ECOSYSTEM MAINTENANCE DEMONSTRATION BURNS MONITORING PROJECT

General Work Plan and Establishment Report for Picture Valley and Findlay Creek Sites

ECOSYSTEM MAINTENANCE RESEARCH
AND EVALUATION (EMBER) PROJECT
NELSON FOREST REGION
NELSON, B.C.

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TABLES

1.0 INTRODUCTION

High-frequency, low-intensity natural fires are a traditional, historical component of lower elevation biogeoclimatic zones in the Nelson Forest Region. Large parts of the Ponderosa Pine (PP), Interior Douglas-fir(IDF) and smaller amounts of the Interior Cedar-Hemlock (ICH) and Montane Spruce (MS) zones were affected. There is ample documentation for this; a study in the adjacent Kootenai National Forest in Montana estimates fire periodicity[1] at between 12 and 27 years in PP stands (George Curtis, pers. comm.). A ponderosa pine stand in Eastern Washington was determined to have an 8-year historical fire periodicity (Weaver, 1974). The mixed pine/fir/larch stands of the Blue Mountains of Eastern Oregon, perhaps the most thoroughly documented in terms of fire impact, have a historical fire periodicity of 10 years (Hall, 1977).

Two periodicity studies are available from within the Region; Dorey (1979) documented historical fire return in a mixed ponderosa pine-Douglas-fir stand near Grasmere in the Cranbrook District to be 6.4 years during the period from 1813 to 1940. Beck (1984) determined the periodicity of a seral ponderosa pine stand in the IDFun near Deer Park (Arrow District) to be 11.6 years in the period between 1762 and 1937.

Other wetter forest subzones in the Region certainly experience fire, but the fire events are less frequent, stand-replacement type fires.

Natural fire periodicity in these zones would have been reestablished sometime after the end of the Wisconsin glaciation, roughly 11,000 years ago, and fluctuated in response to climatic cycles since that time. The trees, shrubs, forbs and grasses, as well as the wildlife, insects and microorganisms of these zones have been exposed to numerous fire cycles, and the ecosystems they make up could be considered to be fire-maintained. If this natural fire regime is dramatically altered through fire suppression, it is logical to expect that certain ecosystem processes such as succession, stand development and nutrient cycling will be disrupted. It has been suggested that these ecosystems have effectively evolved with fire over a much longer time period in areas to the south (areas that escaped glaciation). These fire-adapted plant communities have then migrated northward as the climate has allowed (Covington, pers. comm.).

This is, in fact, what has happened. Beginning in the late 1930's, the Ministry's fire suppression activities have substantially reduced the occurrence of all wildfire. Data from the Region is not available, but the statistics from an adjacent jurisdiction will serve to show this pattern. Figure 1 shows the acreage burned by wildfire in the National Forests of Washington, Idaho and Montana over a fifty-year period.

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[1] The mean length of time between fire events. Also called fire return interval.

This establishment report documents pre treatment and first growing season post treatment conditions at two burns. Both burns took place in May 1994. The comparison of results between study sites must be done with caution as the burn treatments differed in initial conditions and ignition method. What is presented is a case study of two operational burns rather than a replicated experiment.

2.0 OBJECTIVES

Four broad topic areas are being investigated through monitoring of the demonstration burns. They are:

- fire behaviour and smoke emissions;
- Stand structure and mortality;
- understory vegetation composition and production; and
- insect and disease presence.

Specific objectives under the above topics are as follows.

2.1 Fire Behaviour and Smoke Emissions

2.1.1. Fire Behavior Prediction

Monitor fire behaviour in order to test and modify rate of spread and fuel consumption equations for prescribed burning in Douglas-fir (Fd) and ponderosa pine (Py) ecosystems, and to test crown scorch height equations. (Van Wagner 1973)

The rate of spread (ROS) equations of the Canadian Forest Fire Behavior Prediction (FBP) System (Forestry Canada 1992) are for fires originating from a single point or line ignition source. We need to determine if the equations are suitable for prescribed fires ignited with multiple lines. The fuel consumption equations in the FBP System do not use fuel load as an independent variable because they are intended for real-time application in fire suppression. The equations will be reformulated to include variable fuel load and stand characteristics for prescribed burning applications.

2.1.2 Smoke Emissions, Energy Release, and Dispersion Models

1. Assess smoke emissions from the under burns and assess the potential for applying smoke management techniques.

2. Extend the Smoke Plume Evaluation Modeling (SPEM) project smoke modeling system to prescribed burning of unmodified fuels (e.g., under burning or ecosystem maintenance burning). In addition to obtaining data for fuel consumption equations, monitor energy release rate, examine smoke emissions composition, and

The number of stems of shrubs may change after treatment through mortality, sprouting, and seed germination. By assessing the mode of regeneration, insight into how species respond to fire may be gained.

2.4 Insect and disease

Assess insect and disease presence (list of species found) on burned and unburned treatments. If treatment differences in presence are detected, more intensive monitoring activities may be conducted on future burns.

3.0 METHODS

3.1 Study Site Selection

Study sites selected met the following criteria:

1. within IDF or PP biogeoclimatic zones;
2. greater than 20 ha;
3. exhibit higher stocking than conventional range burning blocks, i.e. have significant areas where crown closure was 40 % or greater; and
4. have similar sites nearby of sufficient size to act as untreated control block.

In early spring 1993, one site meeting the above criteria was selected in the Cranbrook Forest District and scheduled for treatment that spring. This site, known as Picture Valley, is located in the IDFdm2 variant, just east of the Kootenay River, about 8 km. south of Fort Steele (see Figure 2). The treatment block is about 35 ha. in size. Another site, in the Invermere Forest District, is found about 17.5 km. west of Highway 93/95 on the Findlay - Doctor Forest Service road and is also in the IDFdm2. Treatment area is about 56 ha. It is referred to as the Findlay site (see Figure 2)

(Another site was selected just north of Skookumchuck in the Invermere Forest District and was burned in May 1993. This site was monitored on a reconnaissance basis due to cost constraints and is not included in this workplan, apart from fire behaviour observations at that site. The fire behaviour observations were gathered using similar methods as on the more closely monitored burns and provide useful comparative information.) Two other sites were selected in the fall of 1993 and scheduled for burning in spring of 1995. The site in Cranbrook Forest District is located about 10 km. south west of the Kikomun bridge over Koocanusa Reservoir and is also in the IDFdm2. The total area proposed for burning about 250 ha. (see Figure 2). This site is known as Twin Lakes. A site located in the IDFun within the Arrow Forest District is found about 4 km. north of the Syringa Creek Provincial Park campground on Lower Arrow Lake. The proposed burn area, known as Tulip Creek, is 500 ha. (see Figure 2).

