CFS CANADIAN FOREST SERVICE

Prescribed burning impacts on some coastal British Columbia ecosystems

W.J. Beese, B.A. Blackwell, R.N. Green, B.C. Hawkes

Natural Resources Canada • Canadian Forest Service
Pacific Forestry Centre • Victoria, British Columbia
Information Report • BC-X-403

Natural Resources Canada
Ressources naturelles Canada
Canada

The Pacific Forestry Centre, Victoria, British Columbia

The Pacific Forestry Centre of the Canadian Forest Service undertakes research as part of a national network system responding to the needs of various forest resource managers. The results of this research are distributed in the form of scientific and technical reports and other publications.

Additional information on Natural Resources Canada, the Canadian Forest Service, and Pacific Forestry Centre research and publications is also available on the World Wide Web at: **www.pfc.cfs.nrcan.gc.ca**. To download or order additional copies of this publication, see our online bookstore at: **bookstore.cfs.nrcan.gc.ca**.

Prescribed burning impacts on some coastal British Columbia ecosystems

W.J. Beese

Western Forest Products Inc.
Nanaimo, British Columbia

B.A. Blackwell and R.N. Green

B.A. Blackwell and Associates Ltd.
North Vancouver, British Columbia

B.C. Hawkes

Natural Resources Canada
Canadian Forest Service
Pacific Forestry Centre

Natural Resources Canada
Canadian Forest Service
Pacific Forestry Centre
Information Report BC-X-403

2006

Canadian Forest Service
Pacific Forestry Centre
506 West Burnside Road
Victoria, British Columbia
V8Z 1M5
Phone (250) 363-0600

www.pfc.cfs.nrcan.gc.ca

ISSN 0830-0453
ISBN 0-662-43289-4
Printed in Canada

Microfiches of this publication may be purchased from:
MicroMedia Inc.
240 Catherine Street, Suite 305
Ottawa, ON K2P 2G8

Library and Archives Canada Cataloguing in Publication

Prescribed burning impacts on some coastal British Columbia ecosystems /
W.J. Beese ... [et al.].

(Information report ; BC-X-403)
Includes bibliographical references.
Includes summary in French.
ISBN 0-662-43289-4
Cat. no.: Fo143-2/403E

1. Prescribed burning--Environmental aspects--British Columbia--Port Alberni Region. 2. Forest productivity--British Columbia--Port Alberni Region. 3. Forest site quality--British Columbia--Port Alberni Region. I. Beese, William John, 1956- II. Pacific Forestry Centre III. Title. IV. Series: Information report (Pacific Forestry Centre) ; BC-X-403

SD387.S53P73 2006 634.9’55 C2006-980109-6

Contents

Tables

Abstract

Prescribed burning is widely used as a forest management tool; however, its long-term impacts on site productivity must be better understood to meet planned burn objectives. MacMillan Bloedel (now Western Forest Products Inc.) and the Canadian Forest Service began a study of the effects of prescribed burning on fuel consumption, tree growth and site nutrition in 1985. This paper quantifies the impacts of fires of different severity on woody debris and soil organic horizons.

Three low-severity spring burns, two high-severity fall burns and two unburned controls were established on three sites near Port Alberni, on Vancouver Island, British Columbia. Most of the low-severity spring burn area was accidentally reburned during an adjacent high-severity fall burn, resulting in a very high-severity burn.

The major differences in impacts between spring and fall burns were greater consumption of forest floor and increased mineral soil exposure on fall burns. The reburned area had forest floor consumption and mineral soil exposure similar to those in the adjacent fall burn, but also exhibited greater large woody fuel consumption. Total slash consumption significantly increased with increasing fire severity, while consumption of forest floor, slash plus forest floor, depth of burn, and mineral soil exposure were all significantly greater on fall burns compared to those in spring burns.

Résumé

Le brûlage dirigé est largement utilisé en tant qu'outil d'aménagement forestier; il est cependant nécessaire de comprendre ses effets à long terme sur la productivité d'une station pour atteindre les objectifs prévus en matière de brûlage. La société MacMillan Bloedel (maintenant Western Forest Products) et le Service canadien des forêts ont entrepris, en 1985, une étude sur les effets du brûlage dirigé sur la consumation des combustibles, la croissance des arbres et la nutrition dans ces lieux. Le présent document quantifie les répercussions qu'ont les feux de toute intensité sur les débris de bois et l'horizon organique du sol.

Trois brûlages de printemps de faible intensité, deux brûlages d'automne de forte intensité et deux zones témoins sans brûlage ont été établis à trois endroits près de Port Alberni, sur l'île de Vancouver, en Colombie-Britannique. La majeure partie de la zone de brûlage de printemps de faible intensité a été accidentellement brûlée de nouveau au cours d'un brûlage d'automne de forte intensité dans une zone adjacente, résultant en un brûlage de très forte intensité.

Les principales différences constatées entre les effets des brûlages de printemps et ceux d'automne consistent en une plus grande consumation de la couche holorganique et en une exposition accrue du sol minéral lors des brûlages d'automne. La consumation de la couche holorganique et l'exposition du sol minéral de la zone brûlée de nouveau sont semblables à celles du brûlage d'automne adjacent, mais elles révèlent également une consumation plus grande des combustibles ligneux de grande taille. La consumation totale des rémanents a beaucoup augmenté avec l'accroissement de l'intensité des feux tandis que la consumation de la couche holorganique, de la couche holorganique et des rémanents, la profondeur du brûlage ainsi que l'exposition du sol minéral associées aux brûlages d'automne sont nettement plus grandes que celles associées aux brûlages de printemps.

Acknowledgements

This project was funded in part through the Unsolicited Proposal Program of Industry Canada and through the Canadian Forest Service under the Federal Direct Delivery component of the 1985 to 1990 Canada–BC Forest Resource Development Agreement. The BC Ministry of Forests, Vancouver Region, and BC Science Council funded several associated studies.

We wish to recognize the valuable contribution of the following people to this project (listed with their associated organizations at the time of the work): Russ Campbell and Dan Powell (BC Ministry of Forests); Bruce Lawson (retired), Steve Taylor, George Dalrymple, Rene de Jong, and Gary Lait (Canadian Forest Service, Pacific Forestry Centre); Bill Motyka, Ray Buck, Randy Lafferty, Arlene Gammell, Jeff Sandford, Mike Hooper, Dave Clark, Gord Medves, Ken Epps and many others from MacMillan Bloedel; and Mark Walmsley (Pedology Consultants). Dr. Bill Warren provided advice on statistical analysis. Dr. Michael Feller (University of British Columbia) and Anne Macadam, Rick Trowbridge and John Parminter (BC Ministry of Forests) provided helpful consultation during the project.

Introduction

Prescribed burning has been widely used in coastal British Columbia (BC) as a silvicultural tool for site preparation and fire hazard reduction following logging. From 1981 to 1990, about 7,500 ha were burned annually in the Coastal Douglas-Fir and Coastal Western Hemlock biogeoclimatic zones. By 1991, this area had dropped to 1600 ha in the Vancouver Forest Region (Taylor and Sherman 1996). The area burned following logging has decreased primarily due to environmental and smoke management concerns, increased availability of excavators for mechanical site preparation and several other factors. It is now rare to find broadcast burning practiced on the BC coast, yet it can be a useful tool for meeting both silviculture and wildlife management objectives.

The ecological effects of prescribed fire on forest ecosystems are highly variable, depending on site characteristics and fire severity. Fire effects have the potential to be either beneficial or detrimental to forest productivity. Concern over possible long-term detrimental effects of fire-consumed woody fuel and forest floor and of accelerated soil erosion due to fire was the basis of fire sensitivity ratings developed by the BC Ministry of Forests (Klinka et al. 1984). These guidelines help foresters make appropriate burning prescriptions. On some sites, potential detrimental effects must be weighed against seedling establishment targets.

Prescribed fire research in BC in the 1980s (Blackwell et al. 1992; Macadam 1987) focused on long-term site productivity and the need for improved, site-specific fire prescriptions. These studies measured the impacts of fire severity on tree growth effects, other biotic responses and site productivity. Although these studies quantified a range of fire effects and resulting vegetation response in sub-boreal forests, their application to coastal forests is limited. Most prescribed fire studies in Pacific coastal forests have inadequately characterized ecosystems and fire severity (Feller 1982). This has limited our ability to extrapolate research results to similar ecosystems for development of site-specific burning prescriptions and guidelines. More recent prescribed fire research in BC (Bellillas and Feller 1998; Kranabetter and Macadam 1998) has provided a better understanding of ecological fire effects; however, information for coastal ecosystems remains limited.

The objectives of this study were to quantify the effects of a range of prescribed fire intensities on fuels, tree growth, and site nutrition on selected coastal ecosystems.

Methods

Study area

The study was conducted on Vancouver Island, west of Port Alberni, BC (Figure 1). Three study sites were selected, based on the following criteria:

1) recently harvested clearcuts available for slashburning;

2) slash accumulations that restricted planting and prevented adequate reforestation; and,

3) ecosystems having potential for adverse effects from burning.

