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Third-Year Assessment of Prescribed Burning on Forest Productivity of Some Coastal British Columbia Sites

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SUMMARY

Prescribed burning is a widely used forest management tool, yet its long-term effects on site productivity must be better understood. MacMillan Bloedel Limited (MB) and Forestry Canada began a co-operative study of the effects of prescribed burning on tree growth and site nutrition in 1985. This study quantifies the impacts of prescribed fires of differing intensity on organic matter and soils. It also measures tree growth and nutrition, plant succession, soil erosion, and soil nutrients associated with these impacts.

Two low-impact spring burns, two high-impact fall burns, and two unburned controls were replicated on three sites west of Port Alberni on central Vancouver Island. Some spring plots were accidentally reburned during an adjacent fall burn. The opportunity to monitor the reburned area produced some unique data.

The major differences in impact between the spring and fall burns were the consumption of soil organic horizons (forest floor) and the increase in mineral soil exposure. Forest floor consumption was much lower on the spring burns (11 and 25%) than on the fall burns (47 and 78%). Spring burns resulted in less than 5% mineral soil exposure compared to 29 and 74% exposure for fall burns. The reburned area had forest floor consumption and mineral soil exposure similar to those in the adjacent fall burn, but large woody fuel consumption was considerably greater on the reburn. Woody fuel consumption was similar for one pair of spring and fall burns despite substantial differences in forest floor consumption and mineral soil exposure. For the other two burns, the consumption of woody fuels was greater in the fall than in the spring.

Total nitrogen (N) losses from the forest floor alone ranged from 216 kg/ha (10%) for the lowest impact burn to 1328 kg/ha (81%) for the highest impact or “worst case” burn. The most severe fire removed nearly half of the total site N reserves. These losses exceeded the maximum in published regional studies by over 50%. The least severe fire consumed only 7% of total N reserves. Consumption of woody fuels less than 7 cm in size, however, was over 70% on even the lowest impact burn. This suggests that increased plantability can be achieved through a prescribed burn, with minimal impact on site nutrients.

Changes to chemical concentrations in the remaining litter after the spring burns included an increase in pH, mineralizable nitrogen, sulphate sulphur, total phosphorus, and total potassium. The most significant chemical changes to the remaining F and H organic layers were increases in pH and sulphate sulphur. Although some changes in concentration persist after 3 years, results suggest that the most important lasting effect of fire on the organic horizons is on total nutrient content rather than on changes in concentration. The most significant changes to the upper mineral soil were an increase in pH and available phosphorus after fall burns.

Mean surface level changes measured with the erosion bridges were extremely variable. Consequently, erosion could not be proven conclusively for any site but one. Nevertheless, the net decrease in surface level for nearly all plots suggests that erosion is taking place on exposed mineral soil. Unburned areas showed an average reduction in forest floor depth of over 1 cm/yr from decomposition and compaction.

All sites were planted in March 1986 with Douglas-fir, western redcedar, and yellow-cedar. Tree growth, vegetation cover, and soil nutrients will be monitored annually for 5 years, followed by periodic long-term monitoring. This report describes 3rd-year results.

After three growing seasons:

- Douglas-fir had the best overall 3rd-year survival (83–91%) of the three conifers. There was no relationship evident between fire impact and Douglas-fir survival. Western redcedar had its best survival on the most severely burned sites. Redcedar mortality was greatest over the first winter. Yellow-cedar survival was better on burned areas than on adjacent unburned areas.
• Seedling stem volume was greater for all species on burned areas than on adjacent unburned areas, except for redcedar at Kanyon. Better growth on burned sites is most likely due to reduced shrub competition. Where spring, fall and spring-fall reburn treatments were adjacent, the reburned area had 2–4 times greater seedling volume for all species than did other treatments. For redcedar and yellow-cedar, the fall burn had greater volume growth than did the adjacent spring burn.

• Trees planted in exposed mineral soil had as good or better survival and volume growth as those planted where there was forest floor remaining.

• Douglas-fir foliar iron (Fe), copper (Cu), calcium (Ca) and zinc (Zn) levels were positively correlated with forest floor reduction; foliar manganese (Mn) was negatively correlated with forest floor reduction. Yellow-cedar and western redcedar foliar Fe increased and phosphorus (P) decreased with greater forest floor reduction.

• Deer browse was greatest in the 1st year on Douglas-fir, and was greater on burns than adjacent controls. Browsing since the 1st year has not been significant.

• Natural seed-in of primarily western hemlock and Douglas-fir is occurring on all sites. The number of natural seedlings is higher on the fall burns (540 trees per hectare) than on the spring burns (110 trees per hectare).

• Higher intensity burns reduced shrub growth to a greater extent than lower intensity burns.

While these early results suggest that even the most severe fire had positive effects on initial seedling growth, substantial losses of organic matter and nutrients may adversely affect long-term productivity. Future measurement of these sites will quantify these effects.

Other projects associated with this study, either completed or under way, include: microsite effects of burning (Forestry Canada), soil variability (MB/B.C. Ministry of Forests [BCMF]), changes in wildlife forage production with fire treatments (BCMF), effects of fire intensity on mycorrhizal inoculum potential (MB/BCMF), effects of fire on sulphur (UBC/B.C. Science Council), and effects of fire on mineralizable nitrogen (UBC/B.C. Science Council).

A final report on 5th-season tree growth and short-term site effects will be completed in 1992.
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- **Mark Walmsley, Pedology Consultants; Dr. Michael Feller, University of British Columbia; Anne Macadam and Rick Trowbridge, B.C. Ministry of Forests, Prince Rupert Region; and John Parminter, B.C. Ministry of Forests Protection Branch.**

- Finally, we dedicate this report to the late Bill Motyka, former Fire Protection Officer at Sproat Lake Division, whose support for the project made it possible.

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1 INTRODUCTION

1.1 Background

Prescribed burning is used widely in coastal British Columbia as a silvicultural tool for site preparation and fuel hazard reduction following clearcut logging. Over 8000 ha are burned annually in the Coastal Douglas-fir and Coastal Western Hemlock biogeoclimatic zones. The effects of fire on forest ecosystems are highly variable, depending on site characteristics and fire intensity. Fire effects may be either beneficial or detrimental to forest productivity. A comprehensive literature review of the ecological effects of slash burning, with particular reference to British Columbia, found that in many previous studies the ecosystems and fires were poorly characterized (Feller 1982). This limits our ability to extrapolate results to similar ecosystems for site-specific burning guidelines.

An issue of the Journal of Forestry (1984:18[2]) on the state of the art of prescribed burning further highlighted the need for additional, well-focussed research on the effects of fire. The position statement of the Society of American Foresters (SAF) in this issue identified the net effect of fire on soil nutrients, specifically nitrogen, as being unclear and warranting further investigation (SAF 1984). Furthermore, a problem analysis of prescribed fire (Auclair 1982) identified a need for research that addresses two key topics:

1. the effect of prescribed fire on site productivity, particularly long term.
2. a need for improved, site-specific fire prescriptions.

The problem analysis concluded that future studies should precisely measure fire intensity and behaviour, tree growth effects and other biotic responses, and the resulting positive or negative impacts on site productivity. This study was designed to address these important gaps in our current knowledge.

1.2 Problem Statement

Concern for possible long-term detrimental effects of forest floor organic matter consumption and accelerated soil erosion from fire was the basis of fire sensitivity ratings developed by the B.C. Ministry of Forests (Klinka et al. 1984). These guidelines help foresters make appropriate burning prescriptions. On some sites, detrimental effects must be weighed against the need to establish full stocking. Excessive slash or brush may prevent adequate reforestation on sites where detrimental long-term effects of burning are predicted and no feasible alternative site preparation methods exist. Foresters may have to make trade-offs between prompt and complete reforestation, and maintenance of site productivity. This study addresses this issue by documenting the specific effects of fires of different intensities on potentially sensitive ecosystems.

1.3 Objectives

The overall objective of this study is to improve our ability to use prescribed fire as a silvicultural tool while minimizing its short- or long-term detrimental effects on tree growth and site productivity.

The specific objectives are to:

1. measure fuel and weather conditions, forest floor consumption, mineral soil exposure, erosion, woody fuel consumption, and nutritional changes for a range of fire intensities on selected ecosystems potentially sensitive to fire; and

2. determine the short-term effects of fire on tree growth and plant succession during plantation establishment, and establish long-term monitoring of site productivity and nutrient status.
2 SITE DESCRIPTION

Three sites were chosen within Sproat Lake Woodlands Division of MacMillan Bloedel Limited (MB), west of Port Alberni, B.C. (Figure 1). The criteria for site selection were:

- clearcuts available for slashburning during 1985;
- slash accumulations that prevent adequate reforestation within the allowable waiting period under B.C. Ministry of Forests' guidelines; and
- ecosystems considered to be potentially adversely affected by burning.

Some important site characteristics for the three study areas are given in Appendix 1.

The sites are south to southeast-facing slopes between 450 and 650 m in elevation, within the Coastal Western Hemlock Biogeoclimatic Zone, Wetter Maritime Subzone (Nuszdorfer et al. 1985). The Cous and Macktush sites are within the Leeward Submontane Maritime (CWHb3) Variant; the Kanyon site is mapped as the Windward Submontane (CWHb1) Variant, although it more closely resembles the CWHb3 Variant because of its southerly exposure. The upper slopes of all areas border the Windward Montane (CWHb2) Variant.

All sites are moderate to steep, with rapidly to well-drained loamy soils up to 1.5 m deep. Mineral soil bulk density averaged 1170 kg/m³ with no substantial differences among sites (Appendix 2). The soils are generally Orthic Humo-Ferric Podzols derived from glacial till, in many places capped by a veneer of rubbly colluvium. Outcrops of the underlying Karmutsen basalt bedrock are common.

Average total depth, weight per unit area, and bulk density of the pre-burn forest floor (LFH organic horizons) were not found to be significantly different among sites (Appendix 2).

The study areas supported poor to medium productivity old-growth stands of western hemlock and amabilis fir, with varying amounts of western redcedar, yellow-cedar, and Douglas-fir. These stands were all-aged, with a median age of dominant trees of 275 years. Two veteran Douglas-fir were about 890 and 1150 years old.

A salal – Oregon grape site association dominated the study areas before burning (Appendix 3). Red huckleberry, Alaska blueberry, and oval-leaved blueberry were abundant. Salal and total shrub cover were greatest on the Macktush site and the fall burn portion of the Kanyon site. Other than fireweed, herbaceous cover was sparse; vanilla leaf, twinflower, and swordfern occurred in localized patches.

