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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We have third-year results demonstrating the effects of manual cutting on lodgepole pine that were 7–10 years old at the time of treatment and the Aspen Complex in the IDF and MS zones. Manual brushing improved stem diameter increment and height:diameter ratio of lodgepole pine growing among 26% cover of aspen within 3 years, but there were no improvements in stem diameter, height, or leader length. Pine survival was 100% in both the treatment and control during the 3-year measurement period, and most trees were healthy regardless of whether brushing was done. Manual cutting resulted in large between-site variability in broadleaf height and cover in the first year after treatment, resulting in no significant differences between the treatment and control. In year 3, broadleaf height was significantly less in the treatment (166.3 cm) than in the control (367.4 cm), but cover continued to be unaffected.

Competition thresholds for stem diameter of lodgepole pine and Douglas-fir averaged 3180 and 2400 stems/ha for total aspen density, 31 and 21% for total aspen cover, and 31 and 19 for CRH (aspen cover * aspen modal height)/conifer height, respectively. Aspen of all heights relative to target conifers were used in estimation of the thresholds. These thresholds, as well as other competition studies in young aspen-conifer mixtures, suggest that lodgepole pine and Douglas-fir growth rates will not be adversely affected by moderate levels of aspen abundance.

Manual brushing eliminated tall broadleaves and created free-growing stands of lodgepole pine in our study. In contrast, our results suggest control pine would be unlikely to meet the conifer:vegetation height ratio or density requirements for free-growing under the new guidelines (B.C. Ministry of Forests 2000). Cutting aspen had no lasting effects on the richness or diversity of individual species or structural vegetation groups.
Description of the Aspen Complex

The Aspen Complex is characterized by relatively pure stands of trembling aspen (Populus tremuloides), but paper birch (Betula papyrifera) and cottonwood (Populus trichocarpa) may also be present in lesser quantities (Figure 103). On sites where birch and/or cottonwood are at least as abundant as aspen, the community is classified as the Mixed Broadleaf-Shrub Complex, described in Section 11. Common understorey species associated with the Aspen Complex are fireweed (Epilobium angustifolium), thimbleberry (Rubus parviflorus), and pinegrass (Calamagrostis rubescens).

The Aspen Complex occurs throughout the IDF, MS, and ICH zones in the southern interior of British Columbia (Kimmins and Comeau 1990) and is also common in most zones in the northern interior (Butt 1988). Trembling aspen is a seral species in at least 77 subzones or variants of nine biogeoclimatic zones in British Columbia (Peterson and Peterson 1995), and is the most widespread tree species in North America (Burns and Honkala 1990).

Development of the Aspen Complex

Aspen occurs across a range of moisture and nutrient regimes, but is most productive on fresh to moist, well-drained sites with high levels of nutrients (Krajina et al. 1982; Angove and Bancroft 1983; Klinka and Scagel 1984; Haeussler et al. 1990). In the southern interior dry belt (PP and IDF zones), mature aspen stands often occupy moist, rich sites (i.e., gullies, floodplains) and also talus slopes; they are abundant in some areas of the MS zone and not in others; and in the wet belt (ICH zone), they are often found on rich, fluvial toe slopes (D. Lloyd, pers. comm., 2000). However, dense stands of juvenile aspen commonly develop following logging on mesic and submesic sites in all three zones (Mather 1988). It does not usually occupy nitrogen-poor sites because it has high nitrogen requirements (Peterson and Peterson 1995). Aspen helps improve nutrient availability through its rapid rate of litter decomposition, rapid growth rate, and high nitrogen uptake (Paré and Van Cleve 1993). Aspen is very shade-intolerant (Krajina et al. 1982).

Aspen reproduces primarily by suckering from parent tree roots; reproduction from seed is uncommon because seed is short-lived and requires constant moisture, and also because seedling survival and growth are reduced at temperatures exceeding 30°C (Doucet 1989). Occasionally, seedlings can establish in abundance in localized patches, but little is known about the factors governing their success (D. MacIsaac, pers. comm., 2000). Sucker initiation and growth are promoted by high light levels and warm soils (to an optimum of 23°C) (Burns and Honkala 1990), so treatments that remove the canopy (e.g., clearcut harvesting) and expose mineral soil (e.g., scarification and severe broadcast burns) tend to promote suckering. Treatments that break up the root system (e.g., deep ploughing to 30 cm) (Haeussler et al. 1990) or compact the soil (Kabzems 1996) are reported to reduce suckering. In dry ecosystems, however, soil ripping has been observed to encourage sprouting (T. Newsome, pers. comm., 2000).

Aspen suckers appear soon after disturbance (Bailey and Anderson 1979; Zieroth 1984; Debyle and Winokur 1985; Burns and Honkala 1990), and early growth tends to be rapid. Under ideal conditions, suckers can grow 2 m the first year (Steneker 1976). Vigorous growth such as this occurs in the southern ICH zone (Simard and Vyse 1992), but elsewhere in the southern interior, 1-year-old suckers are commonly less than 1 m tall (Haeussler et al. 1990). Aspen is capable of growing to a height

![Figure 103](Image 103) The Aspen Complex prior to manual cutting at McConnell Lake (Site 66) in the IDFdk1 variant in the Kamloops Forest District. Photo credit: Jean Mather.
of 9 m within 8 years (Perala 1987); however, on our probe sites in the IDF and MS zones, height was about 3 m after 8 years. Aspen grows more slowly in the northern than the southern interior of British Columbia, but can still reach 5–9 m by age 15 years (Bella 1986; Butt 1988; Doucet and Veilleux 1982, cited by Doucet 1989). Initial sucker densities of 30 000–100 000 stems/ha are common (Jones 1976; Crouch 1983; Bella 1986; Doucet 1989, citing Doucet 1979), but self-thinning is rapid because of aspen’s shade-intolerance. On probe sites in the southern interior, aspen density averaged 28 000 stems/ha (16% cover) 8 years after mechanical site preparation. Similar aspen densities were observed on cutovers in northern British Columbia by Butt (1988).

Interactions with Conifer Seedlings

Aspen is considered a serious competitor to conifers throughout most of interior British Columbia, including the southern interior (Kimmins and Comeau 1990). The exception may be the wetter ICH subzones of the southern interior, where birch tends to be the dominant broadleaf species, and aspen densities are rarely high enough to reduce survival and growth of young conifers (Mather 1988). In north-central British Columbia, high densities of aspen can reduce light and soil moisture to levels that are limiting to conifer growth for at least part of the growing season (DeLong and Tanner 1996); however, the severity and nature of aspen competition appears to vary from southern to northern British Columbia and from wet to dry ecosystems.

Aspen may also indirectly reduce health of young conifers because it is the primary host of the rust fungus Melampsora albertensis. Alternate hosts are conifers, including Douglas-fir and lodgepole pine (Callan 1996). Douglas-fir, in particular, may be reduced in vigour if they are growing among infected aspen clones (J. Wright, pers. comm., 2000).

In spite of its ability to compete for resources, aspen also benefits conifers in several ways. It takes up large amounts of nutrients, especially calcium, at an early age and retains them within the ecosystem (Pastor 1990). It may also slow the spread of root disease in mixed stands because it is immune to Phellinus weirii (Morrison et al. 1991) and more resistant to Armillaria ostoyae than most conifers (Peterson and Peterson 1995). Mature aspen canopies also reduce frost damage to seedlings in the understorey (DeLong et al. 2000) by restricting radiative heat loss during the night and improving air temperatures at seedling height (Stathers 1989). Because of its sucker-origin communal root system, aspen is mechanically stable (Strong and La Roi 1983), and its presence may increase resistance of neighbouring conifers to windthrow (Frivold 1985; Yang 1989).

Importance to Wildlife and Range

Aspen ecosystems are extremely important to wildlife, providing habitat for at least 55 species of mammals and 155 species of birds (DeByle and Winokur 1985; Peterson and Peterson 1995). Dense stands of sapling aspen, pure maturing aspen forests, and mixed aspen-conifer forests all provide different habitats for wildlife, but species diversity is probably greatest in mixed stands because of the variety of niches they provide (DeByle and Winokur 1985).