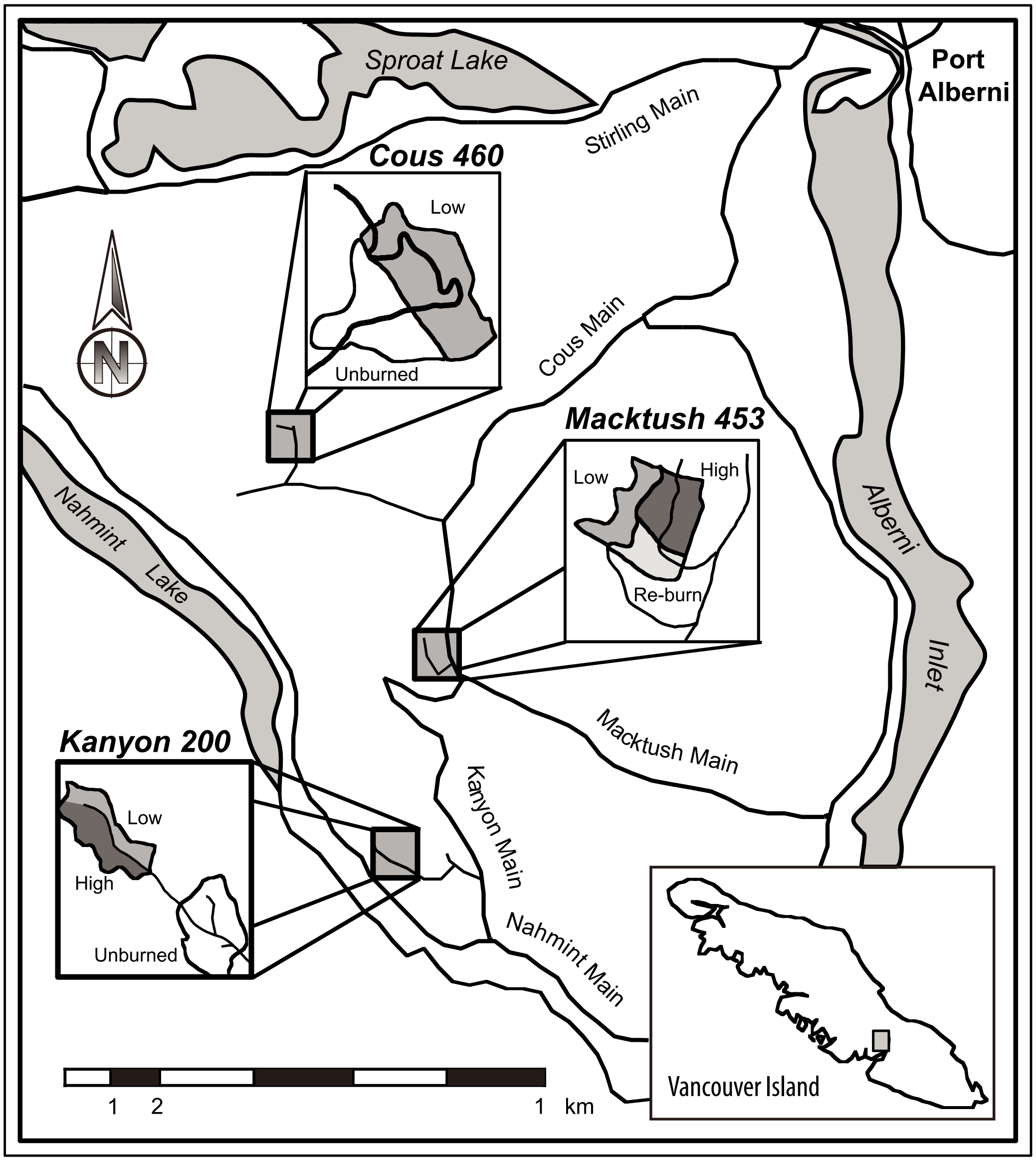

Figure 1. Study area location and treatment layout.

Some important site characteristics of the three study areas are given in Table 1. The sites are on south- to southeast-facing slopes, between 450 and 650 m in elevation, within the Coastal Western Hemlock (CWH) biogeoclimatic zone (Green and Klinka 1994). Two sites, Cous and Macktush, are within the Submontane Moist Maritime CWH variant (CWHmm1). The Kanyon site is within the Submontane Very Wet CWH variant (CWHvm1), although it more closely resembles the CWHmm1 variant because of its warm aspect, local climate and proximity to the CWHmm1.

All sites are moderate to steeply sloping (average 40% to 60%), with rapidly to well-drained, moderately deep, sandy loam textured soils. The soils are generally Orthic Humo Ferric Podzols (Soil Classification Working Group 1998) derived from glacial till and are, in many places, capped by a veneer of rubbly colluvium. Outcrops of underlying basalt bedrock are common.

The study sites were classified as the CWHmm1/HwCw–Salal and CWHmm1/HwBa–Pipecleaner moss site series (Green and Klinka 1994) on the Cous and Macktush sites, and the CWHvm1/HwCw–Salal and CWHvm1/HwBa–Blueberry site series on the Kanyon site. The general trend on all three sites was a transition from the "zonal" site series on lower slopes to the drier "salal" site series on upper slopes. The post-harvest understory vegetation was dominated by salal (*Gaultheria shallon* Pursh), red huckleberry (*Vaccinium parvifolium* Smith), Alaska blueberry (*Vaccinium alaskaense* Howell), and oval-leaved blueberry (*Vaccinium ovalifolium* Smith) in the shrub layer; fireweed (*Epilobium angustifolium* L.), vanilla leaf (*Achlys triphylla* [Smith] DC), twinflower (*Linnaea borealis* L.), and swordfern (*Polystichum munitum* [Kaulf.] Presl) in the herb layer; and stepmoss (*Hylocomium splendens* [Hedw.] B.S.G.), lanky moss (*Rhytidiadelphus loreus* [Hedw.] Warnst.), Oregon beaked moss (*Kindbergia oregana* [Sull.] Ochyra), and pipecleaner moss (*Rhytidiopsis robusta* [Hedw.] Broth.) in the bryophyte layer. Minor areas of drier or nutrient-poor and fresh or nutrient-rich sites occur within the study areas. The study sites supported poor- to medium-productivity old-growth stands of western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) and amabilis fir (*Abies amabilis* [Dougl. ex Loud.] Dougl. ex J. Forbes), with varying amounts of western redcedar (*Thuja plicata* Donn ex D. Don) and Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco). These stands contained trees of all ages, with a median age of 275 years for dominant trees.

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. Only two study plots in the Kanyon area were classified differently: one as low sensitivity and one as very high sensitivity. Smaller portions of other study plots were also represented by these classes of low and very high sensitivity. Areas with a 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%.

Experimental design

The treatments were replicated using a balanced incomplete block design. Originally, two replicates each of two prescribed fire treatments (low-severity spring and high-severity fall) and a control (unburned) were allocated to three blocks (Cous, Macktush, and Kanyon). The combination of treatments and sites was such that one block had both fire treatments, while the two remaining blocks each had a fire treatment and a control (Table 2). The original design was altered after accidental reburning of four spring plots changed the number of high- and low-severity plots at the Macktush site. This accidental reburn of the four Macktush plots created an opportunity to quantify a very high-severity fall burn, thus adding an additional prescribed fire treatment. One low-severity plot was established in a spring burn carried out to create a fuel break for the upcoming fall burn.

The trees on the Macktush site were felled in early 1982, while trees on the other sites were felled in 1983. The majority of the area was yarded in 1983 using highlead and grapple cable yarding systems. The slash age (the time of falling to time of burning) was 2 years at the Cous site, 2.5 years at the Kanyon site, and 3 to 3.5 years at the Macktush site. Slash age was older than that of many operational burns.

The low- and high-severity burn treatments were applied in the spring and fall of 1985, respectively. Fire prescriptions were designed to reduce surface organic matter by a specified depth (from 0% to 50%

for a low-severity treatment and more than 50% for a high-severity treatment) using the Prescribed Fire Predictor/Planner (Muraro 1975). The prevailing fire weather and the Canadian Forest Fire Weather Index (FWI) System codes and indices for each of the burning days are given in Table 3. Fire weather data were obtained from an on-site weather station. Electronic weather stations (Forest Technology Systems, Ltd, Victoria B.C.) were established on each site in early March 1985 to record temperature, relative humidity, wind speed and direction, 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 a backup at each site. Relative humidity was also measured at each site using sling and fan psychrometers. The hygrothermographs proved to be more accurate than the electronic sensors when compared to the sling and fan psychrometers; consequently, the hygrothermograph values were used for all calculations. Standard fire weather readings were taken at 1200 hours, Pacific Standard Time, for temperature and relative humidity at 115 cm above ground, wind velocity and direction at 10 m above ground, and accumulated precipitation in the previous 24 hours. Temperature, relative humidity and wind velocity were recorded immediately preceding and during burns. All FWI System codes and indices were calculated using the most recent FWI system equations (Van Wagner and Pickett 1985).

Prescribed fire treatments

Burning prescriptions to meet the desired severity levels were developed using the Canadian Forest Fire Danger Rating System (CFFDRS) (Stocks et al. 1989). Preferred ranges of CFFDRS Fire Weather Index System codes and indices are given in Table 3. All burns were ignited with a helitorch, except for the Macktush high-severity treatment where manually ignited narrow strip headfires were used for the upper part of the treatment while the rest was left to burn through the night with a slow-moving backing fire down the slope. A horizontal strip ignition pattern was used for all burns except the Macktush high-severity treatment.

Low-severity spring burning

The three spring burns occurred May 21, 1985. Details on light-up conditions and FWI system codes and indices are given in Table 3. The Cous Creek area was ignited shortly after 1600 hours. With the helitorch, strips 20 m to 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 to 5 hours prior to 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. The only exception was at a gap in the line near the lower boundary of the setting. The Martin Mars water bomber was used to eliminate this gap, which prevented loss of control (unburned) plots. A small strip above the road that crosses the Kanyon fall burn site was ignited immediately following the Cous burn to act as a fire break for the fall burn. 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 all spring burns. The slash was lit immediately adjacent to mature timber without control problems because of the moist condition of the forest floor.