3.3.1 Picture Valley

The objectives of the prescribed burn at Picture Valley were to:
- eliminate 75% of the trees < 5cm DBH;
- eliminate 25% of trees <15cm DBH;
- limit mortality of tress >30cm DBH to less than 10%;
- prune all trees to a height of 2m;
- reduce ground fuels <10cm diam. by 50-75% and
- reduce ground fuels >20 cm diam by 5-10%.

An aerial drip torch was the primary ignition device used to light the fire; hand drip torches were also used on the upper guard and lower road boundaries.

3.3.2 Findlay Creek

The objectives of the prescribed burn at Findlay Creek were to:
- remove 40 to 50% of the small diameter Douglas-fir and ponderosa pine
- reduce crown closure from 40 to 30%
- reduce lodgepole pine by 50-100% in areas that it occurred.

The prescribed fire prescription was: FFMC (Fine Fuel Moisture Code) 88-93; DMC (Duff Moisture Code) 16-32; DC (Drought Code) 50-250; ISI (Initial Spread Index) 4-8; BUI (Build Up Index) 20-35; FWI (Fire Weather Index) 6-16. Desired weather conditions were: temperature 15-25 C; RH (relative humidity)15-05%; wind speed 5-15 km/h. An AID machine (aerial ignition device) was primarily used to ignite the fire; there was some hand ignition on the upwind (W) side of the block.

3.4 Experimental Design

Each burn is considered to be an independent treatment. While broad trends may be detectable within a site series, it is not anticipated that sufficient "replicates" will be produced, to permit detailed analysis at that level.

In its simplest form this study can be regarded as a paired treatment (control vs. burn). As such, tests will be restricted to T-tests or one-way ANOVAs. More meaningful results will likely be produced by examining stand structural trends over time, within a single stratum.

3.5 Plot Layout

Plot centres were established on a systematic grid with plot spacing varying from 50 to 100m depending on site and stratum size and orientation. Plot centres are a minimum of 30 m from any stratum boundary. The centres are marked with electrical conduit or rebar about one metre high. The number of plots per stratum and the number of strata measured vary between sites. Trees <12.5 cm DBH are assessed at all plots. Trees >12.5 cm DBH, woody fuels, and insects and diseases are assessed on every second plot. Understory

3.6.1 Fire Behaviour and Smoke Emissions

3.6.1.1 Crown fuels

Stand data collected as outlined in section 3.6.2 were used to calculate tree volumes using taper based volume equations; volumes are needed to estimate crown biomass. The crown fuel load (defined as foliage and branches <0.5 cm diam.) was calculated using equations of Standish *et al.* (1985) for > 12.5 cm DBH trees; equations of Brown (1978) were used for < 12.5 cm DBH trees because the former gave unreasonable values for small diameters. The basal area, volume and biomass calculations use the diameter class midpoints for the <12.5 cm DBH trees as individual diameters were not measured.

3.6.1.2 Surface fuels

Woody fuels on the forest floor surface were assessed using the line intersect technique, generally following the procedures in Trowbridge *et al.* (1986), excepting that pieces were measured along permanently-marked, randomly-oriented, 30 m single line transects. Calculations of the pre-burn and post-burn fuel load were carried out using the FUELOADER computer program (deJong *et al.* 1989).

Ten depth-of-burn pins were placed along each transect in order to measure forest floor depth-of-burn. Samples of forest floor material were collected to determine relative density. Forest floor depth-of-burn and total depth measurements were made following burning. Forest floor mass and mass loss were calculated from density and total depth, and density and depth-of-burn measures, respectively. Forest floor density was sampled by 1 cm depth layers, but no significant relationship with depth was found for these shallow layers so an average value was used.

The biomass of understory vegetation was determined using procedures of Brown et al. (1982) for the Picture Valley burn. At each plot measured for woody fuels, four 1.0 m^2 subplots were established. In one subplot grasses and herbs were destructively sampled (clipped) to determine the oven-dry biomass. The relative amount of grasses and herbs was visually rated in other three 1.0 m^2 subplots compared to the clipped subplot. A plot mean was determined from the measured value and the proportion estimates. The number of shrub stems were counted by species and diameter class in two 1.0 m^2 subplots in

3.6.1.5 Fire weather and fuel moisture

Standard (noon daily) fire weather observations (temperature, relative humidity, 10-m wind speed and direction, and precipitation) were recorded at weather stations adjacent to the sites, in order to calculate Canadian Forest Fire Weather Index (FWI) System values. Temperature, RH, and wind speed were also recorded hourly during the burns in order to adjust the values for diurnal variation.

The moisture content of the litter, forest floor, woody fuels, and tree foliage was also sampled prior to burning .

3.6.1.6 Smoke chemistry, atmospheric conditions and smoke plume dispersion

Smoke chemical sampling, atmospheric soundings, and smoke plume mapping were carried out at Findlay Creek and Picture Valley. Smoke chemistry was sampled by staff of the Fire Chemistry Project, U.S. Forest Service Intermountain Fire Sciences Laboratory using the Fire Atmospheric Sampling System (FASS). This is a ground based system which was installed within the burn unit during the fires. The FASS employs an onboard computer to control sampling protocols of sensors for measuring the fire, environment, and operating parameters. The system measures in real time the concentration of CO, CO_2, NO and O_2; temperatures at several locations; and vector wind. Grab samples of particulate matter and trace gases are collected over specified sample periods of flaming and smoldering combustion for later laboratory analysis (Ward *et al.* 1991). The results will be pooled with data from other fires in the western United States to determine emission factors for underburning needed in the smoke models.

The height and rate of rise of the smoke column, and the movement of the smoke plume was monitored on both of the fires using a fixed wing aircraft. These data will be used to test a smoke column model (Latham 1994) and a wind/smoke dispersion model (Danard and Galbraith 1990).

Atmospheric soundings (temperature, RH, pressure, wind speed and direction with height) were carried out using a ZEEMET W-9000 Meteorological Processing System to support the smoke column/plume modeling. The system tracks and processes data from a radio-sonde (carried aloft with a standard weather balloon) which measures and transmits the atmospheric data to a surface receiver.

