutting of the *Mixed Broadleaf-Shrub* Complex caused short-lived reductions in height of understorey shrubs, probably because some were cut at the same time as broadleaf stems. There were no effects on shrub cover or abundance of the herb layer, which is typical of our results for other complexes dominated by broadleaves or tall shrubs (i.e., *Aspen* Complex, *Wet Alder* Complex, *Dry Alder* Complex), and also similar to the results of Simard and Heineman (1996a). Cutting did not alter the richness or diversity of vascular species, which agrees with our findings for other complexes and with observations by Haeussler (1999).

Girdling

Girdling had a gradual effect on the *Mixed Broadleaf-Shrub* Complex because treated stems died slowly. The full impact of treatment was not expressed until year 3, whereas the manual cutting and cut stump–glyphosate treatments reduced vegetation abundance immediately. Girdling did not significantly reduce average height of broadleaves because scattered stems were missed. Reductions in cover were significant only in year 1 because of the large variability between sites, but, 5 years after girdling, broadleaf cover in the treatment was approximately one-quarter that of the control. In spite of the lack of statistical significance, we assume that the reductions in broadleaf abundance are responsible for increases in Douglas-fir growth.

Birch sprouted minimally following girdling; after 5 years, only 11% of girdled stems had sprouted, and there were only two sprouts per stem. However, those few sprouts grew at similar rates to sprouts in the manual cutting treatment. Our results contrast with reports that birch sprouts vigorously following girdling at breast height (Hart and Comeau

1992), but agree with others that girdling seriously damages or kills birch with minimal sprouting (Haeussler et al. 1990). Birch can apparently be girdled in any season for effective control (Haeussler et al. 1990); our broadleaves were girdled in August and mid-October.

Girdling broadleaf stems had no effect on shrub abundance, but herb cover increased briefly (in year 3 only). There were no differences in the richness of vascular species as a result of girdling, but species diversity was higher in the treatment than in the control in the first year after cutting. The difference did not persist, however, and may be related to variation in assessment date, or to different assessors collecting data from year to year.

Cut stump-glyphosate

The cut stump-glyphosate treatment had a larger and more lasting effect on the *Mixed Broadleaf-Shrub* Complex than either manual cutting or girdling. It reduced both cover and height of broadleaves for at least 5 years, and resulted in a larger growth response among Douglas-fir than the other two treatments. Five years after cut stump-glyphosate, broadleaf cover continued to be about one-quarter that of the control, and height about half. On average, about one-quarter of stumps sprouted following treatment, which was higher than we expected, and is due to poor chemical application at one site. Sprouts grew an average of 55 cm/yr during the monitoring period.

The cut stump-glyphosate treatment killed 72% of birch in our study, in spite of the missed stumps, which is similar to the 83% mortality reported by Simard and Hannam (2000). Biring et al. (1996) confirmed good control of birch with cut stump-glyphosate treatments that use 30–100% solutions. In our study, glyphosate was applied at full concentration rates of 0.74–3.20 kg ai/ha. We have unrepliated data for cut and spray glyphosate applications (birch sprouts are sprayed one season after manual cutting), foliar glyphosate application, and basal application of triclopyr. Preliminary results suggest that cut and spray is nearly as effective as cut stump-glyphosate (Mather and Simard 1998j; Appendix 1) and that foliar glyphosate spray also performs well (Mather and Simard 1998k; Appendix 1). Other sources also report that glyphosate spray has a severe effect on birch (e.g., Expert Committee on Weeds 1987; Biring et al. 1996); Simard and Heineman (1996a) found that birch height and

cover were significantly reduced for at least 9 years by foliar glyphosate applied at 1.07 and 2.1 kg ai/ha. Biring et al. (1996) reported that basal triclopyr has a severe effect on birch, which is supported by results from our two triclopyr PROBE sites (unpublished data; Appendix 2).