Most plots were classified as Site Unit 2 in the CWHb3 variant (Klinka et al. 1984); Site Units 3 and 4 were also represented. The volcanic parent materials and moder humus form on the study areas suggest moderate nutritional status, where soil depth is not a limiting factor. The tree species recommended for reforestation by Klinka et al. (1984) is Douglas-fir.

Fire sensitivity classes were assigned to each plot based on the criteria given in Klinka et al. (1984). Nearly all plots were classified in the medium and high sensitivity classes. Two plots in the Kanyon area were classified as low and very high; portions of the other study areas also represent these classes. Very high sensitivity to fire occurred where the soil was very thin (<25 cm) or where the coarse fragment content of rubbly colluvium was over 80%.

The trees on the Macktush site were felled in early 1982; the other sites were felled a year later. Most of the area was yarded in 1983 using highlead and grapple cable yarding systems. The age of slash from time of falling to time of burning was as follows: Cous, 2 years; Kanyon, 2.5 years; Macktush, 3–3.5 years.
3 METHODS

3.1 Experimental Design

The treatments were replicated using a balanced incomplete block design. Two replicates each of two prescribed fire treatments and a control (unburned) were allocated to three blocks so that one block has both fire treatments and the two others each have a fire treatment and a control (Table 1). The original design was altered after accidental reburning of four spring plots changed the number of high- and low-impact plots at Macktush. One additional low-impact plot was established in a spring burn at Kanyon.

The low- and high-impact treatments occurred in the spring and fall of 1985, respectively. The fires were designed to reduce surface organic matter by a specified depth (from 0 to 50% for a low-impact treatment and over 50% for a high-impact treatment). Reference to treatments throughout the report as spring and fall is not meant to imply that season of burning is the only factor influencing impact.

<table>
<thead>
<tr>
<th>TABLE 1. Modified balanced incomplete block design for prescribed burning treatments</th>
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<tbody>
<tr>
<td>Block (Site)</td>
</tr>
<tr>
<td>-----------------------</td>
</tr>
<tr>
<td>1. Cous Creek</td>
</tr>
<tr>
<td>(Br. 460)</td>
</tr>
<tr>
<td>2. Macktush</td>
</tr>
<tr>
<td>(Br. 453)</td>
</tr>
<tr>
<td>3. Kanyon</td>
</tr>
<tr>
<td>(K200)</td>
</tr>
</tbody>
</table>

a Number of plots.
b Planned and (actual).
c Five fall burn plots, plus four spring plots reburned.

3.2 Prescribed Fire Treatments

3.2.1 Monitoring

Burning prescriptions to meet the desired impact levels were developed for each area in conjunction with MB divisional staff. Burning date was determined using the Canadian Forest Fire Danger Rating System (Stocks et al. 1989). Electronic weather stations (Forest Technology Systems, Inc.) were established on each site in early March 1985 to record temperature, relative humidity, wind and precipitation for the entire fire season, ensuring accurate fuel moisture code calculations. A Weather Measure recording hygrothermograph and manual rain gauge were installed as backup. The hygrothermographs proved to be more accurate than the electronic sensors for relative humidity determination; consequently, the hygrothermograph values were used for all calculations.

Standard fire weather readings were taken at 1200 hours (PST) for temperature and relative humidity at 115 cm above ground, wind velocity and direction at 10 m, and accumulated precipitation in the previous 24 hours. Temperature, relative humidity and wind velocity were recorded immediately preceding and during the burns.

Fuel moisture samples were taken by Forestry Canada personnel before the burns, following the procedures outlined in McRae et al. (1979).

Three burns were ignited with a helitorch; the fourth burn was ignited manually. A horizontal strip ignition pattern was used for all burns. To estimate rate of spread, reference points were established and the fire spread was observed from a convenient vantage point. The progress of the fire was extensively documented on video tape and 35-mm colour slides.
3.2.2 Spring burning

The two spring burns occurred May 21, 1985. Details on light-up conditions and Fire Weather Indices are given in Appendix 4. The Cous Creek area was ignited shortly after 1600 hours. With the helitorch, strips 20–30 m apart were ignited starting at the top of the clearcut area and progressing downslope. Ignition was completed in 45 minutes. After 75 minutes, the convection column collapsed and few open flames were visible from across the valley.

Sprinkler lines were used to control the perimeter of the fire. Water was pumped from a nearby creek for 4–5 hours before the burn. Sprinklers had also operated for 3 hours, 4 days earlier.

The sprinkler lines, wetting a strip about 20 m wide, were successful for control except at a gap in the line near the lower boundary of the setting. The Martin Mars water bomber was used to eliminate this gap.

The Macktush site was ignited 2.5 hours after the Cous site, and took 50 minutes to complete. Sprinklers were used to control the fire along the edge of a gully separating the spring and fall treatment areas.

The helitorch was successful for both spring burns. The slash immediately adjacent to mature timber was lit without control problems because of the moist condition of the forest floor.

3.2.3 Fall burning

The first of two fall burns occurred September 25, 1985, at the Kanyon site (Appendix 4). The area above the road that divides the clearcut in half was burned in the spring to reduce fuel loading. A single plot was established in the spring burn and was protected with sprinklers during the fall burn.

Ignition began with a strip along the lower edge of the road. The ignition plan was to allow this strip to burn downslope before additional strips were lit. Because of heavy fuel loading, however, the fire could not be contained below the road, and so the spring area (except the sprinkled plot) reburned, along with a fringe of poor quality timber on rock outcrops. To draw the fire away from the upper timber edge, the entire area below the road was ignited. Control action was taken the following morning to mop up the perimeter of the fire and continued for several days.

The second fall burn occurred October 5, 1985. This fire was hand-ignited and allowed to burn downslope overnight, taking advantage of downslope winds and maximizing consumption of woody fuels and forest floor. The initial line of fire along the road at the upper boundary of the block was ignited with a truck-mounted diesel torch. The perimeter of the 4-ha area was watered by sprinklers for 36 hours before ignition. Three Martin Mars water bomber drops with Gelguard were applied to the timber edge above the clearcut just before burning.

With these precautions, control of the initial burn was successful. Mop-up began the following morning. Crews controlled a few small spot fires in the adjacent spring burn and kept the smoldering fire within the sprinkler control lines. By midnight of the day after light-up, however, there were unforecasted winds estimated to be over 70 kph. This caused a major escape that spread several kilometres by 3:00 a.m. MacMillan Bloedel and B.C. Ministry of Forests personnel spent 4 days suppressing the wildfire. Approximately 80 ha of untreated slash, 57 ha of mature timber, and 36 ha of 3-year-old plantation were burned.

On the research area, four of the five spring burn plots burned again. Two plots had been sprinkled before the fall burn, one did not reburn, and the other experienced spotty reburning. Fortunately, the reburned plots could be measured to quantify the additional woody fuel and forest floor consumption, and this provided some unique data. Sufficient area was saved by the sprinkler system to allow tree growth monitoring in the spring (low-impact) area as a comparison to the adjacent fall and reburned (high-impact) areas.
3.2.4 Aerial photography and mapping

Low-level air photographs were obtained before and after burning to prepare detailed maps of the study areas and fire boundaries on a 1:1000 topographic base. The corner posts of each plot were marked with plastic targets during photography to allow accurate location of plots. Rock outcrops, large stumps and other features were mapped near each plot. Mapping was done by the Photogrammetry Section of MB Woodlands Services Division. These maps will facilitate plot location for long-term monitoring.

3.3 Field Procedures

Site attributes (slope, aspect, elevation, etc.), vegetation cover, woody fuel conditions, soil characteristics (horizon descriptions, bulk density, organic and mineral horizon nutrient content), and forest floor depth were measured before burning. Conditions affected by burning were remeasured after the prescribed fires. Colour slides were taken annually from six permanent photo points per plot. Details of the sample plot layout are given in Appendix 5.

3.3.1 Woody fuel and forest floor

Woody fuels were measured using the line-intersect method of Van Wagner (1968) as presented by McRae et al. (1979). Five sample plots, consisting of three 30-m line transects arranged as a triangle, were located systematically within each treatment replicate (Figure 1). To select plot locations, a dot grid was placed randomly over a map of the treatment area. Points that fell near a road, timber edge or major gully were omitted; and points that fell on major rock outcrops were eliminated during field layout. The base of each triangle was oriented from a random compass bearing. Steel fence pins with metal identification tags permanently mark each plot.

Forest floor depth was measured in three locations at 5-m intervals along the line transects, using 40-cm t-bar type depth-of-burn pins, for 45 pins per sampling triangle. In addition, 40 point measurements of forest floor reduction were obtained for each plot using a method developed for surface erosion point sampling called the "erosion bridge" (Ranger and Frank 1978). In this technique, 20 repeatable point measurements are obtained over a 2.4-m line transect. Five pins were located near the bridge transects to make a total of 50 pins per plot. The combination of these two forest floor measurement techniques yielded 450 point samples per treatment unit and tested the applicability of the erosion bridge for depth-of-burn measurement.

3.3.2 Soils

Exposed mineral soil was measured along the woody fuel sampling transects and along three additional line transects extending between the midpoints of the sides of the sampling triangle, for a total of 135 m of line transect per plot (875 m per treatment). Soil surface level changes were measured at five erosion bridge stations (100 point samples) located on exposed mineral soil, one within each plot. If exposed soil was not present within the plot, the station was located at the nearest available site. Surface level changes of the remaining forest floor, or exposed mineral soil, were also measured annually on the 200 point samples used for depth-of-burn monitoring.

A systematically located soil pit was described and sampled for each plot. Total coarse fragment content was estimated visually. Surface organic matter (forest floor) and mineral soil bulk density samples were taken at each of the five plots per treatment unit. Forest floor bulk density was estimated by cutting a 30 x 30 cm sample down to mineral soil, measuring depth of the LFH layers on four sides of the hole, and drying and weighing the sample. Mineral bulk density was determined by carefully excavating a hole approximately 1000 cm³ in size to a depth of 20 cm, filling this hole with a known volume of silica sand, and drying and weighing the sample.

Samples of soil organic horizons and the upper 20 cm of mineral soil were taken from 10 locations within each plot and bulked to give one sample of LFH and mineral soil per plot (five samples per treatment replicate). These samples were analyzed for the following nutritional properties: pH (H₂O, CaCl₂), total
carbon (C), total N, mineralizable N, available P, exchangeable cations (potassium [K], Ca, magnesium [Mg], sodium [Na]), cation exchange capacity, pyrophosphate extractable Fe and aluminum (Al), sulphur (S), boron (B), and total elements for organic samples (N, P, K, Ca, Mg, Na, Mn, Cu, Zn, Fe).

In addition, the 10 individual samples from one of the triangles, chosen at random, were analyzed for selected properties to obtain an estimate of soil variability. The additional soil analysis was funded by the B.C. Ministry of Forests through Section 88 of the Forest Act. Results were reported by Reese (1987a). Based on these results, samples were taken from 15 locations per plot in year three to improve confidence levels for several nutrients.