A similar suite of atmospheric and smoke plume assessments were carried out on six broadcast burns in the SPEM project during 1989-92.

be selected to best represent the individuals in that layer. The samples in layers 2 and 3 will be tagged. Age (not layer 4), height, height to live crown and dbh (basal diameter for layer 4) will be recorded for each sample tree. Plot size should be 0.01 ha (r=5.64 m) for layers 2a, 2b, 3a and 3b unless this would consistently result in fewer than 6 stems per plot for each layer, in which case a 0.02 ha plot (r=7.98 m) should be used. A different plot size from that used for layers 2 and 3 is possible for layer 4 if stem numbers demand it. The plot sizes used will be recorded on the tally sheet.

Data will be summarized by location, stratum, species and layer. Layer 1 will also be summarized by 5 cm diameter classes (12.5 to 17.4, 17.5 to 22.4, etc.). Data summarized will include stems per hectare, basal area (m^2/ha), and volume per hectare.

Stems per hectare for layer 1 will be derived from the individual tree data in the prism sweeps. Basal area will be derived from the number of stems in the prism sweeps and the basal area factor of the prism used. Volume per hectare will be derived from the volumes of the individual trees in the prism sweeps (the volume of a simple cone is adequate) weighted by the number of trees per hectare that tree represents.

Stems per hectare for layers 2, 3 and 4 will be derived from the stem counts from FS 748. Basal area will be derived from the average basal area of the sample trees for that layer. Volume will be similarly derived. Layer 4 will be considered to make no contribution to the basal area or volume.

Additional summaries may include determination of the relationship between dbh and tree height, and dbh and height to live crown.

3.6.2.1 Single Tree Mortality

The intent of this study is to test probability of mortality equations related to tree size and percent crown scorch. About ten sample trees in or near each plot with a range of diameters were marked with steel tags, and the top height, height-to-live-crown, and diameter was measured before burning on all sites, and additional small tree transects were established at Findlay (a total of 50, 180 and 239 trees of all species on the Skookumchuck, Picture Valley, and Findlay Creek sites, respectively). Crown scorch height will be assessed following burning, and vigour and crown condition will be assessed one and five years following burning.

Shrub utilization will be estimated using the twig measurement technique (Aldous 1945, Dasmann 1948) as modified by Ross and Wikeem (1993). Two species of interest, (species of interest were determined in consultation with local wildlife biologists, Saskatoon (*Amelanchier alnifolia*) and prickly rose (*Rosa acicularis*) the most abundant erect shrub) are measured at each site. Forty apically dominant shoots on a minimum of four shrubs will be randomly located along each transect and measured for each species. This totals 200 lengths per stratum per species. The assessment will be done before May 1 in each measurement year. Percent use will be estimated using browsed and unbrowsed twig length within the sampled twig clusters using the following formula:

$$\text{Percent Use} = \frac{\text{Unbrowsed Length - Browsed Length}}{\text{Unbrowsed Length}} \text{ X } 100.$$

Annual production for species of interest will be estimated. Ten plants of each species will be randomly selected within each stratum and caged before bud burst. Annual growth will be clipped at the end of the growing season. Leaves and stems will be separated. Samples will be oven dried at 70 C for 48 hours. Sampling will take place at the same time as the sampling of forbs and grasses.

3.6.3.2 Forbs and Grasses

Along each shrub transect, 10 randomly located plots were established (see Figure 4). Each plot was permanently marked with a 10 inch spike at each of the four corners. A 20 X 50 cm quadrat was laid out at each plot location. Cover of all species within the quadrat will be noted. Measurements take place at the same time as the sampling of shrub transects.

Picture Valley sampling took place before the above methods were in place. Sampling for both shrub and herb cover was done on ten - 10m radius plots per treatment at Picture Valley. The transect and small quadrats were adopted for subsequent installations due to concerns with reproducibility of cover estimates on large plots.

3.6.4 Insects and disease

For each plot centre, that is assessed for layer 1 trees, all trees (within all layers described in the stand description) within a 5.64m radius will be assessed for insects and disease. The damage codes will follow those of the *Silviculture Survey Damage and Condition Codes Reference* F.S. 747 form (appendix 2). In the comments section the following will be noted:

1. **A** (animal) codes will include estimate of damage age if within three years.

5.0 RESPONSIBILITIES

Project leader	Tom Braumandl, Research Ecologist, B.C. Forest Service, Nelson
Fuels, fire weather, fire behaviour	Steve Taylor, Fire Research Officer, Canadian Forest Service
Stand measurements	Chris Thompson, Research Silviculturist, B.C. Forest Service,, Nelson
Insect and diseases	Art Stock, Entomologist, B.C. Forest Service,, Nelson
Understory vegetation	Tom Braumandl, Research Ecologist, B.C. Forest Service, Nelson

6.0 INTERIM RESULTS (FINDLAY CREEK AND PICTURE VALLEY BURNS)

6.1 Fire Behavior and Smoke Observations

6.1.1 Fire Weather and Fuel Moisture Conditions

Fire Weather Index System values during the burning period at each study site (Table 1) were calculated from on-site weather observations, except that temperature and RH readings from Cranbrook Airport were used for Picture Valley because the on-site values for these variables were suspect. The ISI values are based on an average wind speed over 10 minutes at the hour and hourly FFMC - higher values may have occurred during wind gusts. On future burns, wind observations will be recorded at 1 min. intervals in order to better characterize this variability,

ISI values are calculated from observations of a standard 10m open wind. This is because the open wind speed is representative of the stand edge, and this is where most wildfires tend to start. However, the wind speed within a stand can be much less than in the open, and so the ISI may not be very meaningful for prescribed fires that are ignited from lines well within the stand. Wind speed within the stand will also be measured on future burns, and we will have to consider how the density effect on wind should be incorporated into prescribed fire models.

The moisture contents of selected fuel components determined from destructive sampling are given in Table 2. The trends in the moisture content of the litter and FH layers are consistent with the trend in FFMC and DMC values, respectively, between sites: FFMC was higher and litter moisture content lower for the Picture Valley and Skookumchuck burns than for the Findlay Creek burn (though ISI values were similar because of a higher wind speed at Findlay Creek). DMC was also higher and the FH layer moisture content lower at Picture Valley than at Skookumchuck and Picture Valley.