Aspen leaves, particularly those on suckers, are highly nutritious and provide summer food for moose, elk, and deer (DeByle and Winokur 1985). In winter, these animals sometimes browse on the bark of mature trees (Banfield 1974). In addition, ungulates favour many of the understorey plants associated with aspen stands (DeByle and Winokur 1985). Aspen communities also provide ungulates with cover (Peterson and Peterson 1995). Invertebrates and small mammals, including mice, voles, shrews, and chipmunks, commonly utilize dead or downed trees in aspen forests (Peterson and Peterson 1995). Porcupines feed on aspen leaves and twigs in spring and summer and bark in winter, and beaver utilize it for food and dam-building materials (Banfield 1974; Enns et al. 1993; Peterson and Peterson 1995). Mixed aspen-conifer stands provide both habitat and food for snowshoe hares (DeByle and Winokur 1985). Aspen forests have about twice the density and diversity of insects as pure conifer stands, and consequently attract insectivores such as bats (Peterson and Peterson 1995). Black bears feed on small mammals that live in early seral to mature aspen stands, and they also forage on aspen buds in the spring (DeByle and Winokur 1985; Enns et al. 1993).

The Aspen Complex is also commonly utilized for livestock range. Aspen suckers are highly
nutritious, and can contribute substantially to livestock diets, although cattle are deterred from entering young aspen stands when they are very dense (DeByle and Winokur 1985). Young aspen sprouts are a preferred forage for sheep (Newsome et al. 1995). Livestock also commonly graze on pinegrass and other understorey plants associated with the Aspen Complex (McLean 1979; Quinton 1984).

**Common Brushing Treatments in the Aspen Complex**

The Aspen Complex is operationally brushed using a variety of methods in southern interior British Columbia, including manual cutting, girdling, foliar glyphosate application, basal triclopyr application, and cut-spray glyphosate (manual cutting followed by foliar glyphosate application to new sprouts) (Table 96). Broadcast treatments are the most common, but some recent silviculture prescriptions have called for retention of up to 1000 aspen stems/ha.

Historically, the most common brushing treatments applied to this community have been manual cutting in relatively young aspen stands and girdling in stands dominated by larger-diameter (>5 cm) trees. Girdling is often preferred over manual cutting because it results in less re-growth (DeByle and Winokur 1985). Girdling inhibits suckering because severing the phloem results in a lower ratio of cytokinins to auxins (C:A) in roots (cytokinins stimulate sucker initiation and auxins depress it), whereas cutting encourages suckering because severing both the phloem and xylem increases root C:A. In stands with a range of aspen diameters, a combination of girdling and cutting is commonly employed. Girdling is as effective as herbicides for killing aspen, probably costs about the same amount, and does not have the complication of requiring permits (Peterson and Peterson 1995). Herbicide treatments that control aspen include foliar spray or stem injection of glyphosate, foliar or basal application of triclopyr, soil application of hexazinone, and cut stump–2,4-D amine (Biring et al. 1996).
Table 96 Common brushing treatments applied to the Aspen Complex in the southern interior of British Columbia

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Objective</th>
<th>Optimum timing</th>
<th>Suggested number of treatments</th>
<th>Tool</th>
<th>Average cost per ha(^a)</th>
<th>Potential disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2. Create a free-growing stand</td>
<td></td>
<td></td>
<td>2. Motorized brush saw</td>
<td>$538</td>
<td></td>
</tr>
<tr>
<td>Girdling</td>
<td>1. Reduce light competition</td>
<td>Unknown</td>
<td>1</td>
<td>1. Chain girdler</td>
<td>Unknown</td>
<td>1. Extended reductions in aspen may negatively affect wildlife</td>
</tr>
<tr>
<td></td>
<td>2. Create a free-growing stand</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2. Suitable only for aspen stands &gt;5 cm diameter</td>
</tr>
<tr>
<td>Cut, then spray sprouts with glyphosate</td>
<td>1. Reduce light competition</td>
<td>Unknown</td>
<td>1</td>
<td>1. Saw and backpack sprayer or squirt bottle</td>
<td>Unknown</td>
<td>1. More expensive than manual cutting (requires two entries)</td>
</tr>
<tr>
<td></td>
<td>2. Create a free-growing stand</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2. Extended reductions in aspen may negatively affect wildlife</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3. Difficulties obtaining herbicide permits</td>
</tr>
<tr>
<td>Foliar glyphosate spray</td>
<td>1. Reduce light competition</td>
<td>Unknown</td>
<td>1</td>
<td>1. Backpack sprayer</td>
<td>$700</td>
<td>1. Suitable only for young (short) aspen stands</td>
</tr>
<tr>
<td></td>
<td>2. Create a free-growing stand</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2. Extended reductions in aspen may negatively affect wildlife</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3. Difficulties obtaining herbicide permits</td>
</tr>
<tr>
<td>Basal triclopyr application</td>
<td>1. Reduce light competition</td>
<td>Unknown</td>
<td>1</td>
<td>1. Sprayer</td>
<td>Unknown</td>
<td>1. Extended reductions in aspen may negatively affect wildlife</td>
</tr>
<tr>
<td></td>
<td>2. Create a free-growing stand</td>
<td></td>
<td></td>
<td>2. Roller</td>
<td></td>
<td>2. Difficulties obtaining herbicide permits</td>
</tr>
</tbody>
</table>

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

Manual Cutting

This section describes third-year lodgepole pine and vegetation responses to manual cutting of the Aspen Complex in the IDF and MS zones (n = 3). Pine were 7–10 years old at the time of treatment.

Lodgepole pine in the IDF and MS zones

Description of study sites and treatments

The three study sites for this treatment cell are widely distributed through the Kamloops Forest Region. The McConnell Lake site is in the Thompson Dry Cool IDF variant (IDFdk1), 18 km south of Kamloops in the Kamloops Forest District; the Kathleen Lake site is in the Cascade Dry Cool IDF variant (IDFdk2), northwest of Summerland in the Penticton District; and the Fowler Creek site is in the Thompson Dry Mild MS variant (MSdm2), 10 km east of Falkland in the Salmon Arm District. All the sites are mesic, situated in mid-slope positions, with Brunisolic silt loam soils (Table 97). The IDF sites have moderately sloping (30–50%) southerly aspects, and the MS site has a 20% easterly aspect. Elevations range from 1220 to 1400 m.

The original stands were clearcut between 1982 and 1988, 8–10 years before brushing. The McConnell Lake and Fowler Creek sites were mechanically prepared 1–2 years after logging, then immediately planted with lodgepole pine. The Kathleen Lake site was left to regenerate naturally without preparation. At the time of brushing, the 7- to 10-year-old lodgepole pine averaged 1.6–2.0 m and was more than two-thirds the height of neighbouring vegetation. Pine were growing at an average rate of 38 cm/yr compared to 46 cm/yr for aspen. All three sites were well stocked with at least 1000 well-spaced conifers/ha. Total conifer density was 1539–2100 stems/ha on the sites that were mechanically prepared and 8136 stems/ha on the unprepared site. All aspen were cut near ground level in September at the McConnell Lake and Fowler Creek sites, whereas, at Kathleen Lake, aspen smaller than 5 cm dbh was cut near ground level and the larger trees were girdled 1 year later (Table 98).

Survival and vigour

Three years after manual cutting, survival of 10- to 13-year-old lodgepole pine (7–10 years old at the time of treatment) was 100% in both the manual cutting treatment and control (p = 1.00) (Table 99), and most trees were healthy (good or moderate vigour) (Figure 104). There was a slight decrease in pine vigour 1 year after cutting, but seedlings outgrew this by year 3.

Growth Lodgepole pine did not respond within 1 year of manual cutting, but after 3 years, diameter increment was larger in the control than in the control (0.72 versus 0.51 cm, p = 0.02) and height:diameter ratio was smaller (55.6 in the treatment versus 66.3 in the control, p = 0.05) (Table 99, Figure 105). Stem diameter and height were unaffected by cutting (p > 0.10) (Figure 106), and leaders showed a negative response in year 3 (40.6 in the control versus 37.6 cm in the treatment, p = 0.00). Three years after manual cutting, when pine were 10–13 years old, they averaged 310.6 cm tall and had 5.48-cm stem diameters.

Standardized distributions for pine stem diameter and height were normal both pre- and post-treatment, and were similar in the treatment and control throughout the measurement period (Figures 107 and 108). The distributions support ANOVA results that pine diameter and height growth did not improve as a result of brushing.

Competitive status Prior to manual cutting, 25% of pine were free of vegetation, 28% were threatened, and 47% were overtopped (Figure 109). Three years later, 87% of treated pine were free of vegetation, 6% were threatened, and only 7% were overtopped. The competitive status of pine in the control was also improving; in year 3, 63% were free of vegetation, 16% were threatened, and 21% were overtopped.