3.3.3 Vegetation cover

Vegetation cover was estimated following the method of Macadam and Trowbridge (1984), as modified from Stickney (1980). Permanent plots consist of a 5 × 25 m transect oriented parallel to one side of the woody fuel triangle. The transect is divided into five 5 × 5 m plots, each containing two smaller nested plots (3 × 3 m, 1 × 1 m). Total vegetation coverage was estimated on the 5 × 5 m plots, shrub coverage on the 3 × 3 m plots, and herb and bryophyte coverage on the 1 × 1 m plots.

Permanent plots were established to monitor natural regeneration. Four circular (2.4-m radius) plots were located in each sampling triangle, for a total of 20 plots per treatment replicate. The number of natural seedlings was recorded by species. Up to three trees per plot were tagged and measured annually for comparison to planted trees.

The MB standard regeneration survey procedure was used to obtain an estimate of existing conifers and plantable spots on each treatment unit before burning.

3.3.4 Plantation establishment and measurement

All treatment units were planted March 14–21, 1986, with Douglas-fir (Pseudotsuga menziesii), western redcedar (Thuja plicata) and yellow-cedar (Chamaecyparis nootkatensis). All trees were planted by the same two planters from the Sprout Lake Division crew, and were the same stock type (PSB 313 — plugs grown in 3 × 13 cm styroblock containers). Details on seedlot, lifting and storage are given in Appendix 6.

A sample of 50 trees of each species was used for root growth capacity testing and examination of roots for mycorrhizal infection. Root growth capacity tests give a relative indication of the physiological vigour of seedlings. All three species were rated as having good vigour using this test.

A mixed plantation of 120 trees, with species allocated randomly to 10-tree rows, was superimposed over each woody fuel sampling triangle. With one exception, each treatment replicate has 200 trees of each species staked and tagged for repeated measurements. Because of the reburned plots at the Macktush site, there are about 150 trees of each species on both the spring burn and reburned areas (stock limitations prevented planting 200 trees on both with the extra treatment). Trees representing the spring impact were planted on the one unburned plot, and in an unburned strip watered for control purposes adjacent to the reburned plots. In total, 4050 trees were staked and tagged for measurement.

Tree height and basal caliper were measured after planting and remeasured annually each fall. Trees were also rated for vigour, deer browse, brush encroachment, planting substrate and shade. The rating system for these assessments is given in Appendix 7.

Tree foliar nutrient samples were taken in the fall of the 3rd year after burning, following the procedures recommended by Ballard and Carter (1983). Foliar sampling will be repeated in the 5th year. Soil nutrient samples were repeated at the time of foliar sampling.
3.4 Laboratory Analysis

Samples were prepared and analyzed by the MB Environmental Laboratory in Nanaimo.

Mineral soil samples were air-dried at 25°C and sieved to remove coarse fragments greater than 2 mm in diameter. Subsamples of the less than 2-mm fraction were ground in a mortar and pestle to pass 60-mesh and 100-mesh sieves. Organic samples were air-dried and ground in a Wiley Mill to pass a 1-mm sieve.

Soil texture was determined on mineral samples by hydrometer and wet sieving after the organic matter was destroyed by hydrogen peroxide and oven-dry weights were assessed (Gee and Bauder 1982). Samples were assigned to textural classes according to the Canadian System of Soil Classification (Canadian Soil Survey Committee 1978).

Soil chemical properties were analyzed using the following methods:

- The pH of the mineral samples was determined with a pH meter in both a 1:1 soil:water suspension and a 1:2 soil:0.01 M CaCl₂ suspension. The pH of the organic samples was determined in a 1:2 soil:water suspension (Pech 1965).
- Total N was determined colorimetrically with a Technicon Autoanalyzer II (Technicon Industrial Systems 1976) after the 60-mesh mineral samples were digested in sulphuric acid and catalysts (K₂SO₄, CuSO₄ and Se) in a block digester (Bremner 1965).
- Available phosphorus was determined for mineral samples using the Bray method of acid ammonium fluoride extraction (Olsen and Dean 1965). The colour was developed in ammonium molybdate and stannous chloride, and read at 660 nm on a spectrophotometer.
- Organic carbon was determined on the 60-mesh mineral samples and <1 mm organic samples using the Walkley-Black wet oxidation method (Allison 1965). Exchangeable cations were determined on the mineral samples by atomic absorption spectrophotometry after extraction with neutral 1 N NH₄OA. Cation exchange capacity (CEC) was assessed by Autoanalyzer after extraction with KC (Chapman 1965). Iron and aluminum were determined on the 100-mesh mineral samples by atomic absorption spectrophotometry after extraction with 0.1 M sodium pyrophosphate (Bascomb 1968).
- Total macro- and micronutrients (N, P, K, Ca, Mg, Mn, Fe, Cu, and Zn) for organic samples were determined by wet oxidation with an acid digest (H₂SO₄ + H₂O₂) using a modification of the Parkinson and Allen (1975) method. Total N and P were determined on the Autoanalyzer II (Technicon Industrial Systems 1976), and the other elements were determined by atomic absorption spectrophotometry.
- Mineralizable nitrogen was determined through the 2-week anaerobic incubation method (Waring and Bremner 1964).
- Available boron was determined through the hot water soluble azomethine H method (McKeague 1978).

3.5 Data Analysis

Data were analyzed using BMDP (Dixon et al. 1990) and SYSTAT (Wilkinson 1988) statistical software. Because of the alteration to the original experimental design caused by the accidental burning, a series of orthogonal contrasts was performed using the SYSTAT Multivariate General Linear Model procedures for unbalanced, incomplete block experiments, and BMDP-P7D.5 user-specified contrasts. When appropriate, multiple comparisons of means were done using a Tukey-Kramer HSD test for unequal sample sizes (Day and Quinn 1989). Simple linear regressions were used to test relationships between foliar nutrients and fire impacts.

Woody fuel consumption was computed for each plot and summarized by treatment replicate using a computer program developed by Forestry Canada.¹

Nitrogen losses from consumption in woody fuels, LFH horizons and the upper mineral soil were estimated for the four prescribed fires. Pre-burn and post-burn soil nutrient content was calculated for L and FH horizons separately. The difference between pre-burn and post-burn nutrient mass was assumed to represent atmospheric losses and leaching, the former having the predominant effect. Calculations did not account for leaching of nitrogen that may have been captured in the lower mineral soil; consequently, estimates are somewhat higher than actual losses.

Several measures of seedling growth were used to compare treatments: total height, height growth, relative height growth (height growth/initial height), caliper (root collar diameter) and total stem volume ((3.14 [D/2]²/3) x HT). Stem volume was chosen as the best measure for comparing treatments because it incorporates both height and caliper growth.
4 RESULTS AND DISCUSSION

4.1 Direct Impacts of Burning

Figure 2 summarizes the direct impacts of fire on woody fuel consumption, forest floor consumption and mineral soil exposure. In these graphs, the six site/treatment combinations are arranged along the x-axis in order of increasing fire intensity, based on forest floor consumption. The spring burn at Kanyon (KL) was included on the graphs, but has been omitted from the discussion because it represents only a single plot. The pre-burn inventory and consumption of woody fuels and forest floor are detailed in Appendix 8.

In addition to the plot-based impact assessment in this study, more localized fire impacts were documented by Forestry Canada using micro-plots on selected areas. These results were summarized by Hawkes (1986).

4.1.1 Woody fuel consumption

Figure 2a presents woody fuel consumption for the <7-cm (small) and >7-cm (large) fuel size classes. Consumption of small woody fuel did not differ significantly among treatments, except for the two spring burns. All fires consumed over 70% of the small slash; on the reburned area, virtually all small slash was consumed.

Large woody fuel consumption ranged from 20 to 44% for the four initial fires, but was 68% for the area burned twice. The mass consumed was greatest on the Kanyon fall burn and Macktush reburn. Most of the consumption on the reburn occurred during the second fire. Consumption from the reburn alone was much greater than on the adjacent fall burn, presumably because fuels were already charred.

Total percent woody fuel consumption was the same for the Cous spring burn and Kanyon fall burn; however, the mass consumed was greater on the Kanyon burn because of greater fuel loading. The total mass of woody fuels consumed at Kanyon was similar to that at the reburn (Appendix 8).

Total pre-burn woody fuel biomass of 84–201 Mg/ha was within the range observed by Feller (1989) for 16 slashburns monitored within the Coastal Western Hemlock zone. Woody biomass was generally higher than for broadcast burning studies on cable yarded sites in the Cascades and Coast Range of Oregon and Washington (Little and Klock 1985; Little and Ohmann 1988). Total slash consumption was within the range measured by Feller (1989), but the percent consumption (45–73%) for the four Sproat Lake fires exceeded the maximum percent consumption recorded by Feller on all but two fires (48 and 50%). The 73% woody fuel consumption on the reburn was exceeded by Little and Klock (1985), but with slash loads of only 24–65 Mg/ha.

The Prescribed Fire Predictor developed by the Canadian Forestry Service (Muraro 1975) underestimated <7-cm fuel consumption at 60% for the two spring burns and Kanyon fallburn. Actual consumption ranged from 71 to 87%. Although the Predictor was not designed for the backing fire used for the Macktush fallburn, it did accurately predict small woody fuel consumption.

4.1.2 Forest floor consumption

The objective of achieving average forest floor depth reductions under 50% for the spring burns and over 50% for the fall burns was met. Depth-of-burn averaged 2.4–3.8 cm on spring burns, and 7.6–12.7 cm on fall burns for average pre-burn LFH depths of 15–20 cm (Appendix 2). Instead of two distinct levels of consumption from the low- and high-impact prescriptions, however, the fires produced a range of forest floor consumption (Figure 2b). This was advantageous for regression analysis.

Forest floor consumption was significantly greater (P <0.01) on the fall burns than on the Macktush spring burn. It was also significantly greater (P <0.01) for the fall burn and reburn at Macktush than at the Kanyon burn.
FIGURE 2. Direct fire impacts.
For the spring burns, the Cous fire consumed 35% more forest floor than the Macktush fire, even though the Fire Weather Indices were the same for the two sites. Several factors could account for this difference. First, the Cous fire took place 2.5 hours earlier than the Macktush fire, so that greater solar heating occurred during the burn. Relative humidity was also higher at the Macktush burn because of the time difference. Second, the Cous site is a direct southern exposure and the Macktush site is more easterly; consequently, fuels were probably somewhat drier at Cous. With these influences on moisture content, the fuel consumption at Cous (62 Mg/ha) was almost 2 times the consumption at Macktush (32 Mg/ha). Heat from this woody fuel combustion would contribute to greater forest floor consumption.