Cut stump-glyphosate resulted in a modest decrease in shrub height 1 and 3 years after application in our study, possibly because of partial cutting of the shrub layer while broadleaves were being cut. There were no effects on shrub cover or abundance of the herb layer, and richness and diversity of vascular plant species associated with the *Mixed Broadleaf-Shrub* Complex were likewise unaffected. Boateng et al. (2000) found that spot application of glyphosate had no effect on structure or diversity of a boreal plant community; however, broadcast application reduced dominance of a tall shrub layer and increased structural diversity and richness of the herb layer. Sullivan et al. (1998) found that broadcast application of glyphosate had no effect on herbs, but it reduced the richness of shrub species. Both authors concluded that a single glyphosate application was unlikely to have an adverse effect on diversity of the vascular plant community. In our study, diversity of structural vegetation groups increased following the cut stump-glyphosate treatment because of the reduced dominance of broadleaves. This may have implications for wildlife species that are dependent on tall broadleaves for perching sites, nesting sites, or other habitat characteristics (e.g., Machmer and Steeger 1995).

Effects of the Community on Resource Availability

The *Mixed Broadleaf-Shrub* Complex occurs predominantly in the ICH zone, which includes some of the most productive ecosystems in southern interior British Columbia. Broadleaf trees and associated vegetation grow vigorously, and compete with conifers primarily for light rather than for soil water and nutrients. Simard (1990a) found that the best competition index for predicting Douglas-fir size in a paper birch-dominated community took into account the height of neighbouring vegetation and its distance from the target conifer, suggesting that light availability was paramount. Simard and Hannam (2000) likewise concluded that light availability was the main limitation to spruce growing among varying densities of birch. In that study,

reducing the density of overtopping birch improved average spruce diameter growth, whereas reducing the density of understorey sprouts did not. Simard and Sachs (2001, in review) studied competitive processes in mixed birch-conifer stands in the southern interior ICH, and found that taller birch neighbours were the most important competitors with 11-year-old conifers, whereas shorter conifers and birch were the main competitors with 25- and 50-year-old conifers. Their results suggest that light competition was the most important determinant of conifer growth in young stands and that competition for soil resources increased as stands aged. Nevertheless, Simard and others noted that a plurality of competitive processes were likely operative in the mixed ICH stands they studied.

In our study, the largest conifer growth responses occurred following brushing treatments that reduced the height of broadleaves relative to conifers within a relatively short period of time (i.e., Douglas-fir response to cut stump-glyphosate and lodgepole pine response to manual cutting), which implies that competition was primarily for light. Wang, Simard and Kimmins (1995) showed that thinning 9- to 13-year-old paper birch from initial densities of 11 000–31 000 stems/ha to 400 or 1000 stems/ha increased photosynthetically active radiation under the canopy from less than 20% of full light to more than 80%. In another study, thinning 35-year-old birch to 600 stems/ha allowed approximately 45% of above-canopy radiation to reach newly planted white spruce, which the authors considered adequate for seedling growth (Comeau et al. 1998). In comparison with complete removal of birch, retention of at least 600 stems/ha also reduced height growth of sprouts in that study.

Although birch is a strong competitor for light, it also benefits conifer seedlings by increasing nutrient availability and contributing to the health and diversity of the rhizosphere. In the presence of birch roots, soil microbial populations are less likely to be nutritionally limited than in non-birch soils (Bradley and Fyles 1995). The diversity or richness of ectomycorrhizae on Douglas-fir roots has also been shown to increase in the presence of birch (Jones et al. 1997; Simard et al. 1997b). Ectomycorrhizae are well-known for their ability to enhance the uptake of water and nutrients (Kozłowski and Pallardy 1997), and they may also facilitate direct transfer of nutrients between two tree species (Simard, et al. 1997a). Birch accumulates

high levels of nutrients within leaves and woody tissues (Wang et al. 1996) compared with neighbouring conifers (Simard 1995), which helps maintain ecosystem productivity when birch litter is cycled. A recent modelling study predicted eventual losses in overall stand productivity if birch were completely eliminated in favour of conifers (Sachs 1996). Nitrogen mineralization rates have been shown elsewhere to increase in the presence of birch, which has high levels of tissue nitrogen and relatively low levels of structural carbohydrates (Bradley and Fyles 1995; Evans et al. 1998). However, Prescott et al. (2000) recently found that birch foliage on ICH sites consistently decomposed more slowly than that of Douglas-fir, possible because of the higher tannin content, which implies that rates of nitrogen mineralization may slow in its presence. Thomas (1997) likewise found that nitrogen mineralization rates were slower under birch than under Douglas-fir.

