Introduction

After harvesting, sites in the Interior Cedar–Hemlock Dry Warm subzone (ICHdw) frequently regenerate to rich, brush-dominated communities that can inhibit successful conifer establishment. Species common to these post-harvested areas include: paper birch (Betula papyrifera Marsh.), Douglas maple (Acer glabrum Torr. var. douglasii [Hook.] Dipp.), redstem ceanothus (Ceanothus sanguineus Pursh), beaked hazelnut (Corylus cornuta Marsh.), ocean spray (Holodiscus discolor (Pursh) Maxim.), common snowberry (Symphoricarpos albus [L.] Blake), thimbleberry (Rubus parviflorus Nutt.), and fireweed (Epilobium angustifolium L.). Located on the lower valley slopes of southeastern British Columbia, the ICHdw subzone also features other important land uses that make forest management complex and controversial. In addition to being the most diverse subzone in the province in terms of tree species (Braumandl and Curran 1992), this subzone often provides critical winter and spring ungulate habitat, and can be important as a source of domestic water. As a result of these resource uses and public pressure, herbicides are rarely used for controlling competition to tree regeneration.

The Redfish Creek Manual Brushing study was established in 1987 by Roger Whitehead of the Canadian Forest Service. The primary objectives of this research trial were to examine the cost effectiveness and productivity of motorized manual brushing treatments (Holmsen and Whitehead 1988) and to compare conifer and vegetation response to multiple motor-manual brushing treatments.

This extension note summarizes the 1997 remeasurement of conifer and vegetation response data collected from blocks 10–13 (Figure 1). These blocks are adjacent to each other and provide a field demonstration of a range of brushing treatments. The objectives of the 1997 remeasurement were to compare brushing treatment vegetation, stocking, and conifer response 10 years after trial establishment. A more detailed report summarizing results from blocks 1–9 can be found in Thompson et al. [1998].

Study Area

The trial was established in 1987 in a recently logged opening along the lower slopes of the mouth of the Redfish Creek drainage located in the West Arm Demonstration Forest, approximately 23 km east of Nelson, B.C. (B.C. Ministry of Forests 1992). The site is in the Dry Warm Interior.
Cedar–Hemlock biogeoclimatic subzone (ICHdw). Prior to harvest, the stand was a mid-seral to early climax stand dominated by western larch (\textit{Larix occidentalis} Nutt.), Douglas-fir (\textit{Pseudotsuga menziesii} [Mirb.] Franco), and ponderosa pine (\textit{Pinus ponderosa} Dougl. P & C Lawson) with varying minor proportions of grand fir (\textit{Abies grandis} [Dougl.] Forbes), western redcedar (\textit{Thuja plicata} Donn), western hemlock (\textit{Tsuga heterophylla} [Raf.] Sarg.), lodgepole pine (\textit{Pinus contorta} Dougl.), and western white pine (\textit{Pinus monticola} Dougl.). Harvesting created a heavy seed tree stand consisting of Douglas-fir, western larch, and ponderosa pine. Over time, many of the seed trees have been blown over and salvaged. The main trial treatment area (blocks 1–9) was broadcast burned in 1983. Blocks 10–13, however, were located in an adjacent area that was burned in 1985. Larch and ponderosa pine were planted during 1987. Most of the post-harvest conifer stocking is of natural origin (Whitehead and King 1990).

At the time of trial establishment, blocks 10–13 contained Douglas-fir and ponderosa pine. Target species consisted of scattered paper birch over 2 m in height and redstem ceanothus, thimbleberry, and fireweed at 1–2 m height and 75% cover (Holmsen and Whitehead 1988). Larch were found only on skid trails in the control block.

**Experimental Design**

Treatments used in blocks 10–13 were: 1) brushed once (1987) (block 12); 2) brushed twice (1987, 1988) (block 13); 3) brushed three times (1987, 1988, and 1989) (block 11); and 4) no treatment (block 10). At each brushing, operators were instructed to “... cut all non-crop vegetation as low to the ground as practical ...” (Holmsen and Whitehead 1988). Husqvarna clearing saws were used to clear all non-conifer vegetation.