The depth-of-burn on the Macktush fall burn and reburn was nearly twice the maximum mean depth-of-burn reported by Feller (1989). It also exceeded that reported in other studies in British Columbia and the U.S. Pacific Northwest (Sandberg 1980; Brown et al. 1985; Little and Klock 1985; Macadam 1987). All three fall burns had greater combined LFH and woody fuel consumption (179–251 Mg/ha) than the maximum of 173 Mg/ha measured by Feller (1989), and that of other studies (Little and Klock 1985; Little and Ohmann 1988). Feller's data included understory plant biomass. This substantiates our view that the Macktush fall burns represent a maximum or “worst case” scenario for prescribed fire impacts over a large area. Similar localized impacts may occur on many fall burns.

The Prescribed Fire Predictor (Muraro 1975) tended to underpredict forest floor depth reduction for these fires. Predicted spring burn depth reduction was equal to or 10% less than actual values. Depth reduction on the Kanyon fall burn was double the predicted value. For the backing fire at Macktush, actual forest floor reduction was 10% greater than predicted.

More depth-of-burn pins survived the spring burns (94%) than the fall burns (80%). The second method for calculating forest floor consumption — the erosion bridge stations — yielded an average of 38 point measurements (95% survival) per plot for both spring and fall burns. They also allowed forest floor consumption to be measured on the reburn. The mean depth-of-burn from both methods was not significantly different (P <0.10). Although bridges have some advantages for measuring depth-of-burn, including not introducing a foreign object at the measuring point, traditional burn pins are an easier and more precise technique for measuring forest floor consumption than are the bridges. Bridges, however, should be considered as a back-up whenever there is a high chance of reburning, or where long-term measurement of forest floor levels or erosion of exposed mineral soil is desired.

4.1.3 Mineral soil exposure

Figure 2c summarizes average mineral soil exposure from burning. Pre-burn exposure on all areas was less than 4%. Spring and fall burns resulted in substantially different levels of exposure. For all spring burns, mineral soil exposure was increased from pre-burn values by less than 5%. The Kanyon burn had lower exposure (P <0.05) than the Macktush fall burn and reburn.

Morris (1970) found a 28% difference in mineral soil exposure on 58 paired burned and unburned plots in the Cascades and Coast Range of Oregon and Washington. For depths-of-burn similar to those in the Macktush spring burn, Little et al. (1982) measured 13 and 15% exposure from burning thinner forest floors (7.5–10.3 cm). Other studies reported mineral soil exposure increases ranging from 0 to 66% (Dyrenn et al. 1957; Silen 1960; Mersereau and Dyrenn 1972; Sandberg 1980; Amaranthus and McNabb 1984; Kaufman and Martin 1989). The exposure by the Macktush fall burn was greater than that reported in any published studies in the Pacific Northwest.

Compared to the values suggested by the Prescribed Fire Predictor (Muraro 1975), the mineral soil exposure of the spring burns had less than the predicted 10%. Both fall burns had 2.5–3 times greater exposure than the predicted values. The Predictor's lack of suitability for the Macktush backing fire was most evident for mineral soil exposure.
4.1.4 Vegetation

Vegetation cover was examined after all burns. Of the 20 plots on burned areas, only two on the Macklush spring burn had any remaining above-ground vegetation. A few scorched stems of salal and blueberry were the only survivors on these plots. Within days of the spring burns, fireweed was emerging throughout the burns.

The spring burns were examined in the fall of 1985 to assess regrowth of vegetation. Where salal was present before burning, it had resprouted from rhizomes to a height of 10–20 cm. Red huckleberry and Alaska blueberry also resprouted vigorously to a height of 30 cm. Fireweed, vanilla leaf, common groundsel and other herbs were also abundant by the fall. Results of annual assessments are given in Section 4.3.

4.1.5 Nutrient losses

Nitrogen, sulphur and phosphorus are the most volatile nutrients, and are therefore subject to the greatest losses from burning (McNabb and Cromack 1990). Some calcium, magnesium and potassium can also volatilize in high-intensity fires (Raison et al. 1985), though the greatest losses of these and other cations is through convection (Grier 1975). Losses of N are considered to be the most critical because of limited N availability on most sites. Most other elements — except part of the S and P — remain in the ash layer after a fire and are not usually limiting (McNabb and Cromack 1990). In some coastal soils, however, P can be limiting (Radwan and Shumway 1984; Weetman et al. 1989).

Estimates of N losses from consumption of woody fuels, LFH horizons and organic matter in the upper mineral soil show the study areas represent a broad range of impacts (Table 2). The greatest losses occurred from consumption of forest floor, which represented 61–88% of total N losses. Some burns had greater losses of N from volatilization in the upper mineral soil than from consumption of woody debris. The Cous fire showed the greatest losses of N from the upper mineral soil, with significantly lower concentrations of N after burning. This value is suspect, however, because the adjacent unburned site

| TABLE 2. | Post-harvest total nitrogen reserves and losses from burning |
|-----------------|-----------------|-----------------|-----------------|-----------------|
|                | Pre-burn inventory |                | Consumption     |                |
|                | Total N           |                | Total N         |                |
|                | Woody  | LFH  | Mineral soil | Total | Woody  | LFH  | Mineral soil | Total |
| ML kg/ha | 148   | 2083 | 2529       | 4760  | 48     | 216 | 66    | 328   |
| %        | 3      | 44   | 53         | 100   | 31     | 10   | 3     | 14    |
| CL kg/ha | 177   | 1736 | 2900       | 4816  | 83     | 583 | 234   | 900   |
| %        | 4      | 36   | 60         | 100   | 47     | 33   | 8     | 19    |
| KH kg/ha | 255   | 1295 | 2611       | 4161  | 122    | 622 | 84    | 828   |
| %        | 6      | 31   | 63         | 100   | 48     | 48   | 3     | 20    |
| MH kg/ha | 155   | 1639 | 1405       | 3199  | 88     | 1328 | 89    | 1505  |
| %        | 5      | 51   | 44         | 100   | 57     | 81  | 6     | 47    |

a ML = Macklush Low; CL = Cous Low; KH = Kanyon High; MH = Macklush High.
b All consumption values were calculated by subtracting post-burn N concentrations × mass, from pre-burn values.
c Above-ground woody debris, excluding stumps and roots; average pre-burn total N concentration of slash from Feller (1988) × kg of pre-burn woody biomass.
d Total forest floor materials; L and FH horizon volume (m3/ha) × bulk density (kg/m3) × pre-burn N concentration.
e Total N for mineral soil above the C horizon. Pre-burn total N concentration for 0–20 cm from composite sampling × bulk density (kg/m3) × horizon volume (m3/ha) × proportion of soil <2 mm (adjustment for coarse fragments, % by weight); total N calculations for the 21–40 cm and 41+ cm depth ranges used the average N concentration for Bf and Bc horizons, respectively.
f Annual streamwater exports of 1.5 kg/ha and precipitation inputs of 2.0 kg/ha, estimated by Feller and Kimmins (1984), are assumed to be in balance.
g Value is suspect, due to possible sampling error.
also showed a drop in N, although only half as much, over the same period. The most severe fire removed nearly half of the total N reserves. This site happened to have the greatest proportion of its pre-burn N reserves in the forest floor, among all sites.

There were substantial differences between the N losses on both the two spring burns and two fall burns. The Kanyon fall burn and Cous spring burn had similar absolute losses of N in the midrange of the two burns at Macktush.

Feller (1989) calculated N consumption from 16 broadcast burns in the Coastal Western Hemlock zone to be 10–982 kg/ha. Total N consumption for four burns in the Oregon Cascades ranged from 223 to 571 kg/ha (Little and Klock 1985). Little and Ohrmann (1988) reported N losses of 0–666 kg/ha from forest floor alone on 33 prescribed fires in Oregon and Washington. The highest reported N loss for this region besides Feller’s (1989) was for a severe wildfire in north central Washington. Grier (1975) estimated N losses of 907 kg/ha, including forest floor and the upper 36 cm of mineral soil. The calculated losses for the Macktush fall burn exceeded the maximum in published regional studies by over 50%. Losses from all but the lowest impact spring burn exceeded an estimated 672 kg/ha loss of N from logging old growth (McNabb and Cromack 1990).

An influence that is rarely discussed as a factor contributing to nutrient losses after fire is wind erosion. A considerable amount of ash is blown away from the site during dry periods after the burn. For the spring burns at Cous and Macktush, the first significant rainfall (7.6 cm) occurred 8 days after the burns. At Kanyon, a light rain occurred 6 days after the burn but it was another 8 days until the next rain (15.7 cm). After the Macktush fall burn, it was only 5 days before rainfall over 10 cm occurred. Grier (1975) found 2900 kg/ha of ash on the soil surface after a wildfire. Although this ash layer contained a relatively small amount of N (23 kg/ha), it had considerable amounts of Ca and Mg relative to total soil reserves. Unfortunately, the influence of rain and wind before and during sampling is uncontrollable.

Losses of site N from leaching following burning are low (Grier 1975; Feller and Kimmins 1984), as are natural losses of N on unburned sites, because of low rates of denitrification and low levels of transport in the soil solution (McNabb and Cromack 1990).

Sanborn and Ballard (1990) found similar trends in percent S losses to those of N on the Sproat Lake study sites. Consumption of S ranged from 33 kg/ha for the Macktush spring burn, to 274 kg/ha for the Macktush fall burn. They estimated the greatest S loss would take approximately 38 years to replace from atmospheric sources.

4.2 Effects of Burning on Soils

4.2.1 Organic horizons

Table 3 presents selected properties before and after burning for organic (LFH) horizons.

Surface litter was completely consumed by the fires except for some small pockets on the spring burns. The most apparent changes to chemical concentrations in the remaining litter after the spring burns were increases in pH, mineralizable nitrogen, sulphate sulphur, total phosphorus and total potassium. The significance of these changes is given for selected properties (Table 3). Total N was greater in the post-burn litter layers, but this was also true of unburned areas sampled at the same time. Litter C:N ratios decreased (P <0.02) after both spring burns, but not for unburned sites. Total P increased substantially between sampling periods for one unburned site. No other consistent trends in litter chemical properties were evident.