High-severity fall burning

The first of two fall burns occurred September 25, 1985 at the Kanyon site. Ignition began with a strip along the lower edge of the road. The ignition plan was to allow this strip to burn downslope before continuing with additional strips. Because of heavy fuel loading, however, the fire could not be contained below the road. Consequently, the spring area reburned (except one plot that was protected by sprinklers), 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 km/h. This caused a major escape that spread several kilometers by 0300 hours. Fire fighters 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, which provided some unique data. Sufficient area was saved by the sprinkler system to allow tree-growth monitoring in the spring (low-severity) area as a comparison to the adjacent fall and reburned (high to very high severity) areas.

Woody fuel, forest floor and mineral soil exposure

Woody fuels (>0.1 cm in diameter) were measured pre- and post-burn in each of the treatment and control plots using the line intersect technique (Van Wagner 1968), as presented by McRae et al. (1979). Prior to burning, five sample plots, each consisting of three 30-m line transects arranged as a triangle, were located randomly within each treatment replicate. Intersecting woody fuel pieces less than 7 cm in diameter were tallied by size class (0.1 cm to 0.5 cm, 0.6 cm to 1.0 cm, 1.1 cm to 3.0 cm, 3.1 cm to 5.0 cm, 5.1 cm to 6.9 cm, and >7.0 cm diameter) along each transect, and species composition was estimated. Woody fuel pieces greater than 7 cm in diameter were individually measured and the species identified.

Fuel loading and consumption were calculated using equations presented by Van Wagner (1982*a*, *b*), with some modifications (Deas and Macadam 1985). Specific gravity of woody fuel was calculated for the major species by size class, based on oven-dry weight, and volume determined by displacement. Woody fuel consumption was computed for each plot and summarized by treatment replicate using a computer program developed by de Jong (1986) at the Canadian Forest Service, Pacific Forestry Centre, in Victoria, BC.

Forest floor (LFH) depth was measured in three locations at 5-m intervals along the line transects using 45 metal depth-of-burn (DOB) pins, plus five supplemental pins for a total of 50 pins for each triangle. In addition, 40 point measurements of forest floor reduction were obtained for each plot using the "erosion bridge" technique described by Blaney and Warrington (1983). This technique involves installing three leveled metal posts along the contour. A modified masonry level is placed on the posts, and a measuring rod is placed through evenly spaced holes in the level. In this way, 20 repeatable point measurements from the level to the ground surface are obtained over a 2.4-m line transect without disturbing the forest floor with a pin. The combination of these two methods yielded 450 point samples per treatment replicate.

Fuel moisture sampling was carried out prior to ignition on the burn. Each of the blocks had two destructive fuel sampling areas established and samples were collected on each pre-burn rainless day. The destructive organic layer samples (forest floor) are comprised of litter (L) and duff (FH) layers. The L layer samples were obtained beneath the woody fuel bed and included needles and detached twigs less than 1.0 cm diameter. The FH layer was stratified into three depth layers from the bottom of the litter layer to the mineral soil interface. The Cous site also had additional 0.1 m^2 forest floor samples collected the day of the burn. Samples of fine (0.1 cm to 1.0 cm) and medium (1.1 cm to 3.0 cm) woody fuels were also collected from a mid-woody fuel bed location. All moisture samples were oven-dried at 100° C for a period of 24 to 48 hours. Gravimetric moisture contents (g H_2O/g dry mass) were calculated based on oven-dried sample weights (Table 4). Forest floor (LFH) bulk density was estimated from a systematically located point in each of the fuel sample plots. A 30-cm × 30-cm sample was cut down to mineral soil, and the depth of the LFH layers was measured on four sides of the hole to obtain the average depth of each layer. The samples were then oven-dried, weighed and summed to determine forest floor mass (kg/m^2; Table 5).

Exposed mineral soil was measured along the 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 (675 m per treatment replicate). Total length of exposed and unexposed mineral soil (measured as duff and woody material) was measured along the entire 135 m transect on each plot. Percent exposure was calculated as the total length of transect falling upon mineral soil, measured to the nearest 0.1 m, divided by the transect length.

Data analysis

Mineral soil exposure, woody fuel consumption, and forest floor consumption data were analyzed to determine the effect of burning severity on each variable, as expressed in both absolute and relative percent values. This objective was achieved by subjecting each variable to a Type III analysis of variance. For the analysis of variance, the assumption of normality could not be tested because of the limited number of data points. All percent consumption data were normalized using an arcsine transformation (Zar 1984). Data were analyzed using BMDP (Dixon et al. 1990) and SYSTAT (Wilkinson 1988) statistical software. Because the accidental burning altered the original experimental design, a series of orthogonal contrasts were performed using the SYSTAT Multivariate General Linear Model procedures for unbalanced, incomplete block experiments, and BMDP-P7D.5 user-specified contrasts.

Results and discussion

Table 5 summarizes the pre- and post-burn fuel loads in control and treatment plots. Mean pre-burn fuel loads (woody fuel and forest floor) ranged from 23 kg/m^2 to 46 kg/m^2. Forest floor biomass was the most substantial contributor to surface fuel loads, ranging from 15 kg/m^2 to 33 kg/m^2. Average woody fuel loads prior to burning ranged from 8 kg/m^2 to 20 kg/m^2.

Total pre-burn woody fuel biomass was within the range of values observed by Feller et al. (1983) and Feller (1989) for 16 slash burns monitored within the Coastal Western Hemlock zone. The amount of woody fuel biomass was generally higher than the range of values 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).

Woody fuel consumption

Table 6 shows biomass (kg/m^2) and Table 7 shows percent woody fuel consumption for the small (0.1 cm to 7 cm) and large (>7 cm) woody fuel size classes. Consumption of small woody fuel did not differ significantly among treatments (Tables 8 and 9). Small woody fuel consumption ranged from 0.2 kg/m^2 in the Kanyon low-severity treatment to 2.5 kg/m^2 in the Cous low-severity treatment. With the exception of the low-severity treatments at Kanyon and Macktush, consumption of small woody fuel exceeded 85% in all severity classes (Table 7). Virtually all small woody fuel was consumed as a result of the reburn at Macktush (Figure 2).

Large woody fuel consumption (>7 cm) ranged from 0.8 kg/m^2 to 7.4 kg/m^2 for the three fire severity treatments (Table 6), increasing from low to very high-severity ($p<0.01$; Tables 8 and 9). The mass consumed was greatest with the Kanyon high-severity burn and the Macktush very high severity burn. Most consumption in the Macktush very high severity burn occurred during the reburn. Consumption from the reburn was greater than on the adjacent high-severity Macktush burn, presumably because fuels were already charred and the black surface increased the large woody fuel internal temperatures, thus increasing drying rates. The lowest fuel consumption of large woody fuel occurred in the single low-

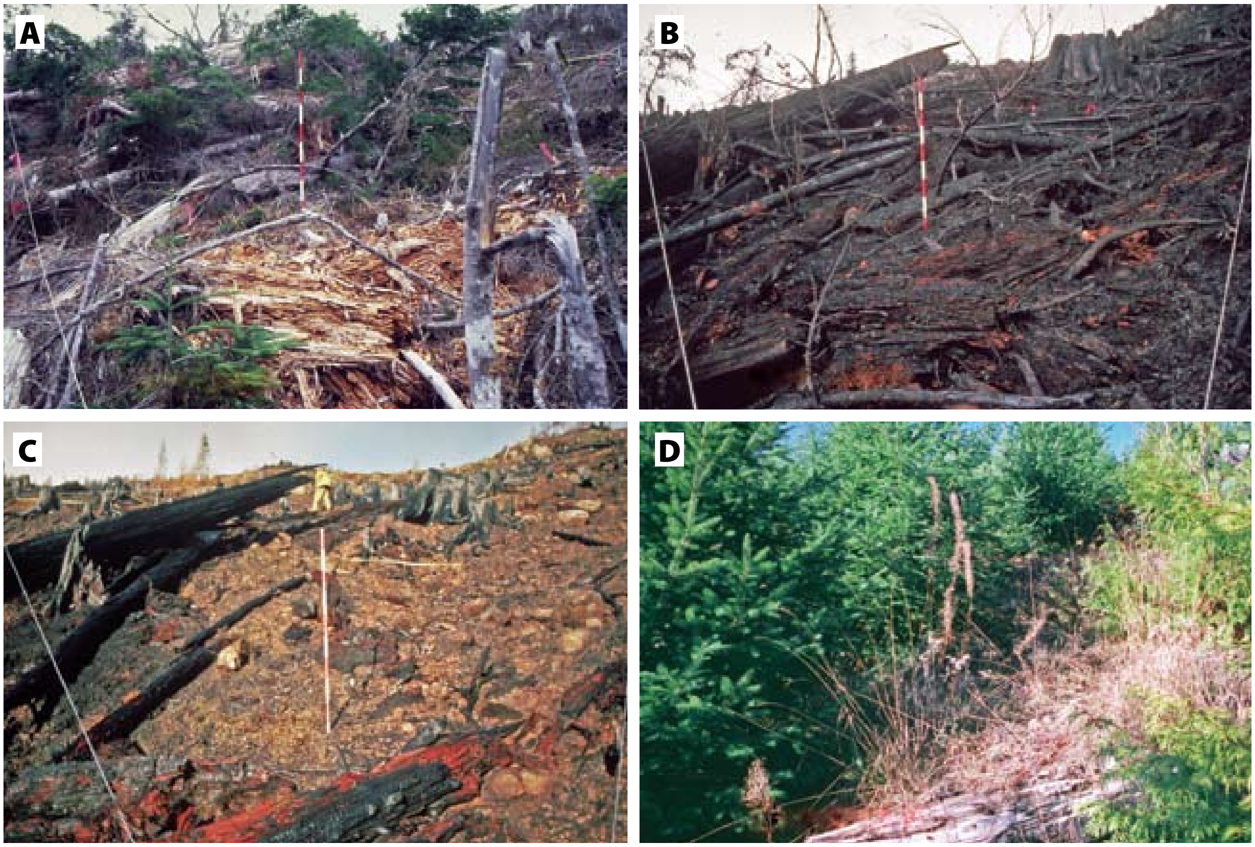

Figure 2. Permanent photo point at Macktush illustrating impacts of low and high severity burns on organic matter consumption and mineral soil exposure: a) pre-burn, 2 May 1985; b) post spring burn, 23 May 1985; c) post fall reburn, 23 October 1985; d) 10 years post-burn revegetation, 31 October 1995.