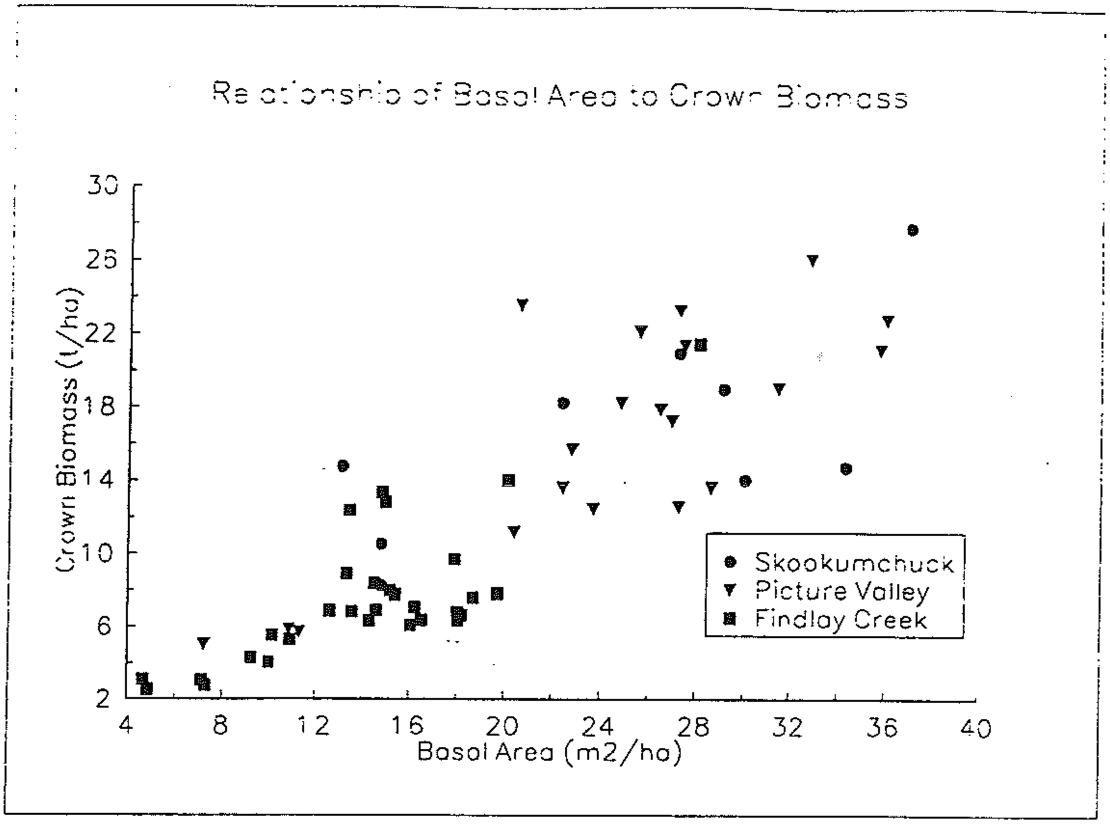

Figure 5. Relationship between crown biomass and tree basal area on the study sites

6.1.3.1 Fire Spread

The percentage of the surface burned as determined along the fuels transects was 60, 53, 90, and 61% for the Skookumchuck and Findlay Creek sites, and Picture Valley Strata 1 and 2, respectively. On all of the sites, spread was probably limited by the sparse cover of fine fuels. In general, fire spread was greater in the more open areas and poor within dense thickets. At Findlay Creek, fire spread was greater on the south than on the north aspect, probably because there was a light rain shower on the day before the burn and surface fuels on the north aspect were still moist.

Ground-based measurements of fire spread rates (ROS) are not easily made on mass aerially-ignited operational burns. Aerial infra-red imaging was carried out at both the Findlay and Picture Valley sites in order to document spread, but analysis of these data is still in progress. The imagery gives a reasonable estimate of total fire size at a particular time and of growth in fire size over time, but it is difficult to precisely measure spread rates between ignition lines.

Table 2. Fuel moisture contents (%) before burning on the study sites.

					Woody fuel (cm diam.)			
	Crown foliage	Litter	FH (forest floor 0-2cm)	Grass	0-1	1-3	3-5	5-10
Skookumchuck	105	8	22					
Findlay Creek	114	12	66	13	9	19	17	28
Picture Valley	114	8	11		8	9	41	67

Table 3. Stand biomass (t/ha) on the study sites.

	---------- Layer 1 -------------			--------- Layers 2-4 ----------		
	Crown[a]	Branch[b]	Stem	Crown	Branch	Stem
<u>Skookumchuck</u>	9.1±2.0[c]	15.1±2.5	63.9±12.6	5.3±1.0	1.4±0.4	8.2±1.7
<u>Findlay Creek</u>						
Burn site	5.2±0.5	10.8±1.2	41.5±4.9	1.2±0.3	0.4±0.08	1.7±0.4
Control	5.7±0.7	9.8±1.4	38.6±5.2	3.0±0.5	0.6±0.1	3.6±0.5
<u>Picture Valley</u>						
Stratum 1	9.5±1.5	15.1±2.3	53.1±8.1	5.1±1.3	1.3±0.3	5.5±1.4
Stratum 2	12.2±1.0	14.2±1.0	67.0±5.2	8.5±1.3	2.1±0.3	9.5±1.4

a. Foliage and <0.5 cm diam. branches.
b. >0.5 cm diam. branches
c. Mean ± standard error.

6.1.3.2 Fuel Consumption

Fuel consumption (Table 4) was greater on the Picture Valley than on the Skookumchuck and Findlay Creek sites, which is consistent with the trend in the Buildup Index (BUI). Though forest floor depths are fairly shallow in these ecosystems, the forest floor accounted for the largest proportion of fuel consumption on the Findlay Creek and Picture Valley sites.

The surface fuel consumption values reflect fire coverage- where fire spread, most of the woody fuels were completely consumed. Some old stumps that

6.1.3.2 Surface Temperatures and Fire Duration

Temperature profiles during the fires were obtained at 15 and 20 points on the Findlay and Skookumchuck sites, respectively. The mean time periods that the temperature exceeded 60, 200, and 500 degrees near the surface are given in Table 5. We are assuming that the 60, 200, and 500 degree points are nominal thresholds for lethal heating of plant tissues, and for smoldering and flaming combustion, respectively. Though there is a high degree of variation between sample points, the data show relatively short residence times at the surface. There was very little heat flux to the mineral soil on the Findlay Creek site, but temperatures at the surface on the Picture Valley site were probably sufficient to kill plant tissues in the forest floor. A typical time-temperature profile is shown in Figure 6.