Competition Thresholds

The competition thresholds for stem diameter of Douglas-fir, lodgepole pine, and interior spruce averaged 3664, 3367, and 2500 stems/ha for broadleaf density, 28, 18, and 20% for broadleaf cover, and 39, 15, and 27 for CRH, respectively. These thresholds apply to stands that are of free-growing age. Above the thresholds, interspecific competition appeared to be the most important factor limiting tree size, setting the upper limit for conifer stem diameter. A small proportion (19–39%) of conifers were growing in neighbourhoods above the thresholds, suggesting that competition was not constraining a portion of trees in the plantations. This was consistent among control as well as treated trees, indicating that many untreated conifers were naturally growing under low-moderate levels of broadleaf competition. Below the thresholds, stem diameter was highly variable among both treated and control trees; several trees (6–10%) were able to achieve greater growth ($\geq 80\%$ of the maximum diameter measured on the sites), but many appeared to be limited by other factors (e.g., microsite, genetics, and damaging agents such as root disease).

The regression analyses showed that the three broadleaf competition indices explained at best 43–46% of the variation in conifer stem diameter. The importance of competition in the *Mixed Broadleaf-Shrub* complex to conifer performance,

as expressed by adjusted r^2 values, was moderately high compared to herbaceous and shrub complexes being evaluated with PROBE (this publication) as well as in other studies (e.g., Coates 1987; Simard 1989a; Wagner and Radosevich 1991). This is likely due to the closer equivalence in size and growth form of broadleaf neighbours to conifers (Goldberg and Werner 1983) as well as greater resource uptake by larger than by smaller neighbours (Harper 1977). In contrast, similar r^2 values have been reported in other studies relating individual conifer performance to competitive effects of paper birch or trembling aspen in 5–15-year old plantations (e.g., Simard 1990a; Morris and MacDonald 1991; Navratil and MacIsaac 1996; Newsome 1997, 1999; Simard 2001, in review). The generally moderate predictive ability of the regression models, the variable conifer performance at low and medium levels of competition, as well as the moderate portion of conifers constrained by detrimental broadleaf levels (i.e., above the thresholds), in combination suggest that performance of a portion of trees in the plantations will not improve predictably following broadcast brushing treatments. The regression and threshold results indicate that broadleaf competition was one of several factors affecting conifer growth in our operational plantations, and that alleviating competitive stress for a portion of trees will not alleviate the most important limitation to growth. Under variable stand and site conditions, competition is better viewed as one of many constraints rather than as a determinant of conifer performance (Burton 1993).

In spite of conifer performance variability within and between plantations, lodgepole pine and Douglas-fir increased in diameter by 14–52% following manual and/or cut stump–glyphosate treatments. Manual and chemical brushing treatments were successful at reducing broadleaf abundance below the cover and CRH thresholds for most suppressed conifers, resulting in their release. By contrast, considerably more Douglas-fir remained above broadleaf threshold densities 5 years following girdling, which may be attributed to spotty treatment, the older age of conifers at the time of treatment, and the slow death of girdled broadleaves. As a result, many suppressed trees were not released, and average Douglas-fir diameter still had not responded to girdling 5 years after treatment.

The variability in competition thresholds among sites was high in our study (coefficient of

determination averaged 71% and was similar among conifer species and among broadleaf competition indices). This may reflect variability in stand history and conifer ages among our replicate sites; however, other studies have also found thresholds to vary considerably, even among similar sites (Simard 1990a; Burton 1993; Simard 2001, in review). Others acknowledge that management thresholds are necessarily variable because they are derived from a complex of factors and uncertainties (Cousens 1987), such as variable management objectives, ecosystems, stand compositions, stand ages, disease or insect problems, or administrative risks. As a result, calibration of thresholds on site-specific, target tree species-specific, and age-specific bases may be necessary for successful application of the threshold concept in developing management prescriptions in conifer-broadleaf mixtures.