The most significant chemical changes to the remaining F and H layers were increases in pH and sulphate sulphur. Sulphur increased four-fold after spring burns, and to a lesser extent after fall burns. Phosphorus increased after the Cous spring burn. Variability in mineralizable N made changes in this property difficult to assess (Table 3).
TABLE 3. Selected chemical properties of organic horizons before and after burning^a

<table>
<thead>
<tr>
<th>Site/treatment</th>
<th>Horizons</th>
<th>pH (H₂O)</th>
<th>Total N (%)</th>
<th>Mineralizable N (ppm)</th>
<th>Total P (%)</th>
<th>Sulphate-S (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
</tr>
<tr>
<td>Cous</td>
<td>Unburned</td>
<td>L</td>
<td>4.3</td>
<td>4.3</td>
<td>0.57</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td>(CC)</td>
<td>FH</td>
<td>4.1</td>
<td>4.2</td>
<td>0.71*</td>
<td>0.61*</td>
</tr>
<tr>
<td></td>
<td>Spring</td>
<td>L</td>
<td>4.3**</td>
<td>6.1**</td>
<td>0.55+</td>
<td>0.81+</td>
</tr>
<tr>
<td></td>
<td>(CL)</td>
<td>FH</td>
<td>4.0</td>
<td>4.5</td>
<td>0.66</td>
<td>0.75</td>
</tr>
<tr>
<td>Macktush</td>
<td>Spring</td>
<td>L</td>
<td>4.3**</td>
<td>6.0**</td>
<td>0.80</td>
<td>0.90</td>
</tr>
<tr>
<td></td>
<td>(ML)</td>
<td>FH</td>
<td>3.9</td>
<td>4.0</td>
<td>0.74</td>
<td>0.73</td>
</tr>
<tr>
<td></td>
<td>Fall</td>
<td>L</td>
<td>4.3</td>
<td>—</td>
<td>0.82</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>(MH)</td>
<td>FH</td>
<td>3.8</td>
<td>3.9</td>
<td>0.71</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>(Reburn)</td>
<td>L</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>(MR)</td>
<td>FH</td>
<td>—</td>
<td>3.9</td>
<td>—</td>
<td>0.70*</td>
</tr>
<tr>
<td>Kanyon</td>
<td>Fall</td>
<td>L</td>
<td>4.2</td>
<td>—</td>
<td>0.54</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>(KH)</td>
<td>FH</td>
<td>4.0*</td>
<td>4.6*</td>
<td>0.66</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>Unburned</td>
<td>L</td>
<td>3.9</td>
<td>4.2</td>
<td>0.56</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>(KG)</td>
<td>FH</td>
<td>3.7</td>
<td>3.8</td>
<td>0.67</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>(Spring)</td>
<td>L</td>
<td>4.1</td>
<td>5.4</td>
<td>0.65</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>(KL)</td>
<td>FH</td>
<td>4.0</td>
<td>3.8</td>
<td>0.67</td>
<td>0.80</td>
</tr>
</tbody>
</table>

Significant differences between pre-burn and post-burn means at:
+ P < 0.10
* P < 0.05
** P < 0.01 (reburn compared to ML post-burn)

^a All values represent 5 composite samples, except the Macktush reburn (4) and Kanyon low-impact burn (1); each composite represents 10 subsamples.

^b CC = Cous Control; CL = Cous Low; ML = Macktush Low; MH = Macktush High; MR = Macktush Reburn; KH = Kanyon High; KC = Kanyon Control; KL = Kanyon Low.

The moderate- to high-impact fall burns increased the variability in chemical properties in all but a few cases. The most likely causes of this increased variability were the variable organic horizon and woody debris consumption, and ash deposition. The low-impact spring burns apparently had little effect on variability in chemical properties.

Trends from 3rd-year soil sampling show that the increase in litter pH was temporary; values dropped considerably from post-burn, but remained higher than pre-burn pH. For the FH horizon, pH increased since post-burn sampling and remained the same or increased slightly on controls.

For total N and P, elevated levels in the litter layer after spring burns were temporary; concentrations dropped to pre-burn levels or lower by year three. Nitrogen in the FH horizon of fall burns has decreased since post-burn sampling. In contrast, N in FH horizons on unburned areas has risen steadily over time. Manganese levels in the FH horizon remain significantly higher than in the controls for the spring burns and lower-impact Kanyon fall burn, but are similar to those in the controls for the Macktush fall burn and reburn.

Although some changes in concentration persist after 3 years, results suggest that the most important lasting effect of fire on the organic horizons is on total nutrient content rather than on changes in concentration.
4.2.2 Mineral soil

Table 4 presents selected chemical properties of the mineral soils before and after burning. The most significant changes were an increase in pH and available P after fall burns. Available P tended to decrease on all spring burns and controls between sampling periods.

<table>
<thead>
<tr>
<th>Site/treatment</th>
<th>pH (H₂O)</th>
<th>% organic matter</th>
<th>Total N (%)</th>
<th>Mineralizable N (ppm)</th>
<th>Available P (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
</tr>
<tr>
<td>Cous</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unburned (CC)</td>
<td>4.5</td>
<td>4.5</td>
<td>13.7*</td>
<td>9.2*</td>
<td>0.16*</td>
</tr>
<tr>
<td>Spring (CL)</td>
<td>4.3</td>
<td>4.5</td>
<td>12.6*</td>
<td>10.1*</td>
<td>0.19**</td>
</tr>
<tr>
<td>Macktush</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spring (ML)</td>
<td>4.1</td>
<td>4.2</td>
<td>9.2</td>
<td>8.9</td>
<td>0.14</td>
</tr>
<tr>
<td>Fall (MF)</td>
<td>4.0**</td>
<td>4.7**</td>
<td>10.5*</td>
<td>8.4*</td>
<td>0.13</td>
</tr>
<tr>
<td>Reburn (MR)</td>
<td>—</td>
<td>4.4</td>
<td>—</td>
<td>6.8</td>
<td>—</td>
</tr>
<tr>
<td>Kanyon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fall (KH)</td>
<td>4.2*</td>
<td>5.1*</td>
<td>11.4</td>
<td>9.3</td>
<td>0.12</td>
</tr>
<tr>
<td>Unburned (KC)</td>
<td>4.4</td>
<td>4.4</td>
<td>12.4</td>
<td>12.5</td>
<td>0.14+</td>
</tr>
<tr>
<td>Spring (KL)</td>
<td>4.3</td>
<td>4.3</td>
<td>16.2</td>
<td>10.7</td>
<td>0.21</td>
</tr>
</tbody>
</table>

Significant differences between pre-burn and post-burn means:

* P < 0.10
* P < 0.05
** P < 0.01 (reburn compared to ML post-burn)

---

All values represent 5 composite samples of the upper mineral soil (0 –20 cm), except the Macktush reburn (4) and Kanyon low-impact burn (1); each composite represents 10 subsamples.

CC = Cous Control; CL = Cous Low; ML = Macktush Low; MH = Macktush High; MR = Macktush Reburn; KH = Kanyon High; KC = Kanyon Control; KL = Kanyon Low.

Total post-burn N and organic C were significantly lower at Cous, both on the spring burn and control. The lower value on the control may have resulted from different amounts of Ah horizon in samples from the two periods. Third-year concentrations were similar to pre-burn levels, suggesting that the post-burn decrease in N was due to sampling error rather than losses. An increase in total N occurred on the Kanyon control, and a decrease in organic C occurred after the Macktush fall burn. Other areas did not differ significantly.

Mineralizable N did not show any definitive relationship to treatments. It appears to be lower on the Macktush site than on the other two sites. The Macktush site had generally more salal coverage than the other sites, except the Kanyon fall burn. The highest mineralizable N occurred on the sites with the least salal. Studies from other coastal sites suggest that mineralizable N is lower in the presence of salal (Weetman et al. 1989).

One possible confounding influence on the differences in chemical properties in the mineral soil after spring and fall burning was the amount of rainfall that occurred between treatment and sampling. Approximately 40 mm of rainfall occurred before post-burn sampling on the spring burns and over 500 mm on the fall burns. The higher rainfall before fall sampling could have leached greater amounts of the soluble nutrients from the surface ash into the upper mineral soil than for spring sampling. Soluble cations such as K would be affected; relatively insoluble cations such as P would stay largely in the upper mineral soil.

Third-year data show pH has generally stayed the same or increased slightly since post-burn sampling, except for a decrease on the Kanyon fall burn. Available P has nearly doubled on the Cous
control and both spring burns, while decreasing by nearly half on the burned area. Loss of upper mineral soil to erosion may be a contributing factor to P losses on the reburn.

### 4.2.3 Soil erosion

Soil surface levels were monitored with erosion bridges (Ranger and Frank 1978). While this technique cannot prove conclusively that soil is leaving a site, it does indicate trends. On a cross-section for one of the plots burned in the spring and fall (Figure 3), one can see surface level changes from the two fires and subsequent erosion. The rock at measuring point 12 served as a control point for the profile. Changes in substrate are illustrated below the profile. These profiles showed dynamic surface levels on both exposed mineral soil and forest floor over three seasons.

Mean surface level changes ranged from slight increases to reductions over 7 cm (Table 5). Measurements were extremely variable, as shown by the large standard errors. A few microsites had decreases in surface level of over 30 cm in 3 years. Some sites had greater surface changes on upper slopes; others on lower slopes. The confidence interval for the estimated erosion rate included 0 for all but one site; consequently, erosion could not be proven conclusively for most of these areas.

Nevertheless, the net decrease in surface level for nearly all plots suggests that erosion is taking place on exposed mineral soil. For the unburned sites and spring burns, the amount of exposed soil is inconsequential. For the Kanyon fall burn, where about a third of the site is exposed soil, the annual net loss of soil could be between 10 and 50 Mg/ha per year.

There was more net deposition of material on the Macktush fall burn where the most exposed soil occurred. This site had the only net positive change in surface level. The Cous site, which has the steepest slopes of the three sites, had the greatest surface level changes.

Unburned areas showed a reduction in forest floor depth, most likely caused by compaction during decomposition of the surface litter (Table 5). Some of these reductions could be due to downslope transport as well. This depth reduction averaged over 1 cm/yr. Reduction in the depth of remaining forest floor was much less for burned areas, particularly on fall burns where the remaining organic matter was well-decomposed humus or rotting wood. Being already compacted, this material would change less over time than the litter layer of unburned areas.