Plant community response

Abundance Although broadleaf abundance was reduced by manual cutting, differences in height and cover were not significant 1 year after cutting (p > 0.10) (Table 100). The lack of statistical significance could be explained by the variability among sites. One of the sites was treated over a period of 2 years, where small aspen were initially cut and
### Characteristics and history of the three replicate study sites where the IDF/MS Aspen Complex was manually cut in lodgepole pine stands

| Site location       | BEC unit       | Elev. (m) | Aspect/slope | Soil class/texture | Logging and site prep. history | Years since harvest | Years since site prep. | Est. delay
  (yr) | Origin | Stock | Age (yr) | Height (cm) | Conifer stocking |
<table>
<thead>
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</tr>
</thead>
<tbody>
<tr>
<td>McConnell Lake</td>
<td>IDFdk1 01</td>
<td>1300</td>
<td>S</td>
<td>Brunisol/silt loam</td>
<td>Clearcut 1988 MSP and spot burned 1989</td>
<td>8</td>
<td>7</td>
<td>0</td>
<td>P 1989</td>
<td>PSB 211</td>
<td>7</td>
<td>163</td>
<td>2110</td>
</tr>
<tr>
<td>PROBE 66 Kamloops</td>
<td>(mesic)</td>
<td></td>
<td>30%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>District</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Kathleen Lake</td>
<td>IDFdk2 01</td>
<td>1400</td>
<td>S</td>
<td>Brunisol/silt loam</td>
<td>Clearcut 1982</td>
<td>10</td>
<td>n/a</td>
<td>n/a</td>
<td>N</td>
<td>N/a</td>
<td>10</td>
<td>169</td>
<td>8136</td>
</tr>
<tr>
<td>PROBE 27 Penticton</td>
<td>(mesic)</td>
<td></td>
<td>50%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>District</td>
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<td></td>
</tr>
<tr>
<td>Fowler Creek</td>
<td>MSDm2 05</td>
<td>1220</td>
<td>E</td>
<td>Brunisol/silt loam</td>
<td>Clearcut 1985/86 MSP and spot burned 1988</td>
<td>9</td>
<td>7</td>
<td>0</td>
<td>P 1989</td>
<td>PSB 313</td>
<td>7</td>
<td>199</td>
<td>1539</td>
</tr>
<tr>
<td>PROBE 58 Salmon Arm</td>
<td>(mesic)</td>
<td></td>
<td>20%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>District</td>
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</tr>
</tbody>
</table>

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)
A description of manual cutting treatments applied to the three replicate study sites to release lodgepole pine seedlings growing in the IDF/MS Aspen Complex

<table>
<thead>
<tr>
<th>Site</th>
<th>Treatment date</th>
<th>Treatment type</th>
<th>Treatment specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>McConnell Lake</td>
<td>September 6, 1996</td>
<td>Broadcast</td>
<td>All broadleaves &gt;15 cm tall were cut near ground level</td>
</tr>
<tr>
<td>Kathleen Lake</td>
<td>July 1992</td>
<td>Broadcast</td>
<td>Broadleaves &lt;5 cm dbh were cut near ground level; larger stems were girdled 1 year after manual cutting</td>
</tr>
<tr>
<td>Fowler Creek</td>
<td>Late September 1995</td>
<td>Broadcast</td>
<td>Broadleaves and shrubs within 2 m of the drip line of pine seedlings were cut. Smaller vegetation was cut within 1 m of the drip line.</td>
</tr>
</tbody>
</table>

**Figure 104** Comparison of lodgepole pine vigour between the manual cutting treatment and control before, and 1 and 3 years after, treatment of the IDF/MS Aspen 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 105** Comparison of mean lodgepole pine height:diameter ratio between the manual cutting treatment and control before, and 1 and 3 years after, treatment of the IDF/MS Aspen Complex. Error bars represent one standard error of the mean ($S_y = \sqrt{MSE/n}$ 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>
<thead>
<tr>
<th>Response variable</th>
<th>Means</th>
<th>Standard error</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Manual cutting</td>
<td>Control</td>
<td></td>
</tr>
<tr>
<td>Survival (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>100</td>
<td>100</td>
<td>0.000</td>
</tr>
<tr>
<td>1 yr post-treatment</td>
<td>100</td>
<td>100</td>
<td>0.000</td>
</tr>
<tr>
<td>3 yr post-treatment</td>
<td>100</td>
<td>100</td>
<td>0.000</td>
</tr>
<tr>
<td>Stem diameter (cm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>3.28</td>
<td>3.27</td>
<td>0.223</td>
</tr>
<tr>
<td>1 yr post-treatment</td>
<td>4.02</td>
<td>3.96</td>
<td>0.211</td>
</tr>
<tr>
<td>3 yr post-treatment</td>
<td>5.81</td>
<td>5.15</td>
<td>0.222</td>
</tr>
<tr>
<td>Diameter increment (cm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 yr post-treatment</td>
<td>0.76</td>
<td>0.75</td>
<td>0.044</td>
</tr>
<tr>
<td>3 yr post-treatment</td>
<td>0.72</td>
<td>0.51</td>
<td>0.019</td>
</tr>
<tr>
<td>Height (cm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>175.6</td>
<td>178.4</td>
<td>10.374</td>
</tr>
<tr>
<td>1 yr post-treatment</td>
<td>213.3</td>
<td>220.1</td>
<td>13.447</td>
</tr>
<tr>
<td>3 yr post-treatment</td>
<td>298.6</td>
<td>322.6</td>
<td>17.515</td>
</tr>
<tr>
<td>Leader length (cm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>37.6</td>
<td>38.9</td>
<td>2.702</td>
</tr>
<tr>
<td>1 yr post-treatment</td>
<td>36.9</td>
<td>43.1</td>
<td>6.066</td>
</tr>
<tr>
<td>3 yr post-treatment</td>
<td>37.6</td>
<td>40.6</td>
<td>0.069</td>
</tr>
<tr>
<td>Height:diameter ratio</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>55.4</td>
<td>55.5</td>
<td>0.234</td>
</tr>
<tr>
<td>1 yr post-treatment</td>
<td>56.0</td>
<td>57.2</td>
<td>1.763</td>
</tr>
<tr>
<td>3 yr post-treatment</td>
<td>55.6</td>
<td>66.3</td>
<td>1.699</td>
</tr>
</tbody>
</table>

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 $S_y = \sqrt{\text{MSE}/n}$, where MSE = Mean Square Error and $n =$ number of replicates.

**Figure 106** Effects of manual cutting on the Aspen Complex and lodgepole pine (a) 1 year and (b) 3 years following treatment. The control (c) is shown 3 years post-treatment for comparison. Lodgepole pine height and diameter were unaffected by the treatment. Photo credits: Jean Mather and Ed Yourk.
Figure 107 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 IDP/MS Aspen Complex before and after manual cutting. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 3 years post-treatment.
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 IDF/MS Aspen Complex before and after manual cutting. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 3 years post-treatment.
larger stems were girdled the following year, whereas aspen at the other two sites were all treated at once. By year 3, broadleaves were significantly shorter in the treatment compared to the control (166.3 versus 367.4 cm, p = 0.08) (Figure 110), but their cover remained unchanged. Reductions in height and cover of aspen alone were not statistically significant because of the variability among sites (p>0.10). In year 3, aspen was shorter in the cutting treatment than in the control (194.4 cm versus 509.5 cm, p = 0.11). It was visually obvious that brushing reduced total density of aspen, but post-treatment density was not calculated because the measurements were missing from some plots on some sites. Cover and height of shrubs were unaffected by the manual cutting treatment. There was a short-lived decrease in herb cover in the treatment compared with the control in year 1 (66.9 versus 62.5%, p = 0.03), but this effect had disappeared by year 3.