The ranking of density thresholds among conifers in our study (Douglas-fir $\approx$ lodgepole pine $>$ hybrid spruce) did not follow shade-tolerance patterns described by Krajina et al. (1982), who evaluated spruce as more shade tolerant than either lodgepole pine or Douglas-fir. However, hybrid spruce is more susceptible to moisture stress, and closes its stomata sooner than lodgepole pine (Binder et al. 1987). Therefore, under similar broadleaf densities, spruce may be more negatively affected than lodgepole pine by soil water competition, particularly on mesic and drier sites. In a recent study in the ICH zone, Coates and Burton (1999) found considerable variability and overlap in growth rates of lodgepole pine and hybrid spruce at moderate light levels (30–70% full sunlight), which probably encompass the light levels under the broadleaf thresholds identified in this study. The variability reflects the numerous factors other than light that affect conifer growth rates, such as soil water and nutrient availability, abiotic and biotic damage, and genetics. The lower thresholds identified for spruce than for pine or fir in this study may also have been a result of the low sample size for spruce. Notably, spruce thresholds were highly variable among sites, and standard errors generally overlapped those of the other two conifer species.

When broadleaf densities are very high, brushing may be more critical for the survival of lodgepole pine and Douglas-fir than of spruce. Kobe and Coates (1997) showed, for example, that 5-year survivorship of lodgepole pine (<10%) was considerably

lower than of hybrid spruce (approximately 30%) at very low light levels (5% full sunlight). In our study, however, mortality did not vary among conifer species and little was due to broadleaf competition. Most mortality was caused by *Armillaria* root disease, and it increased following manual and girdling treatments. Our results suggest that broadleaf densities were too low to reduce light or soil water below compensation levels, and that other factors were primary agents of mortality. Growth of lodgepole pine and Douglas-fir may also benefit from dramatic reductions in broadleaves more so than growth of hybrid spruce. At high light levels (>70% full sunlight), Wright et al. (1998) and Coates and Burton (1999) showed that growth response of lodgepole pine was greater than that of hybrid spruce. Lodgepole pine is also more plastic than Douglas-fir in its growth response to increased light levels. In our study, there were too few replicates to evaluate average spruce response, but 5-year diameter response of lodgepole pine to manual cutting was considerably greater than that of Douglas-fir.

The broadleaf density threshold identified for Douglas-fir diameter in this study (3664 stems/ha) agrees with Simard (2001, in review), who found that 11-year-old Douglas-fir performance on mesic ICHmw sites declined dramatically above 4050 broadleaf stems/ha. The thresholds in these studies included broadleaves of all sizes. However, other studies in 9- to 13-year-old mixed broadleaf-conifer plantations have shown that taller broadleaves are the primary competitors with target conifers, and that shorter broadleaves have little additional competitive effect (Navratil and MacIsaac 1996; Simard and Sachs 2001, in review). Simard (2001, in review) found that inclusion of only those broadleaves taller than 11-year-old Douglas-fir resulted in a density threshold of 2575 taller broadleaf stems/ha.

Effectiveness of Treatment at Meeting Management Objectives

Common operational objectives of brushing the *Mixed Broadleaf-Shrub* Complex are to improve seedling growth by reducing competition from broadleaves, and to assist in meeting free-growing requirements (B.C. Ministry of Forests 1995a, 2000). The *Mixed Broadleaf-Shrub* Complex tends to be brushed after conifers are well-established, so that improving seedling survival is not a common

objective, although there is some concern that mortality will increase with development of these stands if they are left untreated (B. Fraser, pers. comm. 2001). The extent to which free-growing and growth goals were met for Douglas-fir increased with the extent to which brushing reduced broadleaf abundance, even though other ecosystem effects are poorly understood. Objectives were met more easily for lodgepole pine than for Douglas-fir because of larger initial seedling size and a faster growth rate.