Smoldering of downed logs and stumps occurred for many hours following ignition on all of the burns, but was not captured by these sampling techniques.

Table 5. Maximum temperatures and average duration (mins.) temperature exceeded selected threshold values near the surface during fires on the study sites.

	+5 cm	0 cm	-1 cm
Findlay Creek			
Max. temp. (C)	663	203	44
Duration > 60 C	9.4	6.2	0.0
Duration > 200 C	1.5	0.1	0.0
Duration > 500 C	0.2	0.0	0.0
Picture Valley			
Max. temp.	843	597	360
Duration > 60 C	27.8	59.0	76.6
Duration > 200 C	3.9	10.9	8.9
Duration > 500 C	0.7	0.5	0.0

6.1.3.3 Fire Intensity

Fire intensity is not an easily measured variable, and is generally calculated from rate of spread (ROS) and fuel consumption measurements. We could not accurately measure rate of spread on the study sites, but estimate that is was less than 1.0 m/min in most areas.

Although we recognize that fire spread rate and intensity were variable, we estimated equilibrium head fire intensity values for the study sites using a nominal spread rate of 1.0 m/min in order to make some preliminary comparisons with values predicted by the FBP System (Table 6), along with comparisons of measured and predicted fuel consumption and crown scorch height. The predicted ROS values are for a range of slope/aspect classes, and the range of hourly wind and FFMC values that occurred during the burning period.

The FBP System over-predicted surface fuel consumption for these sites, probably because the fuel loads were much less than on the sites used to derive the FBP ponderosa pine fuel type model (although our fuel consumption values are averages including unburned area). Because fuel consumption is one element of fire intensity, fire intensity is probably also over-predicted.

Although we could not measure spread rates on these sites, we suspect that they were lower than the FBP equilibrium headfire ROS for these burning conditions even for level conditions. This may be because fire spread in underburns is not at equilibrium due to the ignition pattern.

Fire spread from a strip headfire ignition pattern may undergo acceleration. In this ignition method fires are ignited on the down wind side of the area in successive strips moving upwind, and each fire front spreads with the wind until it reaches the preceding strip. If fire spread rate accelerates from zero to an equilibrium condition, fire intensity and crown scorch height will also increase as the fire spreads between strips, even in uniform fuel conditions. A hypothetical distribution of surface fire intensity in the ponderosa pine - Douglas-fir fuel type (C-7) with a 1.3 m ROS_{eq}, the FBP System acceleration function, and 20 m between ignition lines is shown in Figure 7. This distribution ignores back and flank fire spread, and assumes that the spread of each fire front is independent (no junction zone effects). The model has a wave like form, and suggests that ignition line spacing can be used to control fire intensity in underburns, an observation that has also been made by researchers in the southern United States (Sain 1979; Johansen 1987).

If we want to use elements of the present FBP System to predict a fire intensity and crown scorch distribution on prescribed burns with multiple ignition lines, on sites with varying slope, more work will be needed to link the slope, acceleration, and head/ back/flank fire functions of the FBP System in a model with ignition line spacing and slope distribution.

The effective wind speed used may also have to be modified to predict ROS in underburns. ROS in the FBP System is based on the 10 m open wind speed and is appropriate for wildfires occurring at stand edges, but may not be appropriate for prescribed fires ignited within relatively dense stands where the effective wind speed is much less.

6.1.3.5 Crown scorch height

Crown scorch is caused by the vertical heat flux (through radiation and convection) from the flaming fire front. The height of lethal crown scorch is directly related to fire intensity, and is probably the best physical evidence of the fire intensity that can be assessed following a fire.

The height of crown scorch on the permanent sample trees was assessed about one year following burning on each site. The distribution of scorch height values is shown in Figures 8, 9, and 10. While all of the observations will be useful for testing mortality equations related to scorching, meaningful crown scorch height measurements were obtained on only 54 and 102 of the samples at Picture Valley and Findlay, respectively. If either the entire crown was scorched or the live crown base exceeded the scorch height the observation was excluded from the distribution. The distributions also have not been corrected for the probability of scorching proportional to size. The data are pooled for the two strata at Picture Valley because of the relatively small sample size.

Crown scorch heights predicted from the equilibrium fire intensity values (Table 6) for level ground are similar to the maximum scorch heights observed at the Findlay Creek and Picture Valley, but somewhat greater than the observed heights at Skookumchuck site. The data have to be interpreted cautiously because the underlying spatial distribution of the sample trees is not uniform, and it is uncorrected for probability proportional to size. However, it is clear and significant that scorch height varies across the sites.

This is due to variation in fuel load and consumption and in fire spread rate, which may in turn be related to ignition technique. A hypothetical crown scorch height pattern resulting from the multiple front acceleration model is also shown in Figure 7, and the corresponding scorch height distribution in Figure 11. The shape of the distribution will change with the spread rate and ignition line spacing, but it illustrates how the present equations might be used in a predictive model.

The nature of the distribution is important because percentage crown scorch is one of the variables used to predict tree mortality, and the mortality equations

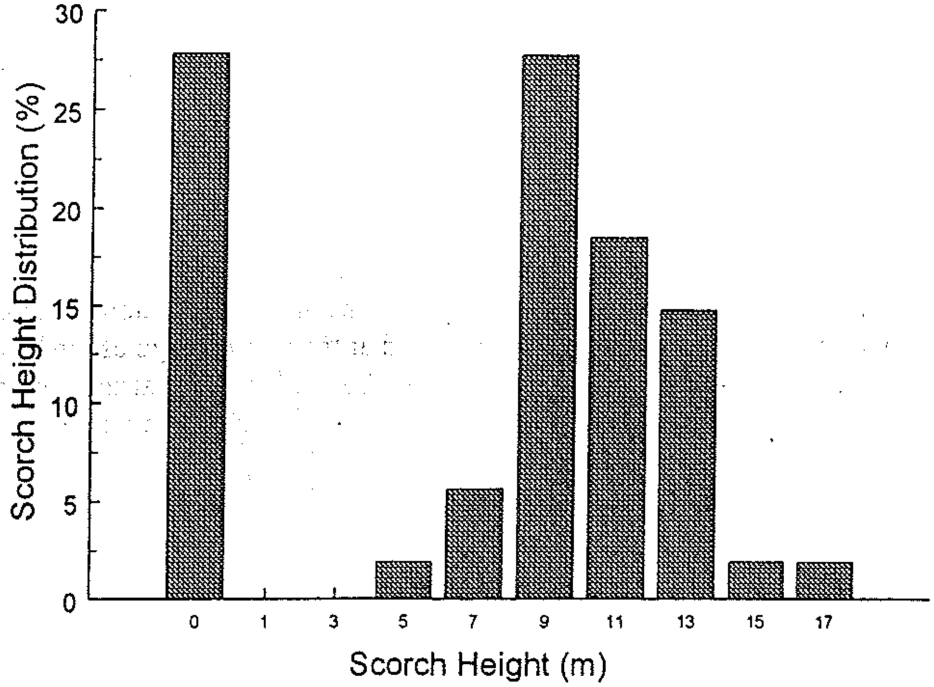

Figure 10. Crown scorch distribution at Picture Valley (n=80)