severity plot at the Kanyon site. This was likely a function of the low initial fuel load. Differences in large woody fuel consumption from low-severity spring burns to high-severity fall burns reflected spring and fall fuel moisture contents. In the spring, moisture content of large (>7 cm) woody fuel starts in the 50% to 60% range; in the fall, it drops to a range of 20% to 30% (Taylor et al. 1991). Sandberg and Ottmar (1983) found that for every 10% increase in moisture content (up to 52%) in large (7.6 cm to 23 cm) woody fuel, diameter reduction from burning decreased by 2.7 cm. The relative percent consumption (4% to 68%) of large woody fuel (>7-cm size class) was substantially lower (27% to 98%) than that of small woody fuel (0.1-cm to 7-cm class).

Total woody fuel consumption for all fire severity treatments ranged from 1.1 kg/m^2 to 9.2 kg/m^2 (Table 6). The highest quantity of woody fuel consumed was measured on the very high-severity fall burn. The Kanyon low-severity burn consumed the lowest amount of woody fuel. Analyses of variance showed that burning treatments had significantly (p<0.001) different effects on quantities of total woody fuel consumed (Table 8) and that woody fuel consumption increased significantly with increasing severity (Tables 7 and 9).

Total woody fuel consumption was within the range measured by Feller (1989); however, the percent consumption (45% to 73%) exceeded the maximum percent consumption recorded by Feller on all but two fires (Kanyon and Macktush low-severity spring burns). Muraro (1971) reported woody fuel consumption ranging from 37% to 53% of the initial fuel loading. Only Little and Klock (1985) reported woody fuel consumption exceeding the 73% woody fuel consumption on the Macktush high-severity burn.

The Prescribed Fire Predictor developed by the Canadian Forest Service (Muraro 1975) underestimated consumption of small (<7 cm) woody fuel by 16% to 43% for all burn treatments. The Predictor underestimated consumption of total woody fuel by 16% to 53% for all burn treatments, using the maximum (<22 cm) woody fuel size class available in the predictor.

Forest floor (LFH) consumption

Forest floor consumption ranged from 2.2 kg/m^2 to 17.9 kg/m^2 for the different fire severity treatments (Table 6). The greatest forest floor consumption was measured on the high-severity fall burn at Macktush. Forest floor consumption was more variable when compared with woody fuel consumption results. For example, forest floor consumption for the two high-severity fall burns differed by over 10 kg/m^2. Some of this variation could be attributed to initial fuel loads, but much of the variation was likely a function of the time of burn, aspect, site-specific weather conditions, and the use of a backing fire on the Macktush site. Backing fires have longer fire duration than heading fires (Beaufait 1965), and increasing fire duration can increase the depth of burn as long as the heat flux to the forest floor surface is sufficient to sustain the combustion zone moving through the forest floor (Hawkes 1993).

For low-severity spring burns, the Cous fire consumed more than two times the forest floor compared to the Macktush fire, even though the FWI codes and indices were the same for the two sites. Several factors could account for this difference. First, the Cous fire was ignited at 1614 hours (Pacific Standard Time), at the peak of the diurnal cycle (greater solar heating) while the Macktush fire took place 2.5 hours later. Relative humidity and litter fuel moisture (Table 4) were higher at the Macktush burn because of the time difference. Second, the Cous site has direct southern exposure, whereas the aspect of the Macktush site is more easterly: consequently, forest floor moisture content was drier at the Cous site. Finally, heat from combustion of the small (<7 cm) woody fuel at the Cous site would contribute to greater forest floor consumption. Little et al. (1986) hypothesized that variability in forest floor consumption is related to high variability in forest floor load, duff moisture, and fuel consumption (e.g., large-diameter rotten logs that smoulder for prolonged periods). Forest floor burning that is independent of woody fuels may also provide insight into variation between sites. Feller (1988) observed that forest floor can be consumed by smouldering ground fires long after surface fuel burning has ceased, suggesting that increased forest floor consumption is possible independent of woody fuel load if forest floor moisture content is below the threshold for independent smouldering.

Forest floor consumption, expressed on a relative basis (%), ranged from 14% to 79% (Table 7), generally increasing with increasing fire severity, although the effect was significant only for spring versus fall burns (Tables 8 and 9). For low-severity fires, the range of consumption was considered small (14% to 26%), and was comparable to other studies characterizing low-severity burns (Macadam 1987; Taylor and Feller 1987; Blackwell et al. 1992). On average, percent consumption was greatest (79%) in the high-severity fall burn at Macktush.

Combined woody fuel and forest floor (LFH) consumption

Both the Macktush high and very high severity fall burns had combined LFH and woody fuel consumption (24.5 kg/m^2 and 23.0 kg/m^2) greater than the maximum of 17.3 kg/m^2 measured by Feller (1989), and other studies (Little and Klock 1985; Little and Ohmann 1988). Feller's data included understory plant biomass. This substantiates our view that the Macktush site fall burns represent a maximum or "worst case" scenario for prescribed fire severity over a large area. Similar localized impacts, however, may occur on many fall burns.

The spring burns consumed an average of 22% of the total fuel load (forest floor and woody fuel); in comparison, the high severity fall burns resulted in an average fuel consumption of 57%. The total consumption in the very high severity fall burn was only marginally higher (60%) than the high-severity fall burns.

Forest floor (LFH) depth of burn

The objectives of forest floor depth reduction of less than 50% for spring burns and greater than 50% for fall burns were achieved. The average pre-burn LFH depths varied from 11 cm to 20 cm (Table 10). . Average depth of burn (from DOB pins) ranged from 2.3 cm to 3.8 cm on spring burns, from 7.6 cm to 12.7 cm on fall burns, and was 14.2 cm (from DOB bridges) on the reburn. Instead of two distinct levels of consumption from the spring and fall prescriptions, the actual fires produced a range of forest floor consumption. Forest floor consumption was significantly greater ($p<0.05$) in both the high-severity and very high severity fall burns compared to that in the spring burns (Table 9).

The depth of burn on the Macktush site high and very high severity fall burns was nearly twice the maximum mean depth of burn reported by Feller (1989). It also exceeded that reported in other studies in BC and the US Pacific Northwest (Sandberg 1980; Brown et al. 1985; Little and Klock 1985; Macadam 1987).

The Prescribed Fire Predictor (Muraro 1975) tended to underestimate forest floor depth percent reduction for these fires. Predicted spring burn depth reduction was 2% to 15% less than actual values. Depth reduction on the Kanyon fall burn was 2.5 times the predicted value. For the backing fire at Macktush, actual forest floor reduction was 10% greater than predicted.

Mineral soil exposure

Pre-burn average mineral soil exposure on all sites ranged from 1.0% to 5.5% (Table 11). High and very high severity burns resulted in significantly ($p<0.05$) more area of mineral soil being exposed compared to that of lower-severity burns (Tables 9 and 11). Average mineral soil exposure in fall burns ranged from 29% to 74%, with high variability among individual plots. The greatest area of mineral soil exposure was measured on the high-severity fall burn at Macktush. Mineral soil exposure results were consistent with forest floor reduction, with more soil exposed in the high and very high severity fall burns compared to results of low-severity spring burns. These differences were attributed to the variations in site and burning conditions discussed previously. The amount of mineral soil exposed during a prescribed fire is a function of the amount of forest floor cover, pre-burn depth, and depth of burn (Little et al. 1986). Where the forest floor is uniform in density and cover, mineral soil exposure will be closely related to forest floor moisture content, fuel consumption, and weather variables.

For depths of burn similar to those in the Macktush spring burn, Little et al. (1982) measured 13% and 15% exposure at burning sites with somewhat thinner forest floors (7.5 cm to 10.3 cm). Other studies reported relative increases in mineral soil exposure ranging from 0% to 66% (Dyrness et al. 1957; Silen 1960; Mersereau and Dyrness 1972; Sandberg 1980; Amaranthus and McNabb 1984; Kauffman and Martin 1989). The exposure induced by the Macktush fall burn was greater than that reported in any published Pacific Northwest studies.

Compared to the values suggested by the Prescribed Fire Predictor (Muraro 1975), the mineral soil exposure of the spring burns was less than the predicted 10%. Both fall burns had 2.5 to 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.