Suckering Almost all (94%) of the cut aspen produced suckers in close proximity to stumps within 1 year of treatment (Table 101). There averaged

<table>
<thead>
<tr>
<th>Year 0</th>
<th>Year 1</th>
<th>Year 3</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Proportion of seedlings</th>
<th>Free of vegetation</th>
<th>Threatened</th>
<th>Overtopped</th>
</tr>
</thead>
</table>

**FIGURE 109** Comparison of lodgepole pine competitive status between the manual cutting treatment and control before, and 1 and 3 years after, treatment of the IDF/MS Aspen 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 100** Cover and height of vegetation in the IDF/MS Aspen Complex before and after manual cutting in lodgepole pine plantations

<table>
<thead>
<tr>
<th>Variable</th>
<th>Cover (%)</th>
<th>Height (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Manual</td>
<td>Control</td>
</tr>
<tr>
<td>Aspen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cover (%)</td>
<td>Pre-treatment</td>
<td>26.6</td>
</tr>
<tr>
<td></td>
<td>1 yr post-treatment</td>
<td>13.5</td>
</tr>
<tr>
<td></td>
<td>3 yr post-treatment</td>
<td>23.2</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>Pre-treatment</td>
<td>305.9</td>
</tr>
<tr>
<td></td>
<td>1 yr post-treatment</td>
<td>213.1</td>
</tr>
<tr>
<td></td>
<td>3 yr post-treatment</td>
<td>194.4</td>
</tr>
<tr>
<td>Broadleaf trees</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cover (%)</td>
<td>Pre-treatment</td>
<td>28.1</td>
</tr>
<tr>
<td></td>
<td>1 yr post-treatment</td>
<td>14.5</td>
</tr>
<tr>
<td></td>
<td>3 yr post-treatment</td>
<td>25.4</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>Pre-treatment</td>
<td>299.2</td>
</tr>
<tr>
<td></td>
<td>1 yr post-treatment</td>
<td>212.9</td>
</tr>
<tr>
<td></td>
<td>3 yr post-treatment</td>
<td>166.3</td>
</tr>
<tr>
<td>Shrub</td>
<td>Cover (%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pre-treatment</td>
<td>23.8</td>
</tr>
<tr>
<td></td>
<td>1 yr post-treatment</td>
<td>21.4</td>
</tr>
<tr>
<td></td>
<td>3 yr post-treatment</td>
<td>24.6</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>Pre-treatment</td>
<td>110.2</td>
</tr>
<tr>
<td></td>
<td>1 yr post-treatment</td>
<td>68.8</td>
</tr>
<tr>
<td></td>
<td>3 yr post-treatment</td>
<td>107.9</td>
</tr>
<tr>
<td>Herb</td>
<td>Cover (%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pre-treatment</td>
<td>59.3</td>
</tr>
<tr>
<td></td>
<td>1 yr post-treatment</td>
<td>62.5</td>
</tr>
<tr>
<td></td>
<td>3 yr post-treatment</td>
<td>61.7</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>Pre-treatment</td>
<td>28.9</td>
</tr>
<tr>
<td></td>
<td>1 yr post-treatment</td>
<td>32.8</td>
</tr>
<tr>
<td></td>
<td>3 yr post-treatment</td>
<td>31.7</td>
</tr>
</tbody>
</table>

- Values denoted with “*” were significant at p ≤ 0.05 according to analysis of variance; n=3. The standard error of the overall mean (s) was calculated as s = √MSE/n, where MSE = Mean Square Error and n = number of replicates.
- Treatment occurred over a 2-year period on one site.
four suckers around each stump, and after 1 year, suckers averaged 44 cm in height. By year 3, 83% of cut aspen still had suckers, but they had thinned to an average of three per stump, and grown to an average height of 138 cm. Second- and third-year sucker growth rates averaged 47 cm/yr.

Richness and diversity of individual species and structural vegetation groups Manual cutting of the Aspen Complex had no effect on either species richness or diversity within 3 years of treatment (p > 0.10) (Table 102). Species richness increased slightly between the pre-treatment assessment (42 species) and the first-year assessment (46 species), and then decreased again in the third-year assessment (40 species). The changes occurred equally in the treatment and control, and were likely related to the timing of assessments.

Richness of structural vegetation groups did not differ between the treatment and control in either the first or third years after cutting (p > 0.10) (Table 103). Diversity of structural vegetation groups was significantly lower in the brushing treatment than in the control in the first year after treatment (p = 0.06 for H, p = 0.05 for SDI), but the difference had disappeared by year 3. This reflects a large initial decrease in broadleaf cover because of the cutting treatment, followed by recovery through suckering.

Data for individual species were available for only two of the three replicate sites. As expected, manual cutting of the Aspen Complex resulted in immediate, large decreases in aspen cover on both sites. Most shrub and herb species occurred low in the understory, and were affected little by the cutting treatment.

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

### Table 101  Suckering characteristics of aspen in the IDF/MS Aspen Complex following manual cutting

<table>
<thead>
<tr>
<th>Response variable</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion of stumps with suckers</td>
<td></td>
</tr>
<tr>
<td>1 yr post-treatment</td>
<td>94</td>
</tr>
<tr>
<td>3 yr post-treatment</td>
<td>83</td>
</tr>
<tr>
<td>Number of suckers per stump</td>
<td></td>
</tr>
<tr>
<td>1 yr post-treatment</td>
<td>4</td>
</tr>
<tr>
<td>3 yr post-treatment</td>
<td>3</td>
</tr>
<tr>
<td>Sucker length (cm)</td>
<td></td>
</tr>
<tr>
<td>1 yr post-treatment</td>
<td>44</td>
</tr>
<tr>
<td>3 yr post-treatment</td>
<td>138</td>
</tr>
</tbody>
</table>

* Treatment occurred over a 2-year period on one site.

### Table 102  Richness and diversity of vascular plant species in the IDF/MS Aspen Complex before and after manual cutting in lodgepole pine plantations

<table>
<thead>
<tr>
<th>Response variable</th>
<th>Manual cutting</th>
<th>Control</th>
<th>Standard error</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Richness</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>41.50</td>
<td>43.50</td>
<td>2.828</td>
<td>0.70</td>
</tr>
<tr>
<td>1 yr post-treatment</td>
<td>45.50</td>
<td>46.00</td>
<td>0.354</td>
<td>0.50</td>
</tr>
<tr>
<td>3 yr post-treatment</td>
<td>40.33</td>
<td>39.67</td>
<td>1.312</td>
<td>0.75</td>
</tr>
<tr>
<td>Shannon-Weaver Diversity Index</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>2.33</td>
<td>2.37</td>
<td>0.150</td>
<td>0.89</td>
</tr>
<tr>
<td>1 yr post-treatment</td>
<td>2.41</td>
<td>2.50</td>
<td>0.218</td>
<td>0.83</td>
</tr>
<tr>
<td>3 yr post-treatment</td>
<td>2.23</td>
<td>2.22</td>
<td>0.107</td>
<td>0.97</td>
</tr>
<tr>
<td>Simpson’s Diversity Index</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>0.83</td>
<td>0.84</td>
<td>0.025</td>
<td>0.81</td>
</tr>
<tr>
<td>1 yr post-treatment</td>
<td>0.82</td>
<td>0.85</td>
<td>0.049</td>
<td>0.71</td>
</tr>
<tr>
<td>3 yr post-treatment</td>
<td>0.81</td>
<td>0.82</td>
<td>0.019</td>
<td>0.76</td>
</tr>
</tbody>
</table>

The standard error of the overall mean (\( \bar{y} \)) was calculated as
\[
S_y = \sqrt{\frac{MSE}{n}},
\]
where MSE = Mean Square Error and n = number of replicates.
cutting treatment. Exotic species of clover (*Tri-fo-lium* spp.) were present at the time of manual cutting, and their cover increased in the treatment within 1 year of brushing. There were no other changes in abundance of individual shrub or herb species across more than one site (Table 104).

**Competition Thresholds**

Competition thresholds were derived for stem diameter of lodgepole pine and Douglas-fir using all PROBE plantations dominated by the Aspen Complex. Most lodgepole pine sites occurred in the the IDFdk and MSdm subzones, and all Douglas-fir sites occurred in the ICHmw subzone (Table 97, Appendix 2). For lodgepole pine, the analysis included three sites that were manually cut, two that were treated with basal applications of tri-clopyr, and one where the aspen was cut and the sprouts sprayed with glyphosate (n = 6) (Table 105). For Douglas-fir, the analysis included two sites where aspen was manually cut and two where it was girdled (n = 4) (Table 106). The range in ages of Douglas-fir, lodgepole pine, and trembling aspen was 2–10, 2–10, and 5–11 years old, respectively. The competition thresholds were derived from total aspen cover (%), total aspen density (stems/ha), and CRH indices (CRH = (aspen cover * aspen modal height)/seedling height).