For our ICH sites, the old (1995) free-growing guidelines specified target stocking of 1200 (minimum 700) well-spaced conifers/ha, and required that 9–15 years after harvest (12–15 years on some sites), that Douglas-fir and lodgepole pine must be at least 1.4 and 2.0 m tall, respectively, and that both species must be 150% as tall as the surrounding vegetation. For our IDF sites, the old guidelines specified target stocking of 1000 (minimum 500) well-spaced conifers/ha, and required that 12–15 years after harvest, Douglas-fir must be at least 0.8 m tall and 125% as tall as surrounding vegetation. The new (2000) guidelines allow retention of specific densities of broadleaves that exceed the height of conifers in one of four quadrants in the free-growing assessment radius. For our sites, the new guidelines allow retention of 600 broadleaf stems/ha in Douglas-fir plantations and 400 stems/ha in lodgepole pine plantations. We have not yet surveyed according to the new guidelines, but fifth-year survey information collected according to the old guidelines showed there were significantly more free-growing trees in the treatment than the control in all the treatment cells. Our survival and growth results suggest that stocking and minimum height requirements were met (on average) in both the treatments and controls of all four treatment cells, and that Douglas-fir in the cut stump treatment (Figure 157) and pine in the manual cutting treatment (Figure 159) were likely to meet the conifer:vegetation height ratio requirement, on average, at the early free-growing assessment age. Girdling left some tall broadleaves (Figure 158), but competitive status data suggest that at least three-quarters of Douglas-fir were no longer overtopped in that treatment. Data collected according to the old free-growing guidelines indicates that although there were more free-growing trees/ha in the girdling treatment than the control (370 versus 166 stems/ha), the majority remained

overtopped to some extent. Results may be different when surveys are conducted under the new guidelines. According to our height data, manual cutting is unlikely to help Douglas-fir meet the conifer:vegetation height ratio requirement (on average) because seedlings were quickly overtaken by broadleaf sprouts (Figure 156). However, silviculture survey data collected according to the old guidelines suggests there were approximately 185 more free-growing trees/ha in the cutting treatment than the control (502 versus 315 stems/ha). Future assessment using the new guidelines will provide more current information. Simard and Heineman (1996a) likewise found that manual cutting did not allow Douglas-fir to grow above the *Mixed Broadleaf-Shrub* Complex, but that foliar glyphosate reduced broadleaf height well below that of seedlings. Simard and Hannam (2000) found that a cut stump–glyphosate treatment allowed spruce to meet the conifer:vegetation height ratio, whereas cutting was ineffective because birch sprouted so vigorously. In our study, control broadleaves were taller than conifers and far exceeded threshold densities throughout the 5-year monitoring period. None of the control stands we studied are expected to meet free-growing requirements under the new guidelines (B.C. Ministry of Forests 2000).

It did not appear necessary to improve survival in our study because conifers were well established and healthy at the time of treatment. To the contrary, manual cutting and girdling resulted in an increase in *Armillaria*-related mortality among lodgepole pine and Douglas-fir, respectively. This has increased disease incidence from moderate to high (B.C. Ministry of Forests 1995a). Further mortality may yet occur, since other studies (e.g., Morrison et al. 1991; Woods 1994; Simard and Heineman 1996a) suggest that our stands are too young for the disease to be fully expressed. Douglas-fir growth was most improved by the cut stump–glyphosate treatment, which was associated with

the greatest reductions in broadleaf abundance compared with other treatments. In comparison, faster-growing lodgepole pine responded well to manual cutting, probably because they were able to keep ahead of sprouts. Longer-term monitoring is required to determine whether growth responses affect yield or rotation length and to monitor the interaction between brushing and *Armillaria* root disease.

In summary, the management objectives of improving juvenile conifer growth and creating free-growing stands were most successfully met in the *Mixed Broadleaf-Shrub* Complex following brushing treatments that severely set back the broadleaves (i.e., chemical treatments). However, such treatments are likely to reduce the presence of broadleaves in seral conifer-dominated stands at maturity (Simard and Sachs [2001, in review]). Many studies have shown that birch has beneficial effects on biodiversity, forest productivity, and forest health (e.g., Sachs 1996; Wang, Simard, and Kimmins 1995; Gerlach et al. 1997; Jones et al. 1997; Peterson et al. 1997; Simard et al. 1997b; DeLong 1999). Our threshold results, as well as those of Simard (2001, in review), indicate that young conifers perform well in the company of 2500–4000 total birch stems/ha, of which Simard suggests 700–3300 stems/ha can be taller than the conifers, depending on the shade tolerance of the species. The new free-growing guidelines acknowledge the benefits of broadleaves by allowing retention of certain densities of broadleaves (B.C. Ministry of Forests 2000). Birch distribution in the *Mixed Broadleaf-Shrub* Complex is typically patchy, so that some conifers are overtopped in dense patches, others are partially encroached upon, and still others are open-grown. With increased understanding of competitive mechanisms and competitive thresholds, Simard (2001, in review) and Simard and Sachs (2001, in review) suggest that brushing of young conifer plantations may be tailored to relieve competition for light to only those trees that need it.