### TABLE 5. Mineral soil exposure, surface level changes and erosion estimates

<table>
<thead>
<tr>
<th>Site/treatment area</th>
<th>No. plots</th>
<th>Mineral soil exposure (%)</th>
<th>Change in surface level (cm)</th>
<th>Erosion rate (Mg/ha·yr⁻¹)</th>
<th>Change in surface level (cm)</th>
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<tr>
<td></td>
<td></td>
<td>Pre-burn</td>
<td>Post-burn</td>
<td>5% confidence interval</td>
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<td>Unburned</td>
<td>5</td>
<td>2.0 (0.6)a</td>
<td>—</td>
<td>-7.1 (4.2)</td>
<td>-19.7 k 8.6</td>
</tr>
<tr>
<td>CC</td>
<td>5</td>
<td>5.5 (0.2)a</td>
<td>—</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>KC</td>
<td>5</td>
<td>2.1 (1.2)a</td>
<td>2.5 (1.4)a</td>
<td>-1.6 (-)</td>
<td>ND</td>
</tr>
<tr>
<td>Spring burns</td>
<td>1</td>
<td>2.3 (0.6)a</td>
<td>6.3 (0.6)a</td>
<td>-6.6 (2.9)</td>
<td>-32.7 k 0.5</td>
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<tr>
<td>ML</td>
<td>5</td>
<td>3.1 (1.0)a</td>
<td>32.5 (8.0)a</td>
<td>-2.4 (0.7)</td>
<td>-50.0 k 10.9</td>
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<tr>
<td>CL</td>
<td>5</td>
<td>2.2 (1.5)a</td>
<td>54.7 (17.4)a</td>
<td>-2.0 (1.1)</td>
<td>-85.2 k 10.6</td>
</tr>
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<td>Fall burns</td>
<td>5</td>
<td>1.0 (1.0)a</td>
<td>75.1 (6.1)a</td>
<td>+0.2 (0.8)</td>
<td>-43.9 k 52.4</td>
</tr>
</tbody>
</table>

Values are mean and (standard error). Means within columns not followed by the same letter are significantly different at P <0.05 using a Tukey-Kramer test.

a CC = Cous Control; KC = Kanyon Control; ML = Macktush Low; CL = Cous Low; KH = Kanyon High; MR = Macktush Reburn; MH = Macktush High.
b Changes from October 1988 to October 1998, based on sample points on mineral substrate only, rock excluded.
c Changes during the same 3-year period as mineral soil, based on sample points on forest floor only.
d ND = no data.
4.3 Effects of Burning on Native Vegetation

4.3.1 Vegetation cover

Estimates of vegetation cover were made before burning in 1985 and in late summer 1986 through 1988 on permanent plots in each treatment. Fall 1988 measurements represent three growing seasons for the controls and fall burns, and four growing seasons for the spring burns.

On unburned areas, shrub cover has increased two- to three-fold since the summer of 1985 (Figure 4). The species representing most of this increase were salal and red huckleberry. Herbs more than doubled in cover after three seasons. Total herb cover consisted mostly of fireweed.

On the low-impact spring burns, shrub cover was equal to the pre-burn cover by the third growing season. Red huckleberry remained considerably reduced in cover compared with pre-burn levels, but sprouted to a height of 60 cm. Most of the increase in shrub cover was due to salal and Oregon grape. Salal ranged in height from 15 to 40 cm, approaching the pre-burn height range of 25–50 cm after three growing seasons.

Herb cover responded differently on the two spring burns. On the lower intensity MacKtush burn, herb cover increased slightly. On the somewhat higher intensity Cous burn, herb cover increased from 2% before burning to 32% after three growing seasons. Herb cover doubled in the 3rd year. This site had greater mineral soil exposure after burning than MacKtush, and also less salal cover. These differences probably account for the greater herb cover.

Tree and moss cover remained at less than 5% on both spring burns.
FIGURE 4. Vegetation cover changes by site and treatment.

On the fall burns, shrub cover averaged 5% or less after two growing seasons, compared with 33 and 40% pre-burn cover for the Kanyon and Macktush sites, respectively. Shrub cover increased more rapidly during the third season on the less severe fall burn at Kanyon. Shrub cover remains substantially below adjacent unburned or spring-burned sites. Herb cover, mostly fireweed, was 6 times the pre-burn cover on the more moderate impact Kanyon burn (30%) and 3 times the pre-burn cover on the severe impact Macktush burn (19%). This result suggests that the more intense fire killed more fireweed roots. Moss cover averaged 7% or less, which is somewhat higher than on the spring burns.

The fall burns have considerably reduced the shrub cover compared with both the spring burns and controls, even when the extra growing season is taken into account for the spring burns. Herb cover increased the most on the two intermediate impact burns (CL, KH) and increased to the same extent as on the unburned areas for the two burns at the extremes (ML, MH). For low impacts, little mineral soil was exposed and shrub competition remained high. For high impacts, mineral soil exposure was great, but heat penetration during the fire probably killed more buried seed and rhizomes.

4.3.2 Natural conifer regeneration

Burns removed natural western hemlock, amabilis fir, western redcedar, yellow-cedar and Douglas-fir regeneration. The Cous site had the highest levels of pre-burn conifer regeneration. Natural seed-in of primarily western hemlock and Douglas-fir is occurring on all sites. The number of natural seedlings is higher on the fall burns (540 trees per hectare) than the spring burns (110 trees per hectare), probably
because of the greater mineral soil exposure on the fall burns. The most abundant seed-in is on the Kanyon site, where plots are all within 50 m of the timber edge. Generally, plots near a seed source had greater amounts of natural seedlings, though this relationship was not as clear as one might expect. Planted seedling height remains substantially behind the total height of advanced regeneration.

4.4 Effects of Burning on Planted Conifers

4.4.1 Seedling survival

Douglas-fir had the least variable, and best overall 3rd-year survival (88%) of the three conifers (Figure 5a). There was no relationship evident between fire impact and Douglas-fir survival.

Where significant differences in survival occurred for western redcedar and yellow-cedar, burning had a positive effect (Figure 5b, Appendix 9).

Yellow-cedar had a wide variation in survival. On the two sites with burned and unburned pairs, yellow-cedar survival was better on the burned areas. At Macktush, survival was significantly lower on the reburned area than on either the adjacent spring or fall burns.

Western redcedar had the most variation in survival. Its lowest survival was on an unburned area and its highest survival was on the two areas with the most severe fire impact. Survival did not differ where burned and unburned areas were adjacent. Of the three species, redcedar had the poorest overall 3rd-year survival (82%), yet it had the best 1st-year survival (95%).

During the early spring of 1987, we noticed a substantial drop in survival for redcedar on some plots. To quantify this observation, we assessed all species for spring 1987 survival. Results showed that average mortality over the 1986–87 winter was high for redcedar (14%) and much lower for Douglas-fir (3%) and yellow-cedar (1%). The drop in redcedar survival varied from 6% to 22% by area. Additional mortality during the second growing season was only 1% for redcedar, and less than 1% for the other species. The reason for the overwintering losses of redcedar is not known. One possibility is that the hot, dry late summer and early fall of 1986 stressed the cedar, leaving them more susceptible to winter damage.

The unburned area at Cous Creek had the poorest survival for all three species. This may be a result of the combined effect of a warmer, drier climate than on the other sites, and vegetation competition. In this case, the variation in precipitation occurs within a small geographic area. The greatest distance between sites is only 8.5 km, and all sites have a mean elevation between 500 and 550 m. However, the study areas straddle the boundary between leeward and windward biogeoclimatic variants, making small distances more important than they might be elsewhere.

4.4.2 Seedling volume growth

Seedling stem volume was more sensitive to treatment effects than total height (Appendix 9). Third-year conifer seedling stem volume by species and treatment is summarized in Figure 5c. Except for western redcedar on the Kanyon control, all species had significantly greater volume on burned areas than on adjacent unburned areas. Reduced competition from shrubs, mainly salal and red huckleberry, and a short-term increase in nutrient availability probably contribute to greater volume on burns.

With one exception, Douglas-fir volume exceeded that of the other species on every treatment. Third-year volume on burned areas exceeded adjacent controls, despite greater 1st-year deer browsing on burns. Browsing since the 1st year has not been significant. Douglas-fir volume was nearly 4 times greater on the reburned area than on either the adjacent spring or fall burn. The Kanyon site had greater Douglas-fir volume on its control and fall burn than did the corresponding treatments on other sites, suggesting some site differences. All three species had greater volume on the Cous spring burn than on the Macktush spring burn. This may reflect either an inherent site difference, or greater competition reduction on the higher-impact Cous burn.
FIGURE 5. Plantation survival and growth.
Western redcedar volume was greater on the high-impact burns at Macktush than on the adjacent low-impact burn. Volume was significantly greater on the Cous low-impact burn than on the adjacent control, but there was no significant difference on the Kanyon burned and unburned pair.

Yellow-cedar volume was greater on burned areas than on adjacent unburned areas, and greater on high-impact burns than on the adjacent low-impact burn, suggesting that burning had a beneficial effect on its growth.

The greatest stem volume for all species occurred on one of the two most severe fires—the Macktush reburn. Volume was 2–4 times greater on the reburned area than on either the adjacent fall or spring burns. For all species, volume was significantly less on the adjacent, high-impact fall burn than on the reburn. Because these sites had similar burn impact, this difference could be due to other factors. Examination of individual plots revealed two on the reburned site with dramatically fall burn than on the reburn. Initial seedling size, vegetation competition, deer browse and site characteristics were examined as possible reasons for the exceptional growth. The seedlings were not larger initially than other seedlings, nor were there differences in browse or brush competition ratings. Both reburn plots and the adjacent fall burn have a high percentage of exposed mineral soil and a low percentage of vegetation cover. Field observations did not suggest major site differences except a more southerly aspect than on most of the Macktush site. Warmer temperatures, combined with the relatively competition-free environment, may explain the difference.

4.4.3 Seedling growth by substrate classes

Seedlings were assigned to classes describing the substrate immediately surrounding the seedling: bare mineral soil, forest floor (LFH) by depth class (less than or greater than 3 cm), and char from burning.

Volume growth for all species was greater on exposed mineral soil than on areas with forest floor. Most of the exposed soil occurred on burned areas. For redcedar and yellow-cedar, volume growth decreased with greater forest floor depth. This trend is the same as that found after the first growing season. Douglas-fir did not have significant differences in volume growth between substrates in the 1st year because of the confounding effect of deer browse on burned sites.

One likely reason for the better growth on mineral soil than other substrates is reduced vegetative competition. More vegetative competition occurred on unburned and lightly burned areas with resprouting shrubs than on areas with exposed mineral soil. Future analysis will attempt to separate substrate and vegetation effects by comparing only those trees with little or no brush competition by substrate, using the individual tree ratings.

Because greater nutrient removal is associated with reduced vegetative competition, these short-term growth response relationships may not reflect the long-term response if site productivity has been adversely affected.

4.4.4 Seedling foliar nutrition

Several measures of fire impact were used in linear regressions of individual plot data for burns (n = 21) and 3rd-year foliar nutrient concentration of the three planted tree species. Figures 6 and 7 show the nutrients most correlated with fire impact, as measured by percent forest floor depth reduction. Dashed lines surrounding the regression line represent the 95% confidence and prediction limits. In most cases, percent depth reduction showed higher correlations with foliar nutrients than with depth-of-burn, weight of LFH consumed or percent LFH consumed.