The competition thresholds for lodgepole pine stem diameter averaged 31% cover, 3180 stems/ha, and 31, using aspen cover, aspen density, and CRH as competition indices, respectively. The thresholds were sharp on most sites, where pine diameter decreased dramatically above the threshold values. Below the thresholds, pine diameter was highly variable across all competition indices (e.g., Figure 111). The proportion of trees that occurred above the thresholds was 45–59% of all trees (treated and control), 33–42% of control trees, and only 8–25% of treated trees. Most trees above the thresholds were control trees (60–90%), whereas most below the thresholds were treated trees (57–71%). Most treated trees (75–92%) were below the thresholds. These results suggest that brushing was moderately successful at reducing aspen density (see earlier density comments) below the thresholds for most treated pine, although many control pine (58–67%) also naturally occurred below the thresholds. As a result of improved competitive environments for

<table>
<thead>
<tr>
<th>Table 103</th>
<th>Richness and diversity of structural vegetation groups in the IDF/MS Aspen Complex before and after manual cutting in lodgepole pine plantations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Means</strong></td>
<td>Manual cutting</td>
</tr>
<tr>
<td><strong>Richness</strong></td>
<td></td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>6.50</td>
</tr>
<tr>
<td>1 yr post-treatment</td>
<td>6.50</td>
</tr>
<tr>
<td>3 yr post-treatment</td>
<td>6.33</td>
</tr>
<tr>
<td><strong>Shannon-Weaver Diversity Index</strong></td>
<td></td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>1.40</td>
</tr>
<tr>
<td>1 yr post-treatment</td>
<td>1.25</td>
</tr>
<tr>
<td>3 yr post-treatment</td>
<td>1.45</td>
</tr>
<tr>
<td><strong>Simpson's Diversity Index</strong></td>
<td></td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>0.70</td>
</tr>
<tr>
<td>1 yr post-treatment</td>
<td>0.63</td>
</tr>
<tr>
<td>3 yr post-treatment</td>
<td>0.72</td>
</tr>
</tbody>
</table>

p-values denoted with “*” were significant at p ≤ 0.10 according to analysis of variance; n = 3. The standard error of the overall mean (y) was calculated as S = \(\sqrt{\text{MSE}/n}\), 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.

**Table 104** Vascular plant species that exhibited trends of increasing cover, decreasing cover, or no change in cover following manual cutting of the IDF/MS Aspen 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).

<table>
<thead>
<tr>
<th>Increasing cover</th>
<th>Decreasing cover</th>
<th>No change in cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broadleaves</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Herbs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Populus tremuloides</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Trifolium</em> spp.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Taraxacum officinale</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Aster</em> spp.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
most treated trees, mean diameter increment improved slightly in the treatment by year 3 (p = 0.02) (Table 99); however, the distribution of pine diameters across aspen neighbourhoods was relatively unchanged (e.g., Figure 111). In addition, only 3% of treated pine trees growing in neighbourhoods below the competition thresholds achieved 80% of the maximum diameter measured on the sites.

The competition thresholds for Douglas-fir stem diameter averaged 21% cover, 24.00 stems/ha, and 19, using aspen cover, aspen density, and CRH as competition indices, respectively. The thresholds were sharp on two sites, where Douglas-fir diameter declined dramatically above the thresholds (e.g., Figure 112), but declined gradually on the other two (e.g., Figure 113). Fewer Douglas-fir than lodgepole pine occurred above the thresholds. The proportion of Douglas-fir that occurred above the thresholds was on average 20–30% of all trees (treated and control), 40–52% of control trees, and only 11–25% of treated trees. Most trees above the thresholds were control trees (78–81%), whereas most below the thresholds were treated trees (61–66%). Most treated trees (75–89%) were below the thresholds. These results suggest that brushing was moderately successful at reducing aspen abundance below the thresholds for most treated Douglas-fir. Douglas-fir diameter distributions appeared to improve following girdling and manual treatments; however, only 5% of treated trees achieved 80% of the maximum diameter measured on the sites.

Unfortunately, there were not enough replicates to test for Douglas-fir diameter responses to either of these brushing treatments.

Linear regressions of lodgepole pine diameter versus competition index were statistically significant (p<0.10) on five of six sites for aspen cover, three of six sites for aspen density, and all sites for CRH (Table 105). The range in adjusted r² values was 0.16–0.42 for aspen cover, 0.07–0.28 for aspen density, and 0.22–0.45 for CRH (significant regressions only). The slopes of the regressions (β) were moderately steep for aspen cover (-0.012 to -0.057), very shallow for aspen density (0 to -0.001), and moderately shallow for CRH (-0.001 to -0.024) compared with other complexes. For Douglas-fir, linear regressions were statistically significant on three sites for aspen cover and CRH, two sites for aspen density (p<0.10) (Table 106). The range in adjusted r² values was 0.21–0.37 for aspen cover, 0.08–0.26 for aspen density, and 0.35–0.39 for CRH (significant regressions only). The slopes of the regressions (β) were moderately steep for aspen cover (-0.014 to -0.042), flat for aspen density (0), and very shallow for CRH (-0.002 to -0.009) compared with other complexes. Fitting a negative exponential function to the diameter-CRH relationships improved the adjusted r² values, from 0.35 to 0.41 for lodgepole pine site 27 (Table 105) and from 0.39 to 0.51 for Douglas-fir site 28 (Table 106).

These results suggest that aspen cover and CRH are better indices than density for predicting lodgepole pine or Douglas-fir growth responses to competition. The cover regressions suggest that aspen competition was moderately important and moderately intense for both lodgepole pine and Douglas-fir.
### Table 105

Competition thresholds, regression equation parameter estimates, p-values, and adjusted $r^2$ values for predicting lodgepole pine stem diameter from the competition indices, aspen density, aspen cover, and CRH, in the Aspen Complex in the IDF/MS zones

<table>
<thead>
<tr>
<th>Site</th>
<th># of trees in the regression (n)</th>
<th>Conifer age (years)</th>
<th>Density threshold (stems/ha)</th>
<th>Linear regression equation predicting diameter from aspen density $^a$</th>
<th>Adjusted $r^2$ for linear regression predicting diameter from aspen density $^a$</th>
<th>p-value for linear regression predicting diameter from aspen density $^a$</th>
<th>Linear regression equation predicting diameter from aspen cover $^a$</th>
<th>Cover threshold (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>4800</td>
<td>10</td>
<td>$y = 4.074 - 0.000 x$</td>
<td>0.00</td>
<td>0.66</td>
<td>40</td>
<td>$y = 5.587 - 0.028 x$</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>1800</td>
<td>2</td>
<td>$y = 7.047 - 0.001 x$</td>
<td>0.28</td>
<td>0.00</td>
<td>20</td>
<td>$y = 7.032 - 0.053 x$</td>
<td></td>
</tr>
<tr>
<td>64</td>
<td>1700</td>
<td>4</td>
<td>$y = 1.479 - 0.000 x$</td>
<td>0.09</td>
<td>0.01</td>
<td>25</td>
<td>$y = 1.709 - 0.012 x$</td>
<td></td>
</tr>
<tr>
<td>66</td>
<td>n.d.</td>
<td>7</td>
<td>$y = 4.827 - 0.000 x$</td>
<td>0.00</td>
<td>1.00</td>
<td>30</td>
<td>$y = 5.224 - 0.031 x$</td>
<td></td>
</tr>
<tr>
<td>67</td>
<td>3900</td>
<td>7</td>
<td>$y = 6.532 - 0.000 x$</td>
<td>0.00</td>
<td>0.94</td>
<td>40</td>
<td>$y = 6.663 - 0.006 x$</td>
<td></td>
</tr>
<tr>
<td>77</td>
<td>3700</td>
<td>3</td>
<td>$y = 8.172 - 0.000 x$</td>
<td>0.07</td>
<td>0.02</td>
<td>30</td>
<td>$y = 8.805 - 0.057 x$</td>
<td></td>
</tr>
<tr>
<td>mean</td>
<td>3180</td>
<td>(s.e.)</td>
<td>(560)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 106

Competition thresholds, regression equation parameter estimates, p-values, and adjusted $r^2$ values for predicting Douglas-fir stem diameter from the competition indices, aspen density, aspen cover, and CRH, in the Aspen Complex in the ICH zone

<table>
<thead>
<tr>
<th>Site</th>
<th>Conifer age (yr)</th>
<th>Density threshold (stems/ha)</th>
<th>Linear regression equation predicting diameter from aspen density $^a$</th>
<th>Adjusted $r^2$ for linear regression predicting diameter from aspen density $^a$</th>
<th>p-value for linear regression predicting diameter from aspen density $^a$</th>
<th>Linear regression equation predicting diameter from aspen cover $^a$</th>
<th>Cover threshold (%)</th>
<th>(s.e.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>10</td>
<td>3500</td>
<td>$y = 5.443 - 0.000 x$</td>
<td>0.26</td>
<td>0.00</td>
<td>20</td>
<td>$y = 5.824 - 0.042 x$</td>
<td></td>
</tr>
<tr>
<td>52</td>
<td>2</td>
<td>1500</td>
<td>$y = 1.930 - 0.000 x$</td>
<td>0.00</td>
<td>0.43</td>
<td>10</td>
<td>$y = 2.420 - 0.014 x$</td>
<td></td>
</tr>
<tr>
<td>74</td>
<td>4</td>
<td>2800</td>
<td>$y = 3.806 - 0.000 x$</td>
<td>0.08</td>
<td>0.01</td>
<td>10</td>
<td>$y = 4.100 - 0.019 x$</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>7</td>
<td>1800</td>
<td>$y = 10.082 - 0.000 x$</td>
<td>0.00</td>
<td>0.80</td>
<td>45</td>
<td>$y = 9.78 - 0.008 x$</td>
<td></td>
</tr>
<tr>
<td>mean</td>
<td>(s.e.)</td>
<td>2400</td>
<td>(460)</td>
<td></td>
<td></td>
<td>21 (8)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 105  
Continued