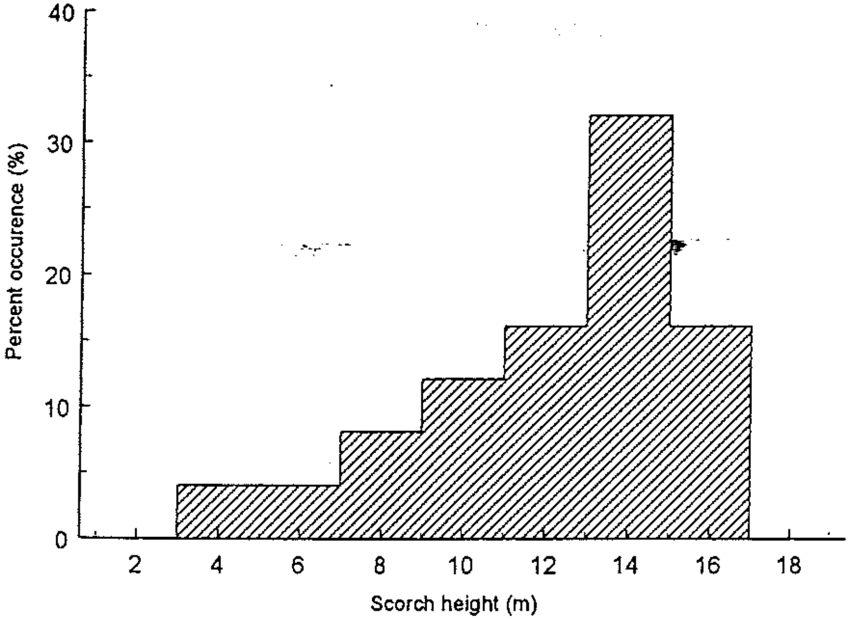

Figure 11. Hypothetical crown scorch height distribution for a fire with spread accelerating to a 1.3 m/min equilibrium value, and 20 m between ignition lines.

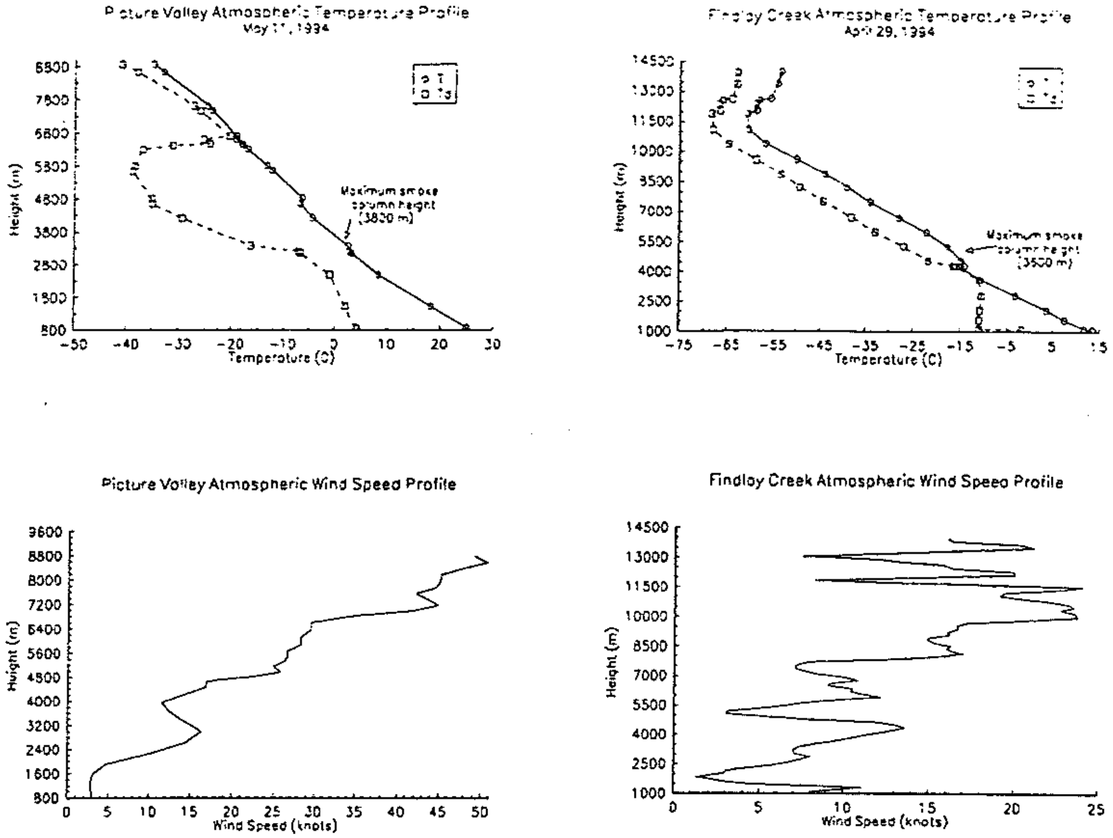

Figure 12. Atmospheric soundings during burning on the study sites. Temperature values in the upper charts are dry bulb (T) and dewpoint (Td) respectively.

6.2 Stand Characteristics - pre treatment

6.2.1 Picture Valley

There are considerable differences between the control and the treatment (Table 7. and Figures 13, 14, 15, and 16). The control has fewer ponderosa pine stems/ha but with higher basal area and more Douglas-fir stems/ha with greater total basal area than the treatment. The control has the classical "J" shaped stem distribution which the treatment stratum 1 also has. The significantly large number of stems in layer 4 of the control is reflected in the higher number of total living stems (15,691) compared with the treatment average of 3,442 stems/ha. Self thinning is occurring in layer 3b of the control, however it is in the 4 layer where excess stems are located. There is double the number of dead stems/ha (34.9) in layer 1 of the control as there is in the treatment average. There is one spruce in layer 1 of the control, one in layer 2a and one in layer 3a. These spruce are excluded from the basal area summaries in Table 8.