Each of blocks 10–13 consisted of a 50 x 50 m treatment plot with the treatment applied to the entire plot. For the purpose of the 1997 plot remeasurement, five 50 m² circular (r = 3.99 m) assessment subplots were established in each treatment block. Analysis of variance (\textit{a n o v a}) and planned comparisons (SAS Institute Inc. 1988) provided statistical evidence for treatment (block) comparisons.
Subplots were used as the design replication (pseudo-replication). Vegetation, crop tree, and silviculture survey assessments were all conducted within these five subplots. Vegetation assessments were conducted during late July 1997 and crop tree and stocking assessments were conducted during early October 1997. Understorey light levels were also assessed in July using a sunfleck ceptometer (Decagon Devices Inc., Pullman, Wash.) to simultaneously record light readings made at approximately 1.3 m and above the canopy.

Standards adopted for crop tree selection were: western larch, Douglas-fir, and ponderosa pine as preferred species; and grand fir, paper birch, lodgepole pine, western redcedar, and western hemlock as acceptable species; with birch as the species of last choice. Target stocking was 1800 trees/ha with an inter-tree spacing of 2.5 m (1.5 m minimum) to a maximum of nine trees per plot. This resulted in mapping the well-spaced trees using conifers first from the preferred list, then from the acceptable list, and then using paper birch to “fill in the holes.” This strategy deviates from current practice in which all acceptable species are considered equal, but it is closer to the intent of the original treatment in which only conifers were considered as crop trees.

All well-spaced crop trees were chosen for individual stem assessments (total height, basal diameter [ground level], diameter at breast height, condition, and vigour). For each well-spaced Douglas-fir, ponderosa pine, and larch, heights were estimated for 1995, 1993, 1991, 1989, and 1987, based on stem internodal distances.

Results

Vegetation Response

Vegetation cover exceeded 120% in all blocks (Figure 2), with birch, ceanothus, thimbleberry, Douglas-fir, and ponderosa pine as the five leading species. However, spotted knapweed (Centaurea maculosa Lam.), a noxious weed, has invaded the area with cover ranging from 5 to 25% of the plots. Redstem ceanothus was found to be over-mature and suffering from snow press, ungulate browse, and low vigor but still maintaining a significant presence. Thimbleberry has formed large dominant understorey patches covering approximately 25% of all plots.

The upper canopy in all treatment plots was dominated by broadleaf and conifer species in varying proportions.

Figure 2 Vegetation cover (%) by treatment. Tall shrub = woody plants 2–10 m, low shrub = woody plants < 2 m (Habitat Monitoring Committee 1990).
Total vegetation cover in the brushed blocks was found to be significantly greater than that in the control block \((p = 0.0166)\) (Figure 2). The control block consisted of a dense birch canopy approximately 7.5 m in height with an understorey layer of low shrubs (predominantly thimbleberry) and herbs. The brushed blocks contained significantly less birch cover \((p = 0.0013)\) with greater cover of Douglas-fir, ponderosa pine, and ceanothus in varying proportions. Birch cover was found to be similar in all the brushed plots. In the untreated control plot, birch cover was approximately twice that of the brushed areas. Significantly less cover of ceanothus was found in the control plot \((6.2\%)\) compared to the brushed blocks \((14-21\%)\) \((p = 0.0014)\). Fireweed, ponderosa pine, and Douglas-fir were also found to have significantly less cover in the control than in the brushed areas \((p = 0.0197, 0.0053, \text{ and } 0.0021\) respectively). There was no difference in thimbleberry cover between any of the treatment areas.

The total number of species found in each plot indicates that there were approximately 20% more species in the area brushed 3X than in any of the other plots \((45, 47, 47, \text{ and } 56 \text{ total species respectively for control, brushed 1X, 2X, and 3X})\). The additional species were found to be both herbs and shrubs. Plot means for number of species were highly correlated with understorey light levels \((r^2 = 0.9925)\).

**Stand Density and Composition**

Stand density and species composition information confirmed visual observations that birch now dominates all treatment areas. Brushing reduced the density and size of birch and promoted the growth and survival of shade-intolerant conifers and other understory vegetation (Figure 3). Late July light measurements showed understorey light to be only 14% of full sunlight in the untreated control, and between 30 and 68% in the brushed areas.

The control plot had 9500 trees/ha, with birch accounting for 84% of the trees. The brushed plots had 6600, 6400, and 7000 trees/ha respectively for the 1X, 2X, and 3X treatments (Figure 3) with birch accounting for 63-65%. Douglas-fir was the predominant conifer species, followed by ponderosa pine and minor...
components of larch, lodgepole pine, cedar, and hemlock. Ponderosa pine was found only as a minor component in the control area (80 trees/ha versus 480–560 in the brushed plots). All ponderosa pine in the control area were found to be unacceptable as crop trees (bent, crushed, browsed). Larch was found only in the control plot in significant numbers (280 sph) and was virtually absent from all the brushed plots. Larch in the control area were large, tall, vigorous trees found within the dominant birch canopy and had height/diameter ratios averaging 95.