<table>
<thead>
<tr>
<th>Adjusted $r^2$ for linear regression predicting diameter from aspen cover</th>
<th>p-value for linear regression predicting diameter from aspen cover</th>
<th>CRH threshold</th>
<th>Linear regression equation predicting diameter from CRH</th>
<th>Adjusted $r^2$</th>
<th>p-value Non-linear regression predicting diameter from CRH</th>
<th>Adjusted $r^2$ Non-linear regression predicting diameter from CRH</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.16</td>
<td>0.00</td>
<td>32</td>
<td>$y = 4.969 - 0.010x$</td>
<td>0.35</td>
<td>0.00</td>
<td>$y = 5.349e^{(-0.004x)}$</td>
</tr>
<tr>
<td>0.42</td>
<td>0.00</td>
<td>10</td>
<td>$y = 6.798 - 0.021x$</td>
<td>0.45</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>0.28</td>
<td>0.00</td>
<td>51</td>
<td>$y = 1.561 - 0.001x$</td>
<td>0.44</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>0.16</td>
<td>0.00</td>
<td>19</td>
<td>$y = 5.123 - 0.021x$</td>
<td>0.22</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>0.00</td>
<td>0.61</td>
<td>30</td>
<td>$y = 6.870 - 0.015x$</td>
<td>0.04</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>0.22</td>
<td>0.00</td>
<td>42</td>
<td>$y = 8.618 - 0.024x$</td>
<td>0.27</td>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>

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

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

* General form of non-linear equation is: $y = ae^{bx}$, where $y$ is pine stem diameter, $x$ is CRH, $a$ is the intercept, and $b$ is the shape parameter.

### Table 106  
Continued

<table>
<thead>
<tr>
<th>Adjusted $r^2$ for linear regression predicting diameter from aspen cover</th>
<th>p-value for linear regression predicting diameter from aspen cover</th>
<th>CRH threshold</th>
<th>Linear regression equation predicting diameter from CRH</th>
<th>Adjusted $r^2$</th>
<th>p-value Non-linear regression predicting diameter from CRH</th>
<th>Adjusted $r^2$ Non-linear regression predicting diameter from CRH</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.37</td>
<td>0.00</td>
<td>10</td>
<td>$y = 5.573 - 0.007x$</td>
<td>0.39</td>
<td>0.00</td>
<td>$y = 6.176e^{(-0.003x)}$</td>
</tr>
<tr>
<td>0.21</td>
<td>0.00</td>
<td>20</td>
<td>$y = 2.259 - 0.002x$</td>
<td>0.36</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>0.26</td>
<td>0.00</td>
<td>25</td>
<td>$y = 4.116 - 0.009x$</td>
<td>0.35</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>0.00</td>
<td>0.86</td>
<td>20</td>
<td>$y = 10.283 - 0.020x$</td>
<td>0.01</td>
<td>0.27</td>
<td></td>
</tr>
</tbody>
</table>

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

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

* General form of non-linear equation is: $y = ae^{bx}$, where $y$ is Douglas-fir stem diameter, $x$ is CRH, $a$ is the intercept, and $b$ is the shape parameter.
Figure 111 Relationship between stem diameter of lodgepole pine growing amongst the IDF/MS Aspen Complex and (a) broadleaf cover or (b) CRH, where CRH = (broadleaf cover * broadleaf modal height)/pine height. Data points include both treatment and control subplots for PROBE site 40 (n = 67). 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).
Figure 112 Relationship between stem diameter of Douglas-fir growing amongst the IDF/MS Aspen Complex and (a) broadleaf cover or (b) CRH, where CRH = (broadleaf cover * broadleaf modal height)/Douglas-fir height. Data points include both treatment and control subplots for PROBE site 28 (n = 65) where the thresholds are sharp. 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).
Relationship between stem diameter of Douglas-fir growing amongst the IDF/MS Aspen Complex and (a) broadleaf cover or (b) CRH, where CRH = (broadleaf cover * broadleaf modal height)/Douglas-fir height. Data points include both treatment and control subplots for PROBE site 52 (n = 71) where the thresholds are vague. 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).
DISCUSSION

Conifer Responses

Three years after manual cutting was applied in our study, 100% of lodgepole pine seedlings survived in both the treatment and control. We anticipated high rates of survival because seedlings were well established (7–10 years old) and healthy when brushing took place. Silviculture survey information suggests that a small amount of mortality occurred prior to brushing, and it is possible that survival could have been affected by brushing if it were done when seedlings were younger. However, target stocking was met on our sites, and improving survival was not a necessary management objective. Newsome (1999) found that removing aspen in at least a 1-m radius around seedlings reduced cover for voles and improved pine survival by year 5.

Aspen is less susceptible than conifers to Armillaria root disease (Peterson and Peterson 1995), and its presence may help reduce the spread of root rot. There was no Armillaria-related mortality in our study, however, and where it did occur in unreplicated brushing treatments, it appeared to be equally prevalent in the treatment and control. In contrast, our Mixed Broadleaf-Shrub results (Section 11) indicate that the removal of birch, which is also resistant, can increase the proportion of conifers killed by Armillaria. Whipping from aspen branches is also a common form of conifer damage associated with the Aspen Complex (Lees 1966; Newsome 1997), but none was recorded in our study.

Three years after the Aspen Complex was manually brushed, pine were growing slightly faster in stem diameter but slower in height (leader length) in the cutting treatment than in the control. Therefore, height:diameter ratio was lower in the treatment (56) than in the control (66). This suggests that treated seedlings were becoming sturdier while those in the control were becoming more spindly. Newsome (1999) also found that height:diameter ratio of 5-year-old lodgepole pine was lower in the treatment (56), where all aspen had been removed, than in the control (65). She predicts that reduced aspen densities in the treated area will eventually result in improved pine growth. By contrast, we doubt that the minor improvement in stem diameter increment measured in our study will result in biologically significant increases in growth over the long term. Pine in the control were healthy in our study, even though they were shorter than the surrounding aspen. Our unreplicated results for basal application of triclopyr suggest that pine responds well to that treatment (unpublished data; Appendix 2).

We have not yet studied spruce responses to brushing in the Aspen Complex, but there has been considerable research in northern ecosystems. Lees (1966) found that removing aspen growing in close proximity to understory spruce improved diameter and height of the conifers across a wide range of age classes. In Manitoba and Saskatchewan, stem diameter of 15- to 40-year-old white spruce improved by up to 177% following removal of an aspen overstorey (Yang 1989). In our study, lodgepole pine growth responses were relatively small. This is possibly because both conifers and aspen were relatively young, and because aspen were smaller relative to conifers, compared with other studies. In our unreplicated girdling and manual cutting treatments, Douglas-fir appeared to increase in stem diameter 3–5 years after brushing treatments were applied to the Aspen Complex (Mather and Simard 1997a, 1998; Appendix 2). Responses may vary among conifer species because of differences in their phenotypic plasticity.

Plant Community Responses

Significant reductions in overall broadleaf abundance did not occur until 3 years after Probe initiation because treatment application was spread over 2 years on one of the sites. At that site, small stems were cut 1 year and large stems were girdled the next, resulting in a decrease in broadleaf height between years 1 and 3. Reductions in cover and height of aspen alone (i.e., excluding other broadleaf species) were not significant because of variability among sites, but aspen averaged 62% shorter in the treatment (194.4 cm) than in the control (209.5 cm) 3 years after cutting. Hart and Comeau (1992) concluded that manual cutting was not particularly effective for controlling aspen because of the rapid growth of suckers. However, in our study, cutting successfully reduced aspen height below that of lodgepole pine during the 3-year measurement period.
Suckers occurred in close proximity to most aspen stumps on the study sites, and they grew to a height of 44 cm in the first year. This was slightly less than the average first-year height (0.5–1.0 m) reported for the Salmon Arm District (Haeussler et al. 1990) and substantially less than that (1.5–3 m) reported by Peterson and Peterson (1995). The lower growth rate in this study was partly due to cattle grazing on one of the sites. Opinions vary regarding the most effective time to cut aspen, but sucker production generally appears to be reduced when treatment occurs during the growing season (Haeussler et al. 1990). In our study, aspen was cut in July on one site and September on the other two sites.