There are considerable differences in the stocking between treatment stratum 1 and stratum 2 (Table 7 and Figures 15 and 16). Stratum 1 has considerably more ponderosa pine, than stratum 2, and a lesser total basal area. Stem distribution also

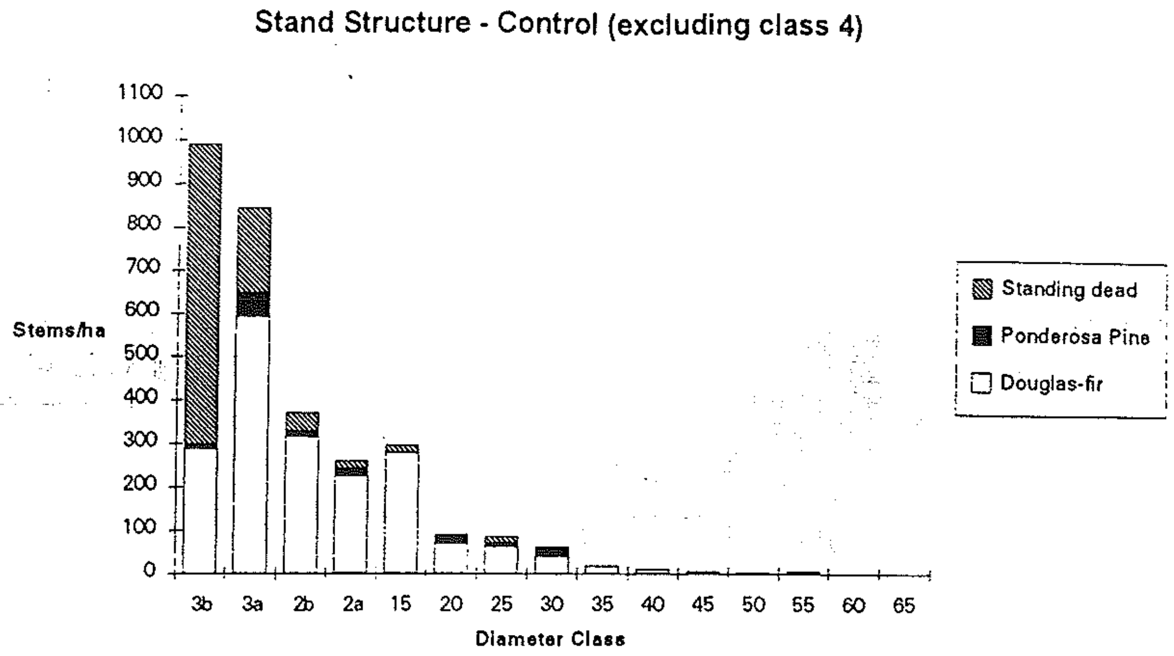

Figure 14. Number of stems per hectare by diameter class (excluding class 4), control Picture Valley (3b through 2a on diameter class axis refer to layers as described in methods while 15 through 65 are diameter class midpoints in cm)

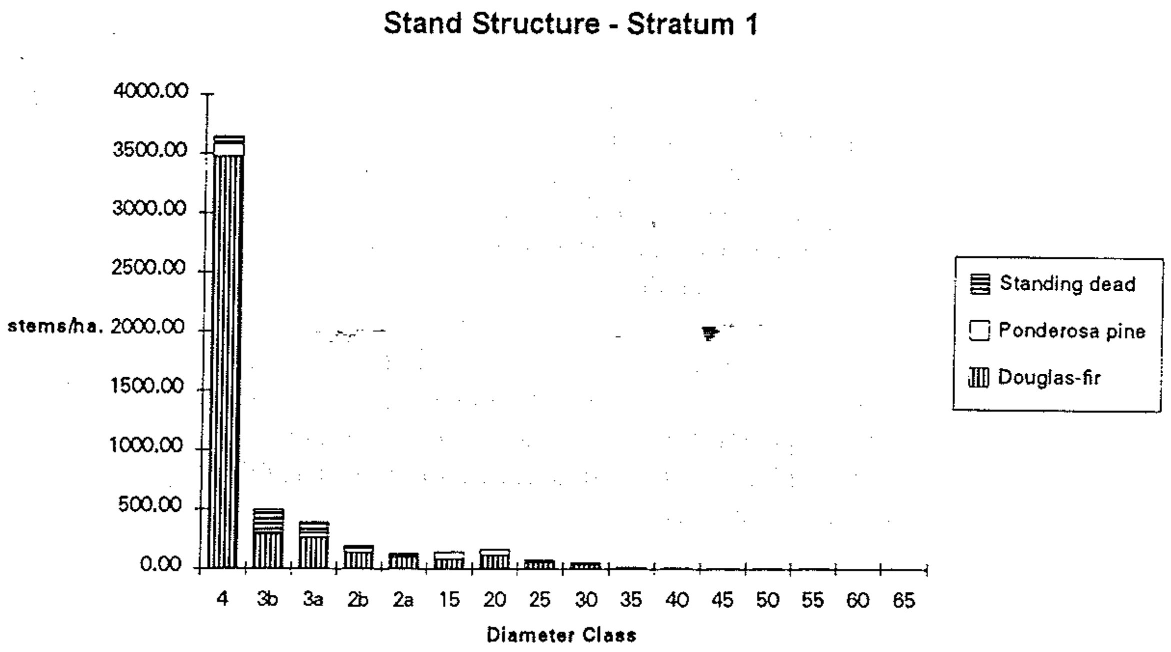

Figure 15. Number of stems per hectare by diameter class, stratum 1 Picture Valley (4 through 2a on diameter class axis refer to layers as described in methods while 15 through 65 are diameter class midpoints in cm)