The total number of well-spaced and free growing crop trees did not differ between the brushed and control areas (Table 1). All blocks could be considered well-stocked mixedwood stands if birch is used as an acceptable species. All brushing treatments

**Table 1** Well-spaced and free growing trees per hectare. Means followed by different letters within each column signify statistical difference at p ≤ 0.05 using planned comparisons.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Total well-spaced (WS)</th>
<th>Total free growing (FG)</th>
<th>Birch</th>
<th>Douglas-fir</th>
<th>Ponderosa</th>
<th>Larch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1720</td>
<td>1240</td>
<td>1120a</td>
<td>280b</td>
<td>0b</td>
<td>240</td>
</tr>
<tr>
<td>Brushed 1X</td>
<td>1720</td>
<td>960</td>
<td>600b</td>
<td>840a</td>
<td>240a</td>
<td>0</td>
</tr>
<tr>
<td>Brushed 2X</td>
<td>1440</td>
<td>960</td>
<td>400b</td>
<td>880a</td>
<td>160ab*</td>
<td>0</td>
</tr>
<tr>
<td>Brushed 3X</td>
<td>1640</td>
<td>1040</td>
<td>360b</td>
<td>920a</td>
<td>280a</td>
<td>40</td>
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<tr>
<td>p-value</td>
<td>0.326</td>
<td>0.422</td>
<td>0.012</td>
<td>0.015</td>
<td>0.018</td>
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</tr>
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* planned comparison control versus brushed 2X, p = 0.0702.
** ANOVA not performed; see Study Area.

**Table 2** Height and diameter at breast height (dbh) of birch, Douglas-fir and ponderosa pine, and basal diameter of Douglas-fir by treatment for well-spaced trees. Means followed by different letters within each column signify statistical difference at p ≤ 0.05 using planned comparisons.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Birch height (cm)</th>
<th>Birch dbh (cm)</th>
<th>Douglas-fir height (cm)</th>
<th>Douglas-fir dbh (cm)</th>
<th>Douglas-fir basal diameter (cm)</th>
<th>Ponderosa pine height (cm)</th>
<th>Ponderosa pine dbh (cm)</th>
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<tr>
<td>Control</td>
<td>760a</td>
<td>5.3a</td>
<td>181</td>
<td>2.3</td>
<td>2.3a</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>Brushed 1X</td>
<td>546b</td>
<td>3.9b</td>
<td>239</td>
<td>3.1</td>
<td>3.5ab</td>
<td>363a</td>
<td>5.7</td>
</tr>
<tr>
<td>Brushed 2X</td>
<td>496b</td>
<td>3.6b</td>
<td>372</td>
<td>4.6</td>
<td>6.5b</td>
<td>348a</td>
<td>5.7</td>
</tr>
<tr>
<td>Brushed 3X</td>
<td>484b</td>
<td>3.2b</td>
<td>324</td>
<td>4.7</td>
<td>6.1b</td>
<td>467b</td>
<td>8.0</td>
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<tr>
<td>p-value</td>
<td>0.0001</td>
<td>0.019</td>
<td>0.172</td>
<td>0.238</td>
<td>0.079</td>
<td>0.066</td>
<td>0.196</td>
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</table>

significantly increased the number of well-spaced Douglas-fir and ponderosa pine. Conversely, the absence of brushing reduced the number of acceptable well-spaced conifers and promoted development of a birch-dominated stand. Ten years after the first brushing treatment, well-spaced crop trees in the control area comprised approximately 65% birch, 16% Douglas-fir, and 14% larch; the brushed once area—35% birch, 49% Douglas-fir, and 14% ponderosa pine; the brushed twice area—28% birch, 61% Douglas-fir, and 11% ponderosa pine; and the brushed three times plot—22% birch, 56% Douglas-fir, and 17% ponderosa pine. These numbers suggest that the brushing treatments have promoted establishment of a conifer-dominated stand with Douglas-fir the leading species. As the number of brushing times increased, the percentage of well-spaced birch decreased and Douglas-fir and ponderosa pine increased.