Our preliminary results for aspen girdling (Mather and Simard 1998; Appendix 1), as well as other sources (Haeussler et al. 1990; Hart and Comeau 1992), suggest that girdling reduces aspen vigour and minimizes suckering, even though it takes 1–3 years for the full impact of treatment to be expressed. Preliminary results for basal triclopyr application suggest that both cover and height of aspen are reduced and suckering eliminated (unpublished data; Appendix 2). These findings agree with those of Biring et al. (1996).

Cutting aspen did not stimulate the low shrub and herb layers to increase in abundance. In fact, herb cover decreased slightly in the first year after cutting, probably because it was pressed down by the aspen slash. Cutting had no effect on richness or diversity of vascular plant species. Haeussler (1999) also found that most silviculture treatments, including manual cutting, tended not to affect diversity. Manual cutting had no lasting effect on richness or diversity of the structural vegetation groups. This is an important consideration for wildlife because aspen use changes according to the successional stage of the stand; mammals use it prominently in young stands (<20 years old), and bird populations use it increasingly as stands age (Peterson and Peterson 1995). The aspen stands were only 7–10 years old at the time of cutting, and the treatment may have temporarily increased abundance of summer forage (young suckers) and decreased both winter forage and cover for large animals. Cattle traffic increased in the first year after cutting, suggesting that they were grazing the new aspen suckers. Aspen suckers are preferred forage for cattle (DeByle and Winokur 1985) and sheep, although slash from cutting can impede their access (Newsome et al. 1995).

**Effects of the Community on Resource Availability**

Little information is available on mechanisms of aspen competition, but it is thought to hinder conifer seedling performance throughout interior British Columbia, mainly by intercepting light. However, the intensity of light competition may be greater in northern ecosystems, where aspen stands tend to be dense, than in the southern interior, where they are more open (P. Comeau, pers. comm., 1999). For instance, Mather (1988) found that aspen cover in wetter ICH subzones in the southern interior rarely exceeded 10% cover within 15 years of site disturbance. In our study, aspen averaged 26% cover, and understory conifers were healthy and growing well. In north-central British Columbia and Alberta, mature aspen canopies were found to transmit 7–36% (DeLong et al., [2000]) and 14–40% (Lieffers and Stadt 1994) of full light, respectively. Rapidly growing, early seral aspen may compete more strongly for light than maturing aspen, particularly if it is of vegetative origin. This is because sucker-origin stands can be dense prior to self-thinning (Jones 1976; Crouch 1983; Bella 1986), and the trees often have large leaves compared with older, or seed-origin aspen (T. Newsome, pers. comm., 2000; J. Wright, pers. comm., 2000). In addition, the dense canopies of juvenile aspen stands are similar in height to understory conifers, which reduces the incidence of oblique and reflective light compared with mature aspen stands. Brushing treatments are usually applied to aspen that has established postlogging, and that is therefore of similar age to the conifer seedlings. Treatments vary in how rapidly they increase light availability to seedlings. Girdling increases light gradually because aspen dies slowly following treatment (Hart and Comeau 1992), whereas manual cutting and chemical treatments cause more rapid increases in light availability.

Aspen may also compete with conifers for water on drier sites. Aspen crowns are thin on dry sites, suggesting that light may be less important to seedling growth than soil water (T. Newsome, pers. comm., 2000). Aspen also develop obliquely descending lateral roots that increase access to deep sources of soil water (Strong and La Roi 1983), suggesting an adaptation to dry sites. DeLong and Tanner (1996) found that, in northern ecosystems, aspen can reduce both light and soil water to levels
that could limit conifer seedling growth for at least part of the growing season. Some of the understorey species associated with the Aspen Complex on dry sites may also contribute to soil water competition with conifer seedlings. Pinegrass, in particular, is a strong competitor for soil water (Petersen and Maxwell 1987; Nicholson 1989).

Aspen provides a number of benefits to conifers. Aspen canopies can improve the thermal environment for young seedlings in comparison with clearcuts. DeLong et al. (2000) found a much lower incidence of frost damage among spruce seedlings planted under a 40- to 80-year-old aspen canopy than those planted in a clearcut and suggested that it was a result of reduced radiative heat loss. However, young aspen are less likely to protect conifer seedlings from frost damage because low canopies are variable in their effects on air temperature at seedling height (Stathers 1989). Studies that have focused on regenerating white spruce in northern ecosystems have concluded that milder soil and air temperatures under aspen canopies are conducive to juvenile spruce growth, but that continued growth is better in the open (Kabzems and Lousier 1992; DeLong et al. 2000). Low soil temperature is not an important growth-limiting factor in southern interior biogeoclimatic zones where the Aspen Complex is common (e.g., ICH, IDF, MS), but it likely increases in importance in more northern ecosystems.

Aspen provides both short- and long-term nutritional benefits to forest sites. It takes up large quantities of nutrients and stores them in woody tissues, thus retaining nutrients within the ecosystem. It is particularly efficient at retaining calcium, sulfur, and zinc, especially in the bark, which has photosynthetic capability (Pearson and Lawrence 1958). Aspen foliage is shed annually, but it decomposes rapidly (Prescott et al. 2000) and tends to be efficiently cycled within the forest system (Pastor 1990). A modelling study based on data collected in boreal forests of northeastern British Columbia suggests that mixed forests of aspen and spruce will produce greater biomass over several rotations than pure spruce forests of the same density (Wang, Comeau, and Kimmins 1995).

**Competition Thresholds**

The competition thresholds for stem diameter of lodgepole pine and Douglas-fir averaged 3180 and 2400 stems/ha for aspen density, 31 and 21% for aspen cover, and 31 and 19 for CRH, respectively. Above the thresholds, aspen competition appeared to be the most important factor limiting conifer growth, setting an upper limit for conifer stem diameter. About half the lodgepole pine (45–59%) and a smaller proportion of Douglas-fir (20–36%) control and treated trees were growing in aspen neighbourhoods above these thresholds, which suggests that competition was constraining more trees in the lodgepole pine than the Douglas-fir plantations. Brushing left only 8–23% of treated lodgepole pine or Douglas-fir trees in neighbourhoods above the thresholds, indicating that brushing should have released most suppressed trees. However, 29–43% of control trees naturally occurred below the thresholds, which suggests that a large portion of trees would not benefit from brushing. Below the thresholds, stem diameter was highly variable among both treated and control trees. Very few (3–5%) trees were able to achieve greater (280% of the site maximums) growth, and most appeared to be limited by other factors.

The regression analyses showed that the three aspen competition indices explained at best 39–51% of the variation in lodgepole pine or Douglas-fir stem diameter. The importance of competition in the Aspen Complex to conifer performance, as expressed by adjusted $r^2$ values, was similar to that measured in our Mixed Broadleaf-Shrub Complex (this publication) as well as aspen stands in southern British Columbia (Newsome 1997, 1999) and northern Alberta (Navratil and MacIsaac 1996). The moderate predictive ability of the regression models, the wide variability in conifer performance at low-moderate aspen competition levels, as well as the low proportion of conifers constrained by detrimental broadleaf levels (i.e., above the thresholds), in combination, suggest that the diameter of many trees in the plantations may not improve following broadcast brushing treatments. They also suggest that aspen competition was only one of several factors affecting conifer growth in the plantations, and that brushing will not necessarily alleviate the most important limitation to growth for many trees, except for those growing among high aspen densities. Indeed, we found that neither average stem diameter nor diameter distributions of lodgepole pine improved 3 years following broadcast manual treatments of aspen. However, pine diameter increment improved slightly, suggesting
that there may be a delayed diameter response. Newsome (1999) also found no effect of competition from suckering aspen on lodgepole pine diameter 5 years after clearing, preparing, and planting lodgepole pine on a 15-year-old aspen site that was allowed to regenerate to a range of aspen competition levels. However, aspen was still young at that assessment, and its competitive effect on pine was expected to increase with time (T. Newsome, pers. comm., 2000). The long-term effects of aspen removal on pine yield are unknown, but simulations with the FORECAST ecosystem simulation model showed that variation in initial aspen densities had little effect on white spruce stemwood biomass over a 120-year rotation (Wang, Comeau, and Kimmins 1995).