CONCLUSIONS

Brushing the *Mixed Broadleaf-Shrub* Complex significantly improved conifer growth in our study, and the largest seedling growth responses occurred where broadleaf abundance was most reduced. However, brushing was not needed to improve survival because conifers were well established at the time of treatment. To the contrary, our results indicate that rates of mortality from *Armillaria* root disease increased following manual cutting or girdling of broadleaves. Without brushing, stands typically cannot meet all the free-growing requirements

(B.C. Ministry of Forests 2000) within the assessment window, and the treatment that most reduced broadleaf abundance (cut stump–glyphosate) was most successful at improving their status. However, many studies have shown that the presence of some broadleaf trees is beneficial to conifers, and our competition thresholds suggest that, depending on species, conifers can be successfully grown with a broadleaf component of approximately 2500–4000 total stems/ha.

MANAGEMENT IMPLICATIONS

1. Brushing the *Mixed Broadleaf-Shrub* Complex is not required to ensure good conifer survival, as long as seedlings are well established at the time of treatment. *Armillaria*-related mortality of lodgepole pine and Douglas-fir seedlings actually increased in manually cut and girdled stands, respectively, compared to untreated stands. In contrast, *Armillaria*-related mortality was unaffected by chemical treatments, which agrees with other studies in the southern interior. Further research is required before recommendations can be made regarding brushing in *Armillaria*-infested stands. A prudent approach to minimizing mortality in these stands would be to avoid brushing these stands altogether if conifers are growing adequately, or to brush only around suppressed conifers using localized chemical application.
2. Conifer diameter growth can be improved by brushing the *Mixed Broadleaf-Shrub* Complex. Height growth responses lag behind diameter responses, and other studies indicate that they generally do not appear until at least 5 years after brushing. Except for the increase in *Armillaria*-related mortality, brushing has tended to improve seedling vigour. However, there are currently no data to indicate whether short-term growth responses will affect stand yield over the long term.
3. Broadleaf thresholds for Douglas-fir, lodgepole pine, and interior spruce stem diameter averaged 3664, 3367, and 2500 stems/ha, 28, 18, and 20% broadleaf cover, and 39, 15, and 27 CRH, respectively. Reducing broadleaf abundance to the thresholds should improve stem diameter, but further reductions will not necessarily affect growth predictably. Broadleaves of all sizes were used in the threshold estimates.
4. Our results suggest that manual cutting will allow lodgepole pine to meet the conifer:vegetation height ratio free-growing requirement, but that Douglas-fir are too slow-growing to keep ahead of birch sprouts. Cut stump–glyphosate and girdling treatments show more promise for allowing Douglas-fir to attain free-growing status. Brushing does not improve the ability to meet stocking or minimum height requirements for free-growing, and increases in *Armillaria* mortality may eventually reduce stocking in brushed stands. In our study, untreated stands occupied by the *Mixed Broadleaf-Shrub* Complex are unlikely to meet the conifer:vegetation height ratio or density requirements for free-growing under the new guidelines (B.C. Ministry of Forests 2000).
5. A possible alternative to broadcast brushing of the *Mixed Broadleaf-Shrub* Complex is selective brushing of only competition-stressed conifers. In another study in stands of free-growing age, Simard (2001, in review) suggests that broadleaves taller than conifers be removed down to thresholds of 3325, 2575, and 733 stems/ha for western redcedar, Douglas-fir, and western larch, respectively.