**Crop Tree Height, Diameter, and Condition**

Significant treatment differences in crop tree height and diameter at breast height (dbh) were noted for birch and ponderosa pine, and in basal diameter for Douglas-fir (Table 2). In general, it was found that the brushing treatments significantly increased the size of the Douglas-fir (basal diameter) over those found in the control. Acceptable well-spaced ponderosa pine were not found in the control, but brushing three times significantly increased tree height over brushing once or twice.

To indicate the relative stand yield of each treatment area, 10-year total stand volume was calculated from the height and diameter data of well-spaced trees (Figure 4). The response of each crop tree species is clearly differentiated. Brushing reduces birch volume through reducing individual size and density. Both Douglas-fir and ponderosa pine volume appear to increase with increasing times.
brushed. Brushing three times is necessary to promote ponderosa pine growth whereas brushing only twice promoted Douglas-fir growth. Brushing three times resulted in minor increases in Douglas-fir growth over brushing twice. The apparent high volume of larch was due to a few very large individuals.

Height development of the well-spaced ponderosa pine and Douglas-fir can be followed in Figures 5 and 6. For ponderosa pine, brushing three times appears to promote height development, but little if any difference was noted between brushed once or twice. Douglas-fir height development also indicates feasible treatment differences. The untreated control Douglas-fir showed obvious height reduction due to the competition from birch, ceanothus, and other vegetation.

Height/diameter ratios were calculated for birch, Douglas-fir, and ponderosa pine (Table 3). Treatment differences were not statistically

![Figure 4](image-url) Volume of well-spaced crop trees per hectare by treatment.

![Figure 5](image-url) Ten-year height growth for ponderosa pine, by treatment. ANOVA p-values are shown below figure for each year's height treatment comparison. No acceptable ponderosa pine were found in control.
evident. However, apparent height/diameter ratio reductions with brushing intensity were apparent in both Douglas-fir and ponderosa pine.

Conclusions

The Redfish Creek Manual Brushing trial offers a unique opportunity to demonstrate the longer-term implications of manual brushing on stand development.

However, due to the lack of true replication in this demonstration area (blocks 10-13), results should be considered with observations and conclusions from similar research trials (Thompson et al. [1998]). It is important to remember that results from a single study are applicable to that site only and repeated studies at different locations are necessary to increase confidence in the interpretations.

This extension note summarizes the general findings during the 10th post-treatment year at plots 10-13 of the Redfish Creek trial site and, together with the results of plots 1-9 (Thompson et al. [1998]), provides needed information to operational staff on the response of an ICHdw site to manual brushing. The results of the 1997 remeasurement suggest that:

1) Manual brushing of an established birch/shrub brush complex can promote the establishment of a conifer-dominated mixedwood stand. Failure to provide conifer release treatments will promote establishment of a birch-dominated stand at the expense of shade-intolerant species.

2) Manual brushing at least once can significantly increase ponderosa pine and Douglas-fir stocking. However, intensive brushing regimes (at least three times) may be required to promote ponderosa

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Birch</th>
<th>Douglas-fir</th>
<th>Ponderosa pine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>110.7</td>
<td>72.1</td>
<td>na</td>
</tr>
<tr>
<td>Brushed 1X</td>
<td>93.6</td>
<td>70.7</td>
<td>50.2</td>
</tr>
<tr>
<td>Brushed 2X</td>
<td>95.5</td>
<td>62.2</td>
<td>46.4</td>
</tr>
<tr>
<td>Brushed 3X</td>
<td>97.1</td>
<td>60.4</td>
<td>44.6</td>
</tr>
<tr>
<td>p-value</td>
<td>0.1467</td>
<td>0.1839</td>
<td>0.8248</td>
</tr>
</tbody>
</table>
pine height growth. Brushing at least twice may be required to significantly improve Douglas-fir diameter growth.

3) Significant differences in birch density, dbh, and height were realized after manual brushing only once. Brushing birch 2× or 3× appeared to have no significant effect on total birch density, dbh, or height compared to brushing once only. It is important to note that operational hardwood or woody stem brushing rarely if ever is carried out 3 years in a row (as with this trial). In birch-dominated areas, multiple manual brushing treatments would be applied over a 10–15 year period, usually coinciding with over-topping of conifers. With a longer period between multiple brushing treatments, better control of birch may be realized, but conifer response may be delayed or reduced.

Literature Cited


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