The aspen density thresholds identified for lodgepole pine in our study generally agree with those of other studies. In the Cariboo Forest Region, lodgepole pine stem diameter growth did not decrease significantly until aspen density within a 1.8-m radius exceeded 2000 stems/ha in the IDFDk3/4 and SBSDw1 variants (Newsome 1997, 1999). Our threshold for pine (3180 stems/ha) in the IDFDk2 variant differed for several possible reasons. Firstly, our threshold included all aspen neighbours, whereas Newsome (1997, 1999) included only those aspen taller than target lodgepole pine, which have been shown to be the strongest competitors with spruce and pine (Navratil and MacIsaac 1993, 1996; Newsome 1997, 1999). The young aspen stands in our study (4–11 years old) were structurally complex with strongly left-skewed height distributions, and had approximately six times as many shorter than taller aspen stems/ha (data not shown). The inclusion of all aspen sizes would therefore result in higher thresholds. Because of the strong skew in aspen height distributions, and the lower competitive effect of shorter versus taller aspen, it is possible that a density threshold based only on taller aspen in our stands may be even lower than that of Newsome (1999). Secondly, aspen thresholds were based on 3.99-m-radius neighbourhood plots in our study and 1.8-m plots in Newsome (1997, 1999). Competitive effects have been shown to decrease with distance (Harper 1977; Simard 1990a), and consequently, pine would tolerate a greater density of aspen >1.8 m than <1.8 m distant. Thirdly, the IDFDk2 sites in our study are climatically warmer and slightly wetter than the IDFDk3/4 sites (Steen and Coupé 1997; Lloyd et al. 1990) in Newsome (1999). Broadleaf threshold densities for conifer growth have been shown in other studies to decrease with site productivity (Simard 1990a, 1990b). If thresholds based on taller aspen are indeed lower in our study than in Newsome (1999), as suggested above, then relations with site productivity follow the findings of Simard (1990a, 1990b).

The aspen cover thresholds are similar to those identified in 5- to 16-year-old lodgepole pine–aspen stands in northern Alberta (Navratil and MacIsaac 1996). Lodgepole pine diameter did not decline until aspen cover exceeded 31% in our study, compared with approximately 20% in Navratil and MacIsaac (1996). Our thresholds may be higher because we used total aspen cover, whereas Navratil and MacIsaac (1996) used cover over the top one-third of the target pine tree. Site characteristics also varied considerably between these studies, and others have suggested that competition thresholds vary with site conditions (Simard 1990a; Simard 2001, in review). Competition indices other than aspen density or cover have been successfully applied to pine–aspen stands. For example, Navratil and MacIsaac (1993) found that basal diameter (BD) ratio (tallest aspen basal diameter divided by pine basal diameter) and Lorimer’s competition index (aspen basal diameter divided by pine basal diameter) were much better correlated with pine diameter and height than were aspen cover or density indices. Using these indices, they found that aspen within a 1.8-m radius with a BD ratio >0.75 resulted in sharp reductions in pine diameter growth.

Aspen competition thresholds were considerably lower for Douglas-fir growing in the ICHmw subzone than for lodgepole pine in the IDFDk and MSdm subzones. There are three possible explanations for these differences. Firstly, lodgepole pine is more plastic in its growth response to varying light intensities than most other British Columbia conifer species (Coates and Burton 1999) and may therefore grow well under a wider range of aspen densities. Secondly, the ICHmw subzone is considerably wetter and more productive than the IDFDk or MSdm subzones (Lloyd et al. 1990), and broadleaf density thresholds have been shown to decrease with increasing site productivity (Simard 1990b). This may be due to greater individual growth rates and faster self-thinning among broadleaf neighbours on more productive sites,
resulting in fewer neighbours of similar or greater competitive effect compared with less productive sites. In the ICH zone, aspen grows very quickly and rapidly overtops conifers, whereas, in the drier zones, aspen grows more slowly and is less competitive with conifers. Thirdly, temperature extremes are greater in the IDFdk and MSdm than in the ICHmw subzone (Lloyd et al. 1990), and greater aspen cover may be necessary to protect conifers against growth-inhibiting frosts or vapour pressure deficits (Statthers 1989).

Effectiveness of Treatment at Meeting Management Objectives

Common management objectives for brushing the Aspen Complex are both to improve conifer seedling growth and to help meet free-growing requirements. In this study, lodgepole pine were well established at the time of brushing, and improving survival was not an objective. We measured minor improvements in pine growth as a result of applying manual cutting treatments to the Aspen Complex, but further monitoring is necessary to determine whether the differences eventually become biologically and economically significant. Pine in both the treatment and control were increasing in height at adequate rates according to Vyse and Navratil (1985), but the cutting treatment will likely prove to be necessary for control seedlings to meet the conifer:vegetation height ratio requirement for free-growing.

For our IDF study sites, the old free-growing guidelines (B.C. Ministry of Forests 1995a) specified target stocking of 1000 (minimum 500) well-spaced stems/ha, and required that, 12–15 years after logging, pine must be a minimum of 1.0 m tall and 125% as tall as neighbouring vegetation. For the MS site, it specified target stocking of 1200 (minimum 700) well-spaced stems/ha, and required that, 9–15 years after logging, pine must be a minimum of 1.0 m tall and 125% as tall as neighbouring vegetation. The new free-growing guidelines (B.C. Ministry of Forests 2000) allow broadleaf height to exceed that of conifers in one of four quadrants of the assessment radius, and allows the retention of 1000 broadleaf stems/ha on the IDF sites and 400 broadleaf stems/ha on the MS sites. Our sites have not been surveyed according to the new guidelines, but 3 years after brushing, when pine were 10–13 years old, those in the manual cutting treatment met all of the old free-growing requirements within the assessment window. Control pine met minimum height and stocking requirements, but averaged only 89% as tall as surrounding vegetation. Because pine were increasing in height (39 cm/yr) more slowly than aspen (69 cm/yr), those in the control were not expected to meet the conifer:vegetation height ratio requirement within the free-growing window (Figure 114). Also, although we did not assess the density of broadleaves that were taller than conifers, modal height and cover observations suggest the allowable density specified in the new free-growing guidelines (B.C. Ministry of Forests 2000) would be exceeded.

Management objectives for the Aspen Complex are currently in a state of flux because of increasing utilization of aspen (Peterson and Peterson 1995) and increasing interest in managing mixedwood stands to maintain diversity and long-term site productivity (Wang, Comeau, and Kimmins 1995). In addition, silviculture and range objectives for the Aspen Complex often conflict. It is important to identify competition thresholds for this community to avoid unnecessary brushing treatments.
Comparison of average lodgepole pine and aspen height profiles in (a) the brushing treatment and (b) the control in the years following manual cutting in the IDF/MS Aspen Complex. Height for year 2 is interpolated from actual data. Treated pine outgrew broadleaves 1 year after manual cutting, whereas control pine are expected to remain below the aspen canopy through the free-growing assessment window.
In our study, applying manual cutting to the Aspen Complex appears to have allowed lodgepole pine that were 7–10 years old at the time of treatment to meet all the requirements for free-growing (B.C. Ministry of Forests 2000), whereas untreated seedlings were not expected to do so. The cutting treatment resulted in minor improvements in lodgepole pine diameter growth within 3 years of brushing, but control seedlings were also healthy and growing well. Increases in seedling growth were small, and preliminary findings suggest that there may be no long-term growth and yield benefits. However, further monitoring is required to confirm this. Brushing had no effect on the richness or diversity of vascular plant species, and only a minor, short-lived effect on the diversity of structural vegetation groups. Competition thresholds were identified for lodgepole pine and Douglas-fir using aspen density, aspen cover, and CRH indices; however, regressions explained at best 39–51% of the variation in conifer stem diameter.
MANAGEMENT IMPLICATIONS

1. Our results suggest that brushing is not required to maintain good survival and health of established lodgepole pine (7–10 years old) growing among moderate cover of aspen (average 26%) in the IDF and MS subzones of the southern interior.

2. On our study sites, lodgepole pine growing among the Aspen Complex are not expected to meet the new free-growing requirements without intervention (B.C. Ministry of Forests 2000). Minimum seedling height and stocking standards may be met, but not the conifer:vegetation height ratio requirement. Our results suggest that manual cutting can reduce aspen height sufficiently to create free-growing stands. However, reducing aspen abundance does not appear to generate a large conifer growth response.

3. Minor improvements in lodgepole pine diameter growth are likely to occur as a result of reducing abundance of the Aspen Complex through manual cutting. However, we are uncertain whether these increases will affect yield at rotation. Other studies, mainly in northern ecosystems, show larger seedling growth increases following brushing in the Aspen Complex.

4. Competition thresholds for stem diameter of lodgepole pine and Douglas-fir averaged 3180 and 2400 stems/ha for aspen density, 31 and 21% for aspen cover, and 31 and 19 for CRH, respectively, where all-sized aspen were used in the analysis. These thresholds are comparable to those reported in other studies.

5. Applying manual cutting treatments to the Aspen Complex is likely to have no effect on richness or diversity of individual vascular plant species. Changes in the diversity of structural vegetation groups may occur, but are expected to be short-lived.