Douglas-fir foliar Fe, Cu, Ca and Zn levels were positively correlated with forest floor reduction (P < 0.02, Figure 6), but the relationship between foliar and soil nutrient concentrations was not always consistent for these elements. Foliar Mn was negatively correlated with forest floor reduction at a low significance level (P = 0.07, r² = 0.15). Manganese concentrations in the FH horizon were increased after the spring burns and Kanyon fall burn, but decreased after the high-impact burns at Macktush. Manganese levels in the FH horizon were higher on burns than on adjacent unburned areas, and higher
on spring burns than on adjacent fall burns. Exchangeable Mn in the FH horizon was negatively correlated with forest floor reduction ($P = 0.01, r^2 = 0.27$), but mineral soil Mn was not related to fire impact. Other foliar nutrient concentrations for Douglas-fir showed no relationship to fire impact.

Yellow-cedar and western redcedar foliar Fe increased and P decreased with greater forest floor reduction (Figure 7). On the fall burns, substantial losses of P occurred from forest floor combustion, whereas P concentrations were increased in litter after spring burns. Correlations were more significant for redcedar than for yellow-cedar. Other foliar nutrients for these species showed no relationship to fire impact.

Despite the substantial N losses from forest floor consumption, foliar N concentration showed no relationship to fire impact. This indicates that for early seedling growth, N supplies are adequate — although the long-term ability of these sites to supply N is not clear. The negative relationship between fire impact and Douglas-fir foliar Mn, with corresponding changes to Mn in remaining FH layers, suggests that fire has had a negative effect on availability of this nutrient for Douglas-fir. Yellow-cedar and western redcedar, however, were not affected. Foliar Fe increased for all three species as fire impact increased. The negative relationship between foliar P and burn impact observed with yellow-cedar and redcedar was not observed for Douglas-fir. The greater number of nutrients correlated with fire impact, together with the generally stronger correlations, suggests that Douglas-fir is more sensitive to site nutrition than the other two species, except for P.
FIGURE 6. Relationships among foliar nutrient concentrations and forest floor reduction for Douglas-fir.
FIGURE 7. Relationships among foliar nutrient concentrations and forest floor reduction for western redcedar and yellow-cedar.
5 RECOMMENDATIONS

The primary silvicultural objectives of coastal prescribed burning are to create plantable spots and reduce shrub competition. Because fire effects are extremely variable, carefully planned and executed fire prescriptions are necessary to achieve the desired impact. Fortunately, we have the tools to help influence fire effects. The Canadian Fire Danger Rating System (Stocks et al. 1989), Prescribed Fire Predictor (Muraro 1975), Prescribed Burning Guidelines (B.C. Ministry of Forests 1985) and Fire Sensitivity Ratings (Klinka et al. 1984) — combined with electronic weather stations, telemetry, and helicopter ignition — give the forester the ability to prescribe and carry out appropriate treatments.

Moisture content in woody fuel and the forest floor is the most important factor under the forester's control to influence fire impact. Woody fuel moisture determines the amount of debris consumption for creating plantable spots. Forest floor and soil moisture controls organic consumption and heat penetration in the soil and, consequently, the effect of fire on the roots and rhizomes of competing vegetation. Higher-impact fires yield the greatest benefit for vegetation control and slash reduction, but may affect long-term site nutrient status.

Once the suitability of burning is determined, the forester should attempt to achieve the lowest-impact burn that still meets the silvicultural objectives. The benefits of this approach include:

- conservation of site nutrients and protective forest floor layers;
- conservation of coarse woody debris;
- conservation of wildlife habitat;
- reduction of atmospheric inputs for human health and visual quality concerns;
- reduction of erosion (i.e., soil loss and stream sedimentation) and other soil degradation (i.e., water repellency, reduced soil flora and fauna); and
- reduction of weed species invasion on exposed mineral soil.

Both spring and fall burning can be used to accomplish these objectives, although low impacts are achieved more easily with spring burning.

Prescribed burning can enhance early plantation growth and survival. To capture the maximum benefit from burning, planting should be done as soon as possible. This allows seedlings to capture the short-term increase in nutrient availability and to take full advantage of the temporary reduction in vegetative competition.

Maintaining site productivity should be the foundation on which a successful and ecologically appropriate burning prescription is built.
ASSOCIATED RESEARCH

Associated research by MB and co-operating organizations has increased the overall value of the study areas.

The B.C. Ministry of Forests contributed funding for analysis of additional soil samples to characterize variability and to investigate the effects of fire on mycorrhizae (Beese 1987a, 1987b). The Ministry of Forests continues to monitor wildlife forage production on the study sites (Peterson 1989).

Michael Curran, a Ph.D. candidate at the University of British Columbia, studying the longer-term effects of fire, completed a greenhouse investigation of mycorrhizae inoculum potential using pre- and post-burn soils from our study sites (funded through the Forest Resource Development Agreement, Canadian Forestry Service, Direct Delivery Program). A journal paper is being prepared, combining his findings with the results of the field study funded by the Ministry of Forests. A poster display on this work was presented by Dr. Shannon Berch (UBC) at the Soil Science Society of America meeting in Atlanta, Ga., in November 1987.

The B.C. Science Council funded a study in 1987 by Jim Fyles and Dr. Michael Feller (UBC) on soil nitrogen availability (Fyles et al. 1991).

Drs. T.M. Ballard and P. Sanborn received a B.C. Science Council grant to fund an investigation of "Prescribed Fire Effects on Sulphur in Soils" (Sanborn and Ballard 1990).
7 REFERENCES


## APPENDIX 1. Study site characteristics

<table>
<thead>
<tr>
<th>Site characteristic</th>
<th>Cous</th>
<th>Macktush</th>
<th>Kanyon</th>
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</thead>
<tbody>
<tr>
<td>Total area (ha)</td>
<td>16.1</td>
<td>9.6</td>
<td>5.1</td>
</tr>
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<td></td>
<td>12.6</td>
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<td>475–605</td>
<td>475–610</td>
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<tr>
<td></td>
<td>455–650</td>
<td>510–565</td>
<td>535–570</td>
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<td>SSE</td>
<td>SW</td>
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<td>SW</td>
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<td>(45–70)</td>
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<td>(45–70)</td>
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<td>Cv/Mbv</td>
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<td>B–D</td>
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<td>M–H</td>
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<td>M–H</td>
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---

a Average and/or range given for five study plots in each treatment.

b CV = Colluvial veneer; Mbv = morainal blanket (> 1 m) or veneer (< 1 m).

c R = rapidly drained; W = well-drained; MW = moderately well-drained.

d From Klinka et al. (1984).

e Low = low; M = medium; H = high; VH = very high.
### APPENDIX 2. Forest floor and mineral soil physical properties and depth-of-burn

<table>
<thead>
<tr>
<th>Properties</th>
<th>Cous (CL)</th>
<th>Cous (CC)</th>
<th>Macktush (ML)</th>
<th>Macktush (MH)</th>
<th>Kanyon (KC)</th>
<th>Kanyon (KH)</th>
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<tr>
<td>Forest floor</td>
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<td></td>
</tr>
<tr>
<td>LFH Bulk density&lt;sup&gt;b&lt;/sup&gt; (kg/m&lt;sup&gt;3&lt;/sup&gt;)</td>
<td>154 (30)</td>
<td>156 (22)</td>
<td>128 (30)</td>
<td>146 (11)</td>
<td>138 (9)</td>
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<tr>
<td>Depth&lt;sup&gt;b&lt;/sup&gt; (cm)</td>
<td>1.8</td>
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<td>Total</td>
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<td>Depth-of-burn (cm)&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>--</td>
<td>2.4a (0.37)</td>
<td>12.7b (0.41)</td>
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<td>7.6c (0.93)</td>
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<td>Mineral soil</td>
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<td>Texture&lt;sup&gt;c&lt;/sup&gt;</td>
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<td>L</td>
<td>L</td>
<td>L</td>
<td>L~SL</td>
<td>L~SL</td>
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<tr>
<td>Average depth to C horizon (cm)&lt;sup&gt;d&lt;/sup&gt;</td>
<td>96 (7.9)</td>
<td>84 (1.8)</td>
<td>78 (4.6)</td>
<td>52 (9.7)</td>
<td>74 (8.7)</td>
<td>63 (15.1)</td>
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<td>Coarse fragment content&lt;sup&gt;e&lt;/sup&gt; (％ by weight)</td>
<td>73 (2.0)</td>
<td>73 (2.7)</td>
<td>72 (5.9)</td>
<td>81 (1.8)</td>
<td>63 (9.1)</td>
<td>64 (3.4)</td>
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<td>Bulk density&lt;sup&gt;f&lt;/sup&gt; (kg/m&lt;sup&gt;3&lt;/sup&gt;)</td>
<td>1172 (55)</td>
<td>1162 (33)</td>
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<td>1178 (74)</td>
<td>1148 (64)</td>
<td>1234 (111)</td>
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All values are: mean (standard error). Only depth-of-burn had significant differences among treatment areas. Means not followed by the same letter are significantly different at P < 0.05 using Tukey’s HSD test.

<sup>a</sup> Based on five 30 x 30 cm samples of each horizon per treatment replicate; F and H horizons composited.
<sup>b</sup> Based on 250 depth-of-burn pins per treatment replicate for burns, and 100 sample points for unburned areas.
<sup>c</sup> Canadian Soil Survey Committee (1978) texture classes: L = loam; SL = sandy loam.
<sup>d</sup> From five soil pits per treatment replicate.
<sup>e</sup> From five samples per treatment replicate of the upper 20 cm of mineral soil; sample volumes approximately 1000 cm<sup>3</sup>.