Fuel consumption correlations

Correlations between fuel consumption variables and fire severity treatments were highest for large (>7 cm) woody fuel (Table 12). Total woody fuel consumption and forest floor consumption all positively correlated with fire severity; however, the relationship between these variables and fire severity treatments was less strong compared to the correlation for woody fuel that was greater than 7 cm in diameter. All fuel consumption variables were generally found to increase with decreasing fuel moisture content, as suggested by Drought Code values in the FWI System. Blackwell et al. (1992) found that fire weather codes (Duff Moisture Code and Drought Code) were best correlated with forest floor mass reduction. They suggested that forest floor consumption was controlled primarily by forest floor mass and moisture content, and not by observed surface fire duration and woody fuel load; they found that comparisons of consumption of >7 cm fuel to the Drought Code (DC) were much weaker and noted that fuel consumption of this size class was related more to fire duration and amount of forest floor heating. In this study, however, high correlation of consumption of >7 cm fuel appears to be related to fuel moisture content rather than fuel load, as indicated by the correlations with the Fine Fuel Moisture Code and DC. Fuels subjected to more drying resulted in increased amounts of fuel consumption as measured by the fire severity treatments.

Conclusions

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), the Prescribed Fire Predictor (Muraro 1975), Prescribed Burning Guidelines (BCMF 1985) and Fire Sensitivity Ratings (Klinka et al. 1984), combined with electronic weather stations, telemetry, and helicopter ignition, give foresters the ability to prescribe and carry out appropriate treatments.

Within the range of burning conditions studied, it is apparent that a considerable range of woody fuel and forest floor consumption and mineral soil exposure is achievable. Results comparable to the high and very high severity burns have not occurred in other coastal studies and are similar to only a few other studies in central and sub-boreal BC (Blackwell et al. 1992; Macadam 1987). We suspect that the typical fall burning window used on the coast in the past probably resulted, in many cases, in high-severity impacts that were not documented. A range in fuel consumption associated with increasing severity was clearly demonstrated in this study, although our ability to accurately predict associated impacts with increasing severity must be questioned, based on our comparisons with the Prescribed Fire Predictor. This suggests that further research quantifying impacts of fire severity on fuel consumption and other ecosystem properties is required to improve the reliability of fire prescriptions. Caution should be used in the development of high-severity prescriptions using the Prescribed Fire Predictor.

Woody fuel and forest floor moisture content are the most important factors under the manager's control to influence fire impact. Woody fuel moisture determines the amount of debris consumption for creating plantable spots. Moisture in the forest floor and soil controls organic consumption and heat penetration in the soil and, consequently, the effect upon the roots and rhizomes of competing vegetation. Higher-impact fires yield the greatest benefit for vegetation control and woody fuel reduction; however, long-term site-nutrient status must be considered.

Once the suitability of burning is determined, the resource manager should attempt to achieve the lowest impact burn that meets the silvicultural or wildlife management 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 than with fall burning. In the past, many prescribed burns for silvicultural purposes were done to reduce small woody fuel for easier planting. This study showed that this objective can be achieved with relatively low-severity fires without substantial losses of soil organic matter. Maintaining site productivity should be the foundation upon which to build a successful and ecologically appropriate burning prescription.

References

Amaranthus, M.; McNabb, D.H. 1984. Bare soil exposure following logging and prescribed burning in southwest Oregon. Pages 234–237 *in* Proceedings of the Society of American Foresters National Convention: New Forests for a Changing World, October 16–20, 1983, Portland, OR. Society of American Foresters, Bethesda, MD.

Beaufait, W.R. 1965. Characteristics of backfires and headfires in a pine needle fuel bed. USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT. Research Note INT-39. 7 p.

Belillas, C.M.; Feller, M.C. 1998. Relationships between fire severity and slashburning - induced nutrient loss to the atmosphere and losses via leaching in British Columbia's Coastal Western Hemlock zone forests. International Journal of Wildland Fire 8:87-10.

Blackwell, B.A.; Feller, M.C.; Trowbridge, R. 1992. Conversion of dense lodgepole pine stands in west-central British Columbia into young lodgepole pine plantations using prescribed fire. 1. Biomass consumption during burning treatments. Canadian Journal of Forestry Research 22:572–581.

Blaney, D.G.; Warrington, G.E. 1983. Estimating soil erosion using an erosion bridge. USDA Forest Service, Watershed Systems Development Group, Fort Collins, CO. WSDG Report, WSDG-TP-00008, 55p.

British Columbia Ministry of Forests. 1985. A guide to prescribed broadcast burning in the Vancouver Forest Region. A cooperative venture between the B.C. Min. of Forests and MacMillan Bloedel Limited, B.C. Min. of Forests, Vancouver Forest Region, Burnaby, B.C., March 1985, 110 p.

Brown, J.K.; Marsden, M.A.; Ryan, K.C.; Reinhardt, E.D. 1985. Predicting duff and woody fuel consumed by prescribed fire in the Northern Rocky Mountains. USDA Forest Service, Intermountain Research Station, Ogden, UT. Research Paper INT-337. 23 p.

Deas, A.; Macadam, A. 1985. A computer program for calculating fuel loading and consumption for prescribed fire studies. British Columbia Ministry of Forests, Victoria, BC Research Report 85004-PR. 22 p.

de Jong, R.J. 1986. Fuel loading and consumption program [unpublished computer program]. Canadian Forest Service, Pacific Forestry Centre, Victoria, BC.

Dixon, W.J.; Brown, M.B.; Engelman, L.; Jennrich, R.I. Eds. 1990. BMDP Statistical Software. University of California Press, Los Angeles, CA.

Dyrness, C.T.; Youngberg, C.T.; Ruth, R.H. 1957. Some effects of logging and slash burning on physical soil properties in the Corvallis watershed. USDA Forest Service, Pacific Northwest Research Station, Portland, OR. Research Paper PNW-19. 15 p.

Feller, M.C. 1982. The ecological effects of slashburning with particular reference to British Columbia: a literature review. British Columbia Ministry of Forests, Victoria, BC Land Management Report No. 13. 60 p.

Feller, M.C. 1988. Relationships between fuel properties and slashburning-induced nutrient losses. Forest Science 34(4):998–1015.

Feller, M.C. 1989. Estimate of nutrient loss to the atmosphere from slashburns in British Columbia. Pages 126–135 *in* D.C. MacIver, H. Auld and R. Whitewood, eds. Proceedings of the 10th Conference on Fire and Forest Meteorology, April 17–21, 1989, Ottawa, ON. Environment Canada, Ottawa, ON.

Feller, M.C.; Kimmins, J.P.; Tsze, K.M. 1983. Nutrient losses to the atmosphere during slashburns in southwestern British Columbia. Pages 128–135 *in* Proceedings of the 7th Conference on Fire and Forest Meteorology, April 25–28, 1983, Fort Collins, CO. American Meteorological Society, Boston, MA.

Green, R.N.; Klinka, K. 1994. A field guide for site identification and interpretation for the Vancouver Forest Region. British Columbia Ministry of Forests, Victoria, BC Land Management Handbook No. 28. 185 p.

Hawkes, B.C. 1993. Factors that influence peat consumption under dependent burning conditions: A laboratory study. PhD dissertation, University of Montana, Missoula, MT.

Kauffman, J.B.; Martin R.E. 1989. Fire behavior, fuel consumption, and forest-floor changes following prescribed understory fires in Sierra Nevada mixed conifer forests. Canadian Journal of Forestry Research 19:455–462.

Klinka, K.; Green, R.N.; Courtin, P.J.; Nuszdorfer, F.C. 1984. Site diagnosis, tree species selection and slashburning for the Vancouver Forest Region. British Columbia Ministry of Forests, Victoria, BC. 180 p.

Kranabetter, J.M.; Macadam A.M. 1998. Ten-year results from operational broadcast burning trials in northwestern British Columbia. British Columbia Ministry of Forests, Victoria, BC Research Report 15. 22 p.

Little, S.N.; Klock G.O. 1985. The influence of residue removal and prescribed fire on distributions of forest nutrients. USDA Forest Service, Pacific Northwest Research Station, Portland, OR. Research Paper PNW-338. 12 p.

Little, S.N.; Ohmann J.L. 1988. Estimating nitrogen lost from forest floor during prescribed fires in Douglas-fir/Western Hemlock clearcuts. Forest Science 34(1):152–164.

Little, S.N.; Ottmar, R.D.; Ohmann, J.L. 1986. Predicting duff consumption from prescribed burns on conifer clearcuts in Western Oregon and Western Washington. USDA Forest Service, Pacific Northwest Research Station, Portland, OR. Research Paper PNW-362. 29 p.

Little, S.N.; Ward, F.R.; Sandberg, D.V. 1982. Duff reduction caused by prescribed fire on areas logged to different management intensities. USDA Forest Service, Pacific Northwest Research Station, Portland, OR. Research Note PNW-397. 8 p.

Macadam, A.M. 1987. Effects of broadcast slash burning on fuels and soil chemical properties in the Sub-boreal Spruce Zone of central British Columbia. Canadian Journal of Forestry Research 17:1577–1584.

McRae, D.J.; Alexander, M.E.; Stocks, M.E. 1979. Measurement and description of fuels and fire behavior on prescribed burns: a handbook. Canadian Forest Service, Great Lakes Forestry Research Centre, Sault Ste. Marie, ON. Report 0-X-287. 44 p.

Mersereau, R.C.; Dyrness C.T. 1972. Accelerated mass wasting after logging and slash burning in western Oregon. Journal of Soil and Water Conservation 27(3):112–117.

Muraro, S.J. 1971. Predicted fire impacts in cedar-hemlock logging slash. Canadian Forestry Service, Ottawa, ON. Canadian Forestry Service Publication 1295. 20 p.

Muraro, S.J. 1975. Prescribed fire predictor. Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. 3 p.

Sandberg, D.V.; Ottmar, R.D. 1983. Slash burning and fuel consumption in the Douglas-fir subregion. Pages 90–93 *in* Proceedings of the 7th Conference on Fire and Forest Meteorology, April 25–29, 1983, Fort Collins, CO. American Meteorological Society, Boston MA.

Sandberg, D.V. 1980. Duff reduction by prescribed underburning in Douglas-fir. USDA Forest Service, Pacific Northwest Research Station, Portland, OR. Research Paper PNW-272. 18 p.

Silen, R.R. 1960. Lethal surface temperatures and their interpretations for Douglas-fir. PhD thesis, Oregon State University, Corvallis, OR.

Soil Classification Working Group. 1998. The Canadian System of Soil Classification. Agriculture and Agri-Food Canada, Ottawa, ON. Publication 1646, revised. 187 p.

Stocks, B.J.; Lawson, B.D.; Alexander, M.E; Van Wagner, C.E; McApline, R.S.; Lynham, T.J.; Dube, D.E. 1989. The Canadian Forest Fire Danger Rating System: an overview. Forestry Chronicle 65:450–457.

Taylor, S.W.; Feller M.C. 1987. Initial effects of slashburning on the nutrient status of Sub-boreal Spruce Zone ecosystems. *In* Papers presented at the Fire Management Symposium, April 8-9, 1987, Prince George, BC Central Interior Fire Protection Committee, Smithers, BC.

Taylor, S.W.; Sherman, K.L. 1996. Biomass consumption and smoke emissions from contemporary and prehistoric wildland fires in British Columbia. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Center, Victoria, BC. FRDA Rep. 249, 23 pp.

Taylor, S.W.; Hawkes, B.C.; Silversides, R.H.; Weber, M.G. 1991. Initial effects of prescribed fire and mechanical site preparation on seedling environment and establishment on a backlog NWR site in central interior British Columbia. Forestry Canada, Victoria, BC. Canada-British Columbia Partnership Agreement on Forest Resource Development: FRDA II, FRDA Report 177.

Van Wagner, C.E. 1968. The line intersect method in forest fuel sampling. Forest Science 14:20–26.

Van Wagner, C.E. 1982*a*. Practical aspects of the line intersect method. Canadian Forest Service, Petawawa National Forestry Institute, Chalk River, ON. Rep. Pl-X-12. 11 p.

Van Wagner, C.E. 1982*b*. Graphical estimation of quadratic mean diameters in the line intersect method. Forest Science 28:852–855.

Van Wagner, C.E.; Pickett, T.L. 1985. Equations and FORTRAN program for the Canadian Forest Fire Weather Index System. Canadian Forest Service, Ottawa, ON. Technical Report 33. 18 p.

Wilkinson, L. 1988. SYSTAT: The system for statistics [computer program]. Version 4.0. Evanston, IL.

Zar, J.H. 1984. Biostatistical analysis. Prentice Hall. 718 p.

Table 1. Study site locations and site descriptions.

Block	Attribute	Control	Low severity	High severity	Very high severity
Cous					
	Total area (ha)	12.6	16.1	-	-
	Latitude	49° 13′ N	49° 13′ N	-	-
	Longitude	124° 56′ N	124° 56′ N	-	-
	Elevation (m)	465-560	475-605	-	-
	Aspect	SSE	SSW	-	-
	Slope (%)	55 (45-70)	60 (55-65)	-	-
	Parent material	Cv/Mbv	Cv/Mbv	-	-
	Soil drainage	R-M	R-W	-	-
	Biogeoclimatic unit	CWHmm1	CWHmm1	-	-
	Site series	01, 03	01, 03	-	-
	Soil moisture / nutrients	2-4 / B-D	2-4 / C-D	-	-
	Site Index (m)	24 - 28	24 - 28	-	-
	Fire sensitivity class	M-H	M-H	-	-
	Date burned	-	May-21-85	-	-
Macktush					
	Total area (ha)	-	9.6	3.7	<5.0
	Latitude	-	49° 9′ N	49° 9′ N	49° 9′ N
	Longitude	-	124° 53′ N	124° 53′ N	124° 53′ N
	Elevation (m)	-	475-610	510-565	475-610
	Aspect	-	SSE	SSE	SSE
	Slope (%)	-	50 (30-60)	40 (25-60)	50 (30-60)
	Parent material	-	Cv/Mbv	Cv/Mbv	Cv/Mbv
	Soil drainage	-	R-W	R-W	R-W
	Biogeoclimatic unit	-	CWHmm1	CWHmm1	CWHmm1
	Site series	-	01, 03	01, 03	01, 03
	Soil moisture / nutrients	-	2-4 / B-D	2-4 / B-D	2-4 / B-D
	Site Index (m)	-	24 - 28	24 - 28	24 - 28
	Fire sensitivity class	-	M-H	M-H	M-H
	Date burned	-	May-21-85	Oct-05-85	May-21-85, Oct-05-85
Kanyon					
	Total area (ha)	5.1	<1.0	5.7	-
	Latitude	49° 8′ N	49° 8′ N	49° 8′ N	-
	Longitude	124° 57′ N	124° 57′ N	124° 57′ N	-
	Elevation (m)	455-530	570-600	535-570	-
	Aspect	SW	SW	SW	-
	Slope (%)	40 (35-50)	40 (35-50)	40 (30-45)	-
	Parent material	Cv/Mbv	Cv/Mbv	Cv/Mbv	-
	Soil drainage	R-M	R-W	R-W	-
	Biogeoclimatic unit	CWHvm1	CWHvm1	CWHvm1	-
	Site series	01, 03	03	01, 03	-
	Soil moisture / nutrients	2-4 / B-D	2 / B-C	2-4 / B-D	-
	Site Index (m)	24 - 28	24	24 - 28	-
	Fire sensitivity class	(L) M	H	M-H (VH)	-
	Date burned	-	May-21-85	Sep-25-85	-

Note: fire severity class, biogeoclimatic unit, site series, and soil moisture and nutrient regimes from Green and Klinka (1994). Parent material: Cv = colluvial veneer, Mbv = morainal blanket veneer. Soil drainage: R= rapidly drained, W = well drained, M = moderately well drained. Site Index is estimated for Douglas-fir at 50 years. All sites were planted March 14-21, 1986.

Table 2. Number of planned and (actual) plots for prescribed burning treatments.

Block	Control	Low Severity	High Severity	Very High Severity
Cous	5 (5)	5 (5)		
Macktush	-	5 (1)	5 (5)	(4)
Kanyon	5 (5)	(1)	5 (5)	

Table 3. Canadian Fire Weather Index System codes and indices for each burning period, with prevailing weather conditions.

Date Burned	No. Plots	Block	Time	Temp (°C) *	RH (%)	Wind (km/h)	FFMC**	DMC	DC	ISI	BUI	FWI
						Low-severity spring burns						
May-21-85	1	Kanyon	16:40	15.5	71	4.8	86	20	43	3	20	5
May-21-85	5	Cous Creek	16:14	19.0	50	3.0	86 (79-88)	19(14-20)	42 (<150)	3	19	4
May-21-85	6	Macktush	18:30	16.0	64	0	86 (80-89)	19(14-22)	42 (<150)	3	19	4
						High-severity fall burns						
Sep-25-85	5	Kanyon	16:40	23.0	39	5.8	89 (80-89)	12(20-30)	215(<300)	4	21	7
Oct-05-85	5	Macktush	18:27	11.7	87	0	82(76-86)	23(30-45)	295(<300)	2	38	4

* all weather data and codes based on readings at 1200 hours PST from on-site weather stations (prescribed preferred range in parentheses)

** FFMC=Fine Fuel Moisture Code, DMC=Duff Moisture Code, DC=Drought Code, ISI=Initial Spread Index, BUI=Buildup Index, FWI=Fire Weather Index. FFMC was adjusted to the time of the burn.

Table 4. Forest floor and woody gravimetric fuel moisture contents (%) for the prescribed burn treatments.

Date	Block		Forest floor (cm)			Woody fuel		
			Litter[1]	0 – 1.99	2.0 – 6.0	>6.0	0.1 – 1 cm	1 – 3 cm
			Low-severity spring burns					
May-21-85	Cous Creek	Mean	28	85	219	215	13	17
		SE	7	60	46	67	1	2
		n	5	6	9	3	8	6
May-21-85	Macktush	Mean	36	205	334	n/a[2]	13	16
		SE	10	104	37	n/a	1	2
		n	4	4	7	n/a	8	6
			High-severity fall burns					
Sep-25-85	Kanyon	Mean	19	87	196	278	12	15
		SE	5	21	32	46	1	1
		n	4	4	8	3	8	6
Oct-05-85	Macktush	Mean	60	70	240	225	15	16
		SE	39	24	35	51	1	1
		n	4	4	8	2	8	6

[1] Litter layer depths were not measured to determine moisture content

[2] Forest floor depths at the Macktush site were less than 6 cm

Table 5. Pre/Post burn woody fuel and forest floor biomass (kg/m^2) by treatment and plot.