### APPENDIX 3. Average cover of major vegetation before burning

<table>
<thead>
<tr>
<th>Cover</th>
<th>Cous (CL)</th>
<th>Cous (CC)</th>
<th>Macktush (ML)</th>
<th>Macktush (MH)</th>
<th>Kanyon (KC)</th>
<th>Kanyon (KH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total trees</td>
<td>15</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Total shrubs</td>
<td>20</td>
<td>11</td>
<td>32</td>
<td>48</td>
<td>11</td>
<td>33</td>
</tr>
<tr>
<td>Total herbs</td>
<td>2</td>
<td>7</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Total mosses</td>
<td>5</td>
<td>3</td>
<td>8</td>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Gaultheria shallon</td>
<td>16</td>
<td>5</td>
<td>17</td>
<td>32</td>
<td>5</td>
<td>19</td>
</tr>
<tr>
<td>Mahonia nervosa</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Vaccinium spp.&lt;sup&gt;a&lt;/sup&gt;</td>
<td>17</td>
<td>6</td>
<td>13</td>
<td>10</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Achlys triphylla</td>
<td>--</td>
<td>--</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Epilobium angustifolium</td>
<td>1</td>
<td>5</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Polystichum munitum</td>
<td>+</td>
<td>+</td>
<td>--</td>
<td>2</td>
<td>+</td>
<td>--</td>
</tr>
</tbody>
</table>

<sup>a</sup> V. alaskaense, V. ovalifolium, and V. parvifolium.
APPENDIX 4. Light-up conditions and Fire Weather Indices for prescribed burns

<table>
<thead>
<tr>
<th></th>
<th>Spring</th>
<th>Fall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cous</td>
<td>Macktush</td>
</tr>
<tr>
<td>Date</td>
<td>21 May 85</td>
<td>21 May 85</td>
</tr>
<tr>
<td>Light-up</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PST</td>
<td>16:14</td>
<td>18:48</td>
</tr>
<tr>
<td>Method</td>
<td>Helitorch</td>
<td>Helitorch</td>
</tr>
<tr>
<td>Weather conditions at light-up</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>19.0</td>
<td>16.0</td>
</tr>
<tr>
<td>Relative Humidity (%)</td>
<td>50</td>
<td>64</td>
</tr>
<tr>
<td>Wind</td>
<td></td>
<td></td>
</tr>
<tr>
<td>km/hr</td>
<td>3.0</td>
<td>0</td>
</tr>
<tr>
<td>Direction (°)</td>
<td>60</td>
<td>0</td>
</tr>
<tr>
<td>Fire Weather Indices</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine Fuel Moisture code (FFMC)</td>
<td>86 (79–88)</td>
<td>86 (80–89)</td>
</tr>
<tr>
<td>Duff Moisture Code (DMC)</td>
<td>19 (14–20)</td>
<td>19 (14–22)</td>
</tr>
<tr>
<td>Drought Code (DC)</td>
<td>42 (&lt;150)</td>
<td>42 (&lt;150)</td>
</tr>
<tr>
<td>Initial Spread Index (ISI)</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Build-up Index (BUI)</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>Fire Weather Index (FWI)</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

* Based on readings at 1200 hours PST from on-site weather stations; prescriptions given in parentheses.
APPENDIX 5. Details of line-transect sampling design and associated measurements
APPENDIX 6. Conifer seedlings planted on the study areas

<table>
<thead>
<tr>
<th>Species&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Nursery</th>
<th>Seedlot/ Elevation (m)</th>
<th>Date Lifted</th>
<th>Cold Storage Duration (days)</th>
<th>RGC&lt;sup&gt;b&lt;/sup&gt; Value</th>
<th>No. Measured Trees&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fd</td>
<td>Campbell R. (BCMF&lt;sup&gt;3&lt;/sup&gt;)</td>
<td>7802/550</td>
<td>05 Feb 86</td>
<td>47</td>
<td>3.05</td>
<td>400 550 500</td>
<td>1450</td>
</tr>
<tr>
<td>Cw</td>
<td>Kokasilah (BCMF)</td>
<td>7303/610</td>
<td>23 Jan 86</td>
<td>59</td>
<td>3.55</td>
<td>400 500 450</td>
<td>1350</td>
</tr>
<tr>
<td>Cy</td>
<td>Sylvan Vale (Private)</td>
<td>7520/1</td>
<td>09 Jan 86</td>
<td>73</td>
<td>3.10</td>
<td>400 500 450</td>
<td>1350</td>
</tr>
</tbody>
</table>

<sup>a</sup> Fd = Douglas-fir; Cw = western redcedar; Cy = yellow-cedar.
<sup>b</sup> Root growth capacity test.
<sup>c</sup> Extra Douglas-fir and western redcedar were planted at Cous (250), Macktush (125) and Kanyon (125) for destructive sampling as part of the mycorrhizae studies.
<sup>d</sup> B.C. Ministry of Forests.

APPENDIX 7. Rating scales for tree measurements

**Vigour<sup>a</sup>**

- 0 = dead
- 1 = poor
- 2 = fair
- 3 = good
- 4 = excellent

**Brush encroachment**

- 0 = none
- 1 = one side
- 2 = two sides
- 3 = three sides
- 4 = four sides

<table>
<thead>
<tr>
<th>Animal Browse&lt;sup&gt;a&lt;/sup&gt;</th>
<th>% Current Foliage Browsed</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 = none</td>
<td>0</td>
</tr>
<tr>
<td>1 = trace</td>
<td>1–5</td>
</tr>
<tr>
<td>2 = light</td>
<td>6–25</td>
</tr>
<tr>
<td>3 = moderate</td>
<td>26–50</td>
</tr>
<tr>
<td>4 = heavy</td>
<td>&gt;50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>% Day that &gt; 50% of Foliage Receives Direct Sun</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shade</td>
</tr>
<tr>
<td>0 = none</td>
</tr>
<tr>
<td>1 = partial</td>
</tr>
<tr>
<td>2 = shaded</td>
</tr>
</tbody>
</table>

**Substrate**

- 0 = mineral soil
- 1 = LFH <3 cm
- 2 = LFH >3 cm
- 3 = charred LFH <3 cm
- 4 = charred LFH >3 cm

<sup>a</sup> From Walmsley et al. 1980.
### APPENDIX 8. Organic matter inventory and consumption

<table>
<thead>
<tr>
<th>Area, No. plots</th>
<th>Pre-burn Inventory</th>
<th>Consumption</th>
<th>Woody fuels</th>
<th>Woody fuels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 7 cm</td>
<td>&gt; 7 cm</td>
<td>Total</td>
<td>LFH</td>
</tr>
<tr>
<td><strong>Spring burns</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ML, 5</td>
<td>17(2)c</td>
<td>100(25)a</td>
<td>117(25)a</td>
<td>278(41)a</td>
</tr>
<tr>
<td>%</td>
<td>30</td>
<td>70</td>
<td>100</td>
<td>71</td>
</tr>
<tr>
<td>KL, 1</td>
<td>8(−)</td>
<td>75(−)</td>
<td>84(−)</td>
<td>100(−)</td>
</tr>
<tr>
<td>%</td>
<td>36</td>
<td>64</td>
<td>100</td>
<td>27</td>
</tr>
<tr>
<td>CL, 5</td>
<td>29(2)a</td>
<td>111(20)a</td>
<td>140(18)a</td>
<td>245(23)a</td>
</tr>
<tr>
<td>%</td>
<td>36</td>
<td>64</td>
<td>100</td>
<td>87</td>
</tr>
<tr>
<td><strong>Fall burns</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KH, 5</td>
<td>21(4)a</td>
<td>108(18)a</td>
<td>201(16)a</td>
<td>202(18)a</td>
</tr>
<tr>
<td>%</td>
<td>50</td>
<td>50</td>
<td>100</td>
<td>87</td>
</tr>
<tr>
<td>MF, 4</td>
<td>19(2)a</td>
<td>110(29)a</td>
<td>129(29)a</td>
<td>285(52)a</td>
</tr>
<tr>
<td>%</td>
<td>31</td>
<td>69</td>
<td>100</td>
<td>98</td>
</tr>
<tr>
<td>MH, 5</td>
<td>18(3)a</td>
<td>104(13)a</td>
<td>122(15)a</td>
<td>226(21)a</td>
</tr>
<tr>
<td>%</td>
<td>35</td>
<td>65</td>
<td>100</td>
<td>91</td>
</tr>
</tbody>
</table>

Means with columns not followed by the same letter are significantly different at P <0.05 using a Tukey-Kramer test.

- **a** ML = Macktush Low; KL = Kanoy Low; CL = Cous Low; KH = Kanoy High; MR = Macktush Reburn; MH = Macktush High.
- **b** Based on 250 depth-of-burn pins per treatment replicate, except as noted.
- **c** Values are mean and (standard error).
- **d** Pre-burn: % of total biomass is given; consumption: % of pre-burn inventory is given. Weight consumed is based on depth and bulk density of L and FH layers.
- **e** Based on 50 depth-of-burn pins only.
- **f** Total consumption from spring burn and reburn; LFH consumption based on 136 point measurements from erosion bridges.
### APPENDIX 9. Third growing season conifer seedling survival and growth

<table>
<thead>
<tr>
<th>Site/treatment, No. plots</th>
<th>Trees/Sp.</th>
<th>Survival (%)</th>
<th>Height (cm)</th>
<th>Stem volume (cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cw</td>
<td>Cy</td>
</tr>
<tr>
<td><strong>Cous</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CC, 5</td>
<td>200</td>
<td>68a</td>
<td>77a</td>
<td>83a</td>
</tr>
<tr>
<td></td>
<td>(3)</td>
<td>(3)</td>
<td>(3)</td>
<td></td>
</tr>
<tr>
<td>CL, 5</td>
<td>200</td>
<td>75a</td>
<td>87b</td>
<td>67a</td>
</tr>
<tr>
<td></td>
<td>(3)</td>
<td>(2)</td>
<td>(2)</td>
<td></td>
</tr>
<tr>
<td><strong>Macktush</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ML, 2</td>
<td>150</td>
<td>76a</td>
<td>89a</td>
<td>94a</td>
</tr>
<tr>
<td></td>
<td>(4)</td>
<td>(3)</td>
<td>(2)</td>
<td></td>
</tr>
<tr>
<td>MH, 5</td>
<td>200</td>
<td>90b</td>
<td>86a</td>
<td>89a</td>
</tr>
<tr>
<td></td>
<td>(2)</td>
<td>(3)</td>
<td>(2)</td>
<td></td>
</tr>
<tr>
<td>MR, 4</td>
<td>150</td>
<td>85ab</td>
<td>78b</td>
<td>87a</td>
</tr>
<tr>
<td></td>
<td>(3)</td>
<td>(3)</td>
<td>(2)</td>
<td></td>
</tr>
<tr>
<td><strong>Kanyon</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KC, 5</td>
<td>200</td>
<td>77a</td>
<td>87a</td>
<td>91a</td>
</tr>
<tr>
<td></td>
<td>(3)</td>
<td>(2)</td>
<td>(2)</td>
<td></td>
</tr>
<tr>
<td>KH, 5</td>
<td>200</td>
<td>75a</td>
<td>94b</td>
<td>87a</td>
</tr>
<tr>
<td></td>
<td>(3)</td>
<td>(2)</td>
<td>(2)</td>
<td></td>
</tr>
<tr>
<td>KL, 1b</td>
<td>40</td>
<td>53</td>
<td>95</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>(7)</td>
<td>(3)</td>
<td>(3)</td>
<td></td>
</tr>
</tbody>
</table>

Mean and (standard error). Means for each species on the same site not followed by the same letter are significantly different at P <0.05 using orthogonal contrasts.

a CC = Cous Control; KC = Kanyon Control; ML = Macktush Low; CL = Cous Low; KH = Kanyon High; MR = Macktush Reburn; MH = Macktush High.

b Because KL consisted only of one plot, it was not used in statistical comparisons.