Block	Plot	Pre Burn					Post Burn				
		Woody Fuel		Total	Forest Floor	Total	Woody Fuel		Total	Forest Floor	Total
		0.1 - 7cm	>7cm				0.1 - 7cm	>7cm			
Control											
Cous	1	1.6	16.8	18.5	59.2	77.7	-	-	-	-	-
	2	2.5	23.6	26.1	25.3	51.4	-	-	-	-	-
	3	1.6	8.8	10.4	10.5	20.9	-	-	-	-	-
	4	3.5	16.8	20.3	14.8	35.1	-	-	-	-	-
	5	1.6	7.9	9.5	11.2	20.7	-	-	-	-	-
	Mean	2.2	14.8	16.9	24.2	41.2	-	-	-	-	-
	SE	(0.4)	(2.9)	(3.1)	(9.1)	(10.7)	-	-	-	-	-
Kanyon	1	1.9	19.4	21.3	30.2	51.5	-	-	-	-	-
	2	3.2	18.4	21.6	9.3	30.9	-	-	-	-	-
	3	3.8	23.5	27.3	22.3	49.6	-	-	-	-	-
	4	3.6	9.7	13.2	31.1	44.3	-	-	-	-	-
	5	2.2	7.7	9.9	17.1	27.0	-	-	-	-	-
	Mean	3.0	15.7	18.7	22.0	40.7	-	-	-	-	-
	SE	(0.4)	(3.0)	(3.1)	(4.1)	(5.0)	-	-	-	-	-
Low-severity spring burns											
Cous	1	3.1	8.7	11.8	15.0	26.8	0.4	5.2	5.6	11.4	17.0
	2	2.3	18.6	20.9	17.5	38.3	0.2	13.0	13.2	12.4	25.6
	3	2.5	8.9	11.4	29.2	40.5	0.4	6.3	6.7	22.2	28.9
	4	3.4	11.5	14.8	16.8	31.6	0.3	7.8	8.1	11.6	19.7
	5	3.0	8.0	11.1	38.0	49.1	0.5	4.8	5.3	30.1	35.4
	Mean	2.9	11.1	14.0	23.3	37.3	0.4	7.4	7.8	17.5	25.3
	SE	(0.2)	(2.0)	(1.8)	(4.5)	(3.8)	(0.1)	(1.5)	(1.4)	(3.7)	(3.3)
Kanyon	1	0.8	7.5	8.4	14.8	23.2	0.6	6.7	7.3	12.6	19.9
Macktush	5	1.6	19.6	21.2	17.1	38.3	0.5	15.9	16.4	14.8	31.2
High-severity fall burns											
Macktush	1	1.1	9.3	10.4	23.6	34.0	0.1	5.7	5.8	5.9	11.7
	2	2.2	15.0	17.2	22.6	39.8	0.1	4.5	4.6	7.2	11.8
	3	1.2	8.5	9.8	21.3	31.1	0.1	6.4	6.5	2.3	8.8
	4	2.2	7.6	9.8	16.1	25.9	0.2	4.6	4.8	1.0	5.8
	5	2.5	11.6	14.2	32.2	46.4	0.2	6.3	6.5	9.9	16.4
	Mean	1.9	10.4	12.3	23.2	35.4	0.2	5.5	5.6	5.3	10.9
	SE	(0.3)	(1.3)	(1.5)	(2.6)	(3.5)	(0.0)	(0.4)	(0.4)	(1.6)	(1.8)
Kanyon	1	2.8	14.2	17.0	24.8	41.8	0.3	8.7	9.0	18.8	27.7
	2	0.7	23.1	23.8	18.5	42.2	0.1	15.6	15.7	11.6	27.3
	3	3.1	21.3	24.3	32.8	57.1	0.3	13.0	13.2	24.8	38.0
	4	2.4	14.7	17.1	10.4	27.5	0.3	9.2	9.5	3.3	12.8
	5	1.6	16.7	18.3	12.4	30.7	0.3	7.7	8.1	3.3	11.4
	Mean	2.1	18.0	20.1	19.8	39.9	0.3	10.8	11.1	12.4	23.4
	SE	(0.4)	(1.8)	(1.6)	(4.1)	(5.2)	(0.0)	(1.5)	(1.5)	(4.2)	(5.0)
Very-high-severity spring/fall burns											
Macktush	1	1.6	19.6	21.2	16.0	37.2	0.0	6.0	6.0	0.0	6.0
	2	1.5	6.9	8.4	44.7	53.1	0.0	1.5	1.5	32.6	34.1
	3	2.5	7.7	10.2	10.0	20.2	0.2	1.9	2.0	0.0	2.0
	4	1.8	9.7	11.5	62.9	74.4	0.0	5.1	5.2	45.5	50.7
	Mean	1.9	11.0	12.9	33.4	46.2	0.1	3.6	3.7	19.5	23.2
	SE	(0.2)	(2.9)	(2.9)	(12.4)	(11.5)	(0.0)	(1.1)	(1.1)	(11.6)	(11.6)

SE = Standard Error (in parentheses)

Table 6. Loss of woody fuel and forest floor biomass (kg/m^2) by treatment and plot.

Block	Plot	Woody Fuel				
		0.1 - 7cm	>7cm	Total	Forest Floor	Total
				Low-severity spring burns		
Cous	1	2.7	3.4	6.1	3.6	9.7
	2	2.0	5.6	7.6	5.0	12.7
	3	2.1	2.5	4.6	7.0	11.6
	4	3.1	3.6	6.7	5.3	12.0
	5	2.5	3.2	5.8	8.0	13.8
	Mean	2.5	3.7	6.2	5.8	11.9
	SE	(0.2)	(0.5)	(0.5)	(0.8)	(0.7)
Kanyon	1	0.2	0.8	1.1	2.2	3.3
Macktush	5	1.2	3.7	4.9	2.3	7.2
				High-severity fall burns		
Macktush	1	1.0	3.6	4.6	17.8	22.4
	2	2.2	10.4	12.6	15.4	28.0
	3	1.1	2.2	3.3	19.0	22.3
	4	2.0	3.0	5.0	15.1	20.0
	5	2.3	5.4	7.6	22.3	29.9
	Mean	1.7	4.9	6.6	17.9	24.5
	SE	(0.3)	(1.5)	(1.7)	(1.3)	(1.9)
Kanyon	1	2.6	5.2	8.0	6.0	14.1
	2	0.6	7.5	8.1	6.8	14.9
	3	2.8	8.3	11.1	8.0	19.1
	4	2.1	5.5	7.6	7.1	14.7
	5	1.3	9.0	10.3	9.1	19.4
	Mean	1.9	7.2	9.0	7.4	16.4
	SE	(0.4)	(0.7)	(0.7)	(0.5)	(1.2)
				Very-high-severity spring/fall burns		
Macktush	1	1.6	13.7	15.3	16.0	31.2
	2	1.5	5.5	7.0	12.1	19.0
	3	2.4	5.8	8.2	10.0	18.2
	4	1.8	4.6	6.4	17.4	23.7
	Mean	1.8	7.4	9.2	13.9	23.0
	SE	(0.2)	(2.1)	(2.1)	(1.7)	(3.0)

SE = Standard Error (in parentheses)

Table 7. Loss of woody fuel and forest floor biomass by treatment and plot as a percentage of individual size classes and of total pre-burn biomass.

Block	Plot	% of Size Class		% of Total woody fuel			Forest floor	Total forest floor and woody fuel
		0.1 - 7cm	>7cm	0.1 - 7cm	>7cm	Total		
				Low-severity spring burns				
Cous	1	86.9	39.6	23.1	29.1	52.1	24.0	36.4
	2	89.8	30.2	9.8	26.9	36.7	28.9	33.1
	3	84.6	28.6	18.5	22.3	40.9	23.9	28.7
	4	90.8	31.8	20.7	24.5	45.2	31.3	37.8
	5	83.1	40.2	22.8	29.2	52.0	21.0	28.0
	Mean	87.0	34.1	19.0	26.4	45.4	25.8	32.8
	SE	(1.5)	(2.4)	(2.4)	(1.3)	(3.1)	(1.9)	(2.0)
Kanyon	1	27.4	4.0	2.7	9.9	12.6	14.9	14.2
Macktush	5	72.6	18.9	5.5	17.4	22.9	13.5	18.8
				High-severity fall burns				
Macktush	1	87.5	39.0	9.4	34.8	44.2	75.2	65.7
	2	97.4	69.6	12.5	60.7	73.2	68.1	70.3
	3	88.9	25.5	11.2	22.3	33.5	89.2	71.7
	4	91.5	39.3	20.5	30.5	51.0	93.6	77.5
	5	90.5	45.9	16.1	37.8	53.9	69.2	64.5
	Mean	91.2	43.9	13.9	37.2	51.2	79.1	70.0
	SE	(1.7)	(7.2)	(2.0)	(6.4)	(6.5)	(5.2)	(2.3)
Kanyon	1	90.6	38.7	15.0	32.3	47.3	24.3	33.7
	2	85.2	32.4	2.5	31.5	34.0	37.1	35.3
	3	90.7	39.1	11.4	34.2	45.6	24.4	33.5
	4	87.8	37.4	12.4	32.2	44.6	68.4	53.6
	5	79.5	53.8	6.9	49.1	56.0	73.3	63.0
	Mean	86.8	40.3	9.6	35.9	45.5	45.5	43.8
	SE	(2.1)	(3.6)	(2.2)	(3.3)	(3.5)	(10.6)	(6.1)
				Very-high-severity spring/fall burns				
Macktush	1	100.0	69.7	7.6	64.4	72.0	100.0	83.8
	2	100.0	79.0	17.9	64.9	82.8	27.1	35.8
	3	93.9	75.5	23.3	56.8	80.1	100.0	90.1
	4	97.9	47.2	15.5	39.7	55.2	27.7	31.8
	Mean	98.0	67.8	16.1	56.4	72.5	63.7	60.4
	SE	(1.4)	(7.2)	(3.3)	(5.9)	(6.2)	(21.0)	(15.4)

SE = Standard Error (in parentheses)

Table 8. Results of analyses of variance of the effects of fire severity and location on the magnitude of and percent biomass consumption by the prescribed burns.

Source of Variation	SS	Df	MS	F	P*
			Woody fuel 0.1 - 7 cm		
Block	0.250	2	0.018	6.9	0.007
Fire Severity	0.289	2	0.006	2.4	0.120
Error	0.086	16	0.003		
			Woody fuel >7 cm		
Block	0.058	2	0.029	2.2	0.141
Fire Severity	0.311	2	0.155	11.8	0.001
Error	0.210	16	0.013		
			Woody fuel total		
Block	0.122	2	0.061	5.5	0.015
Fire Severity	0.319	2	0.160	14.5	<0.001
Error	0.176	16	0.011		
			Forest floor		
Block	0.250	2	0.125	2.3	0.131
Fire Severity	0.390	2	0.195	3.6	0.051
Error	0.866	16	0.054		
			Depth of burn		
Block	0.151	2	0.075	1.9	0.186
Fire Severity	0.406	2	0.203	5.0	0.020
Error	0.645	16	0.040		
			Total woody fuel and forest floor		
Block	0.190	2	0.095	3.8	0.044
Fire Severity	0.272	2	0.136	5.5	0.015
Error	0.398	16	0.025		
			Mineral soil exposure		
Block	0.416	2	0.208	5.1	0.019
Fire Severity	0.448	2	0.224	5.5	0.015
Error	0.652	16	0.041		

* significance at $p < 0.05$

Table 9. Mean percent biomass consumption for woody fuel, forest floor, depth of burn (%), total woody fuel and forest floor, and increase in mineral soil exposure by burning severity treatment.

	Woody[1] fuel	Woody fuel	Woody fuel	Forest floor	Total woody fuel and forest floor	Depth of burn	Mineral soil exposure
	0.1 - 7 cm	>7 cm	Total				
Treatment							
Low-severity spring burn	9a	18a	27a	18a	22a	30a	2a
High-severity fall burn	12a	37b	48b	62b	57b	73b	52b
Very high severity fall burn	16a	56c	73c	64b	60b	66ab	53b

Note: Means followed by different letters within a column are significantly different ($p<0.05$) for a given treatment.

[1] The percent woody fuel consumption by size class is the proportion of total woody fuel biomass consumed.

Table 10. Pre-burn forest floor depth and forest floor depth of burn (cm) by treatment and plot.

		Forest floor depth (cm)		Depth of burn*		
Block	Plot	Pre-burn	Post-burn	Pins (cm)	Bridges (cm)	(%)
Low-severity spring burns						
Cous	1	20.5	16.3	4.2	3.4	31.1
	2	13.0	8.9	4.1	4.2	48.6
	3	13.9	10.6	3.3	5.4	35.0
	4	14.3	10.5	3.8	5.0	42.4
	5	13.0	9.4	3.6	6.8	41.8
	Mean	14.9	11.1	3.8	5.0	39.8
	SE	(1.4)	(1.3)	(0.2)	(0.6)	(3.1)
Kanyon	1	11.3	8.8	2.3	4.1	23.2
Macktush	5	17.8	14.8	3.1	2.3	26.6
High-severity fall burns						
Macktush	1	14.9	3.3	11.6	13.5	86.6
	2	20.3	6.6	13.7	12.9	81.2
	3	14.2	1.4	12.9	22.2	90.0
	4	12.8	0.8	12.0	14.3	92.2
	5	19.4	5.8	13.5	10.4	73.3
	Mean	16.3	3.6	12.7	14.7	84.7
	SE	(1.5)	(1.2)	(0.4)	(2.0)	(3.4)
Kanyon	1	15.9	10.7	4.8	5.5	45.2
	2	18.1	9.7	8.4	6.9	59.0
	3	19.0	13.0	6.0	5.5	45.0
	4	13.9	4.1	9.8	4.0	73.5
	5	11.4	2.5	8.8	13.5	84.5
	Mean	15.7	8.0	7.6	7.1	61.5
	SE	(1.4)	(2.0)	(0.9)	(1.7)	(7.8)
Very-high-severity spring/fall burns**						
Macktush	1	14.6	0.0	2.3	26.5	100.0
	2	24.9	17.2	1.4	7.6	30.9
	3	13.1	0.0	3.4	13.5	100.0
	4	27.0	18.2	1.9	9.0	32.7
	Mean	19.9	8.9	2.3	14.2	65.9
	SE	(3.5)	(5.1)	(0.4)	(4.3)	(19.7)

SE = Standard Error (in parentheses)

* Depth-of-burn (DOB) percentage losses were calculated based on the mean of individual pin measures except for the Very High Severity plots (see next note).

** Macktush Very-high-severity: depth-of-burn pins represent the initial spring burn; all other figures represent the combined impact of the spring burn and fall reburn estimated by erosion bridges.

Table 11. Mean percent mineral soil exposure (MSE) before and after treatment.

Block	**Plot**	Pre Treatment MSE (%)	Post Treatment MSE (%)	Change (%)
		Controls		
Cous	1	4.0	-	-
	2	2.1	-	-
	3	1.2	-	-
	4	2.4	-	-
	5	0.3	-	-
	mean	2.0		
	SE	(0.6)		
Kanyon	1	5.6	-	-
	2	4.9	-	-
	3	6.0	-	-
	4	5.0	-	-
	5	5.9	-	-
	mean	5.5		
	SE	(0.2)		
		Low-severity spring burns		
Cous	1	4.8	7.6	2.8
	2	1.9	6.1	4.2
	3	1.6	7.0	5.4
	4	1.4	6.9	5.5
	5	1.7	4.1	2.5
	mean	2.3	6.4	4.1
	SE	(0.6)	(0.6)	(0.6)
Kanyon	1	0.8	2.4	1.6
Macktush	5	2.0	2.7	0.7
		High-severity fall burns		
Macktush	1	0.0	77.6	77.6
	2	0.0	89.9	89.9
	3	0.0	86.2	86.2
	4	5.2	62.9	57.7
	5	0.0	59.3	59.3
	mean	1.0	75.2	74.1
	SE	(1.0)	(6.1)	(6.7)
Kanyon	1	5.7	13.5	7.8
	2	1.1	23.2	22.1
	3	5.2	23.6	18.4
	4	2.2	45.3	43.0
	5	1.4	56.9	55.5
	mean	3.1	32.5	29.3
	SE	(1.0)	(8.0)	(8.7)
		Very-high-severity spring/fall burns		
Macktush	1	2.1	88.0	85.9
	2	0.0	45.2	45.2
	3	6.5	75.6	69.1
	4	0.0	10.1	10.1
	mean	2.1	54.7	52.6
	SE	(1.5)	(17.4)	(16.4)

SE = Standard Error (in parentheses)

Table 12. Correlation between fire severity, percentage biomass consumption and mineral soil exposure variables, and Fire Weather Index System codes for the experimental plots.

	Biomass/Mineral Soil Exposure and Fire Weather Index System Variables						
	Woody fuel consumption		Forest floor consumption	Mineral soil exposure	FFMC*	DMC	DC
	>7 cm	Total					
Fire Severity	0.73	0.54	0.52	0.59	-0.45	0.26	0.88
FFMC*	-0.45	-0.55	-0.50	-0.59	-	-	-
DMC	0.35	0.42	0.37	0.45	-	-	-
DC	0.57	0.69	0.68	0.79	-	-	-

* FFMC=Fine Fuel Moisture Code, DMC=Duff Moisture Code, DC=Drought Code

Canadian Forest Service Contacts

For more information about the Canadian Forest Service, visit our website at
www.nrcan.gc.ca/cfs-scf/
or contact any of the following Canadian Forest Service establishments

① Atlantic Forestry Centre
P.O. Box 4000
Fredericton, NB E3B 5P7
Tel.: (506) 452-3500 Fax: (506) 452-3525
atl.cfs.nrcan.gc.ca/

Atlantic Forestry Centre – District Office
Sir Wilfred Grenfell College Forestry Centre
University Drive
Corner Brook, Newfoundland A2H 6P9
Tel.: (709) 637-4900 Fax: (709) 637-4910

② Laurentian Forestry Centre
1055 rue du P.E.P.S., P.O. Box 3800
Sainte-Foy, PQ G1V 4C7
Tel.: (418) 648-5788 Fax: (418) 648-5849
www.cfl.scf.rncan.gc.ca/

③ Great Lakes Forestry Centre
P.O. Box 490 1219 Queen St. East
Sault Ste. Marie, ON P6A 5M7
Tel.: (705) 949-9461 Fax: (705) 759-5700
www.glfc.cfs.nrcan.gc.ca/

④ Northern Forestry Centre
5320-122nd Street
Edmonton, AB T6H 3S5
Tel.: (403) 435-7210 Fax: (403) 435-7359
nofc.cfs.nrcan.gc.ca/

⑤ Pacific Forestry Centre
506 West Burnside Road
Victoria, BC V8Z 1M5
Tel.: (250) 363-0600 Fax: (250) 363-0775
www.pfc.cfs.nrcan.gc.ca/

⑥ Headquarters
580 Booth St., 8th Fl.
Ottawa, ON K1A 0E4
Tel.: (613) 947-7341 Fax: (613) 947-7396
www.nrcan.gc.ca/cfs/

To order publications on-line, visit the Canadian Forest Service Bookstore at:

bookstore.cfs.nrcan.gc.ca