Douglas-fir in treatment-stratum 2:

$$\text{Ln height} = 0.705 + 0.659*\text{Ln diameter (adj } r^2 = 0.868)$$

Ponderosa pine in treatment-both strata:

$$\text{Ln height} = 0.212 + 0.781*\text{Ln diameter (adj } r^2 = 0.786)$$

Table 8. Basal area (m^2/ha) distribution at Picture Valley

	Layer 3b	Layer 3a	Layer 2b	Layer 2a	layer 1	Total
Control						
Douglas-fir	0.26	1.69	1.98	2.39	17.6	23.92
Ponderosa pine	0.31	1.34	0.08	0.18	3.2	5.11
Standing dead	0.62	0.55	0.27	0.19	1.2	2.83
Total	1.19	3.58	2.33	2.76	22.0	31.86
Stratum 1						
Douglas- fir	0.23	0.71	0.85	1.08	13.80	16.67
Ponderosa pine	0.01	0.11	0.27	0.20	5.20	5.79
Standing dead	0.16	0.25	0.14	0.15		0.69
Total	0.39	1.07	1.28	1.43	19.00	23.16
Stratum 2						
Douglas- fir	0.22	1.60	1.83	2.00	18.20	23.85
Ponderosa pine		0.07	0.12	0.08	0.60	0.87
Standing dead	0.72	1.59	0.56	0.21	1.00	4.08
Total	0.94	3.26	2.51	2.29	19.80	28.80

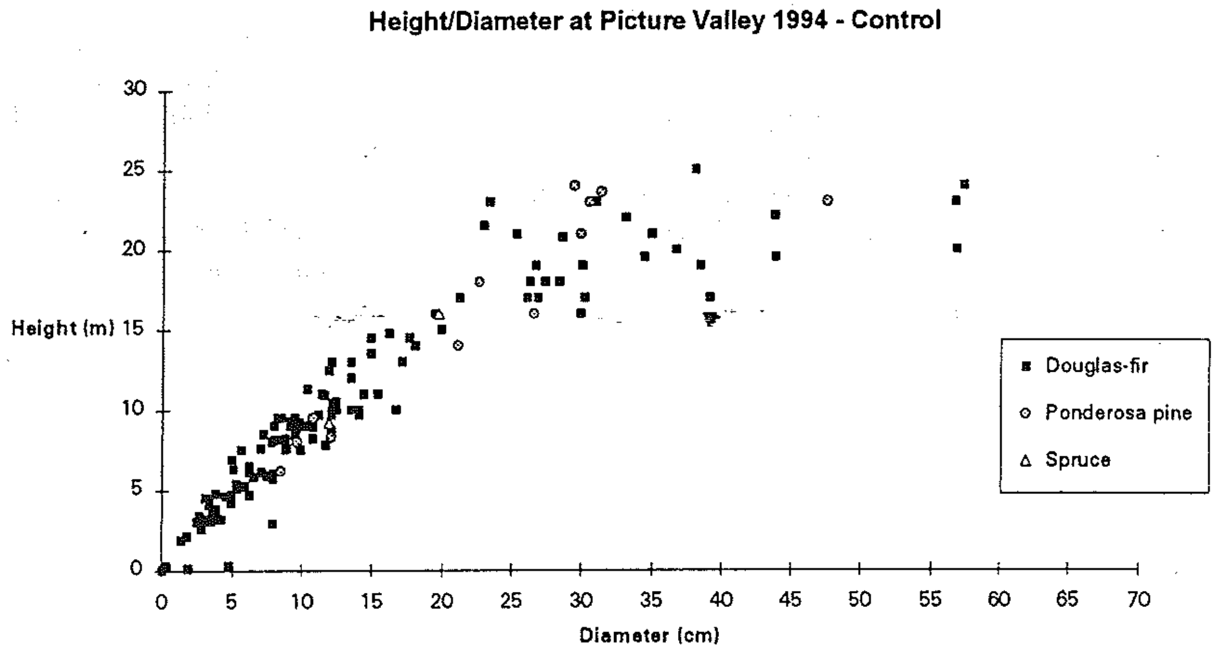

Figure 17. Height versus diameter, control Picture Valley

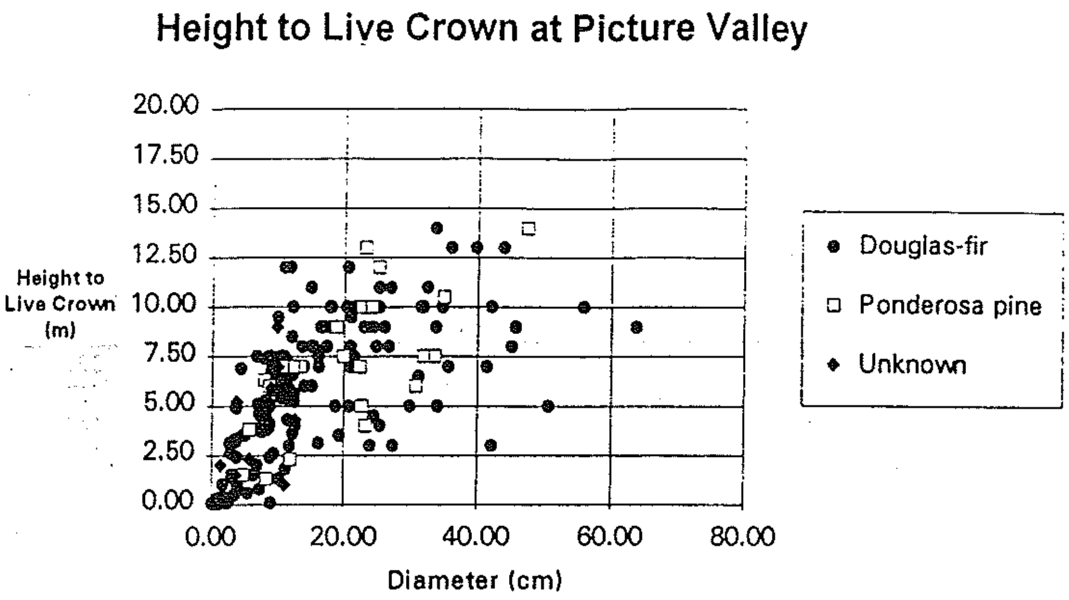

Figure 19. Height to live crown versus diameter, Picture Valley

6.2.2 Findlay Creek

There are considerable differences in the stocking between the burn and control treatments (Table 9, and Figures 20, 21, and 22). The control treatment has four times the total stocking of the burn treatment. This is mostly in layer 4. Layers 2 and 3 in the control have double the stocking of the same layers in the burn. Only in layer 1 is stocking equivalent. Layer 4 is dominated by lodgepole pine in the burn and by Douglas-fir in the control. Lodgepole pine is also dominant in the smaller diameter classes in the burn and is conspicuously sparse in the control. Larch is completely absent from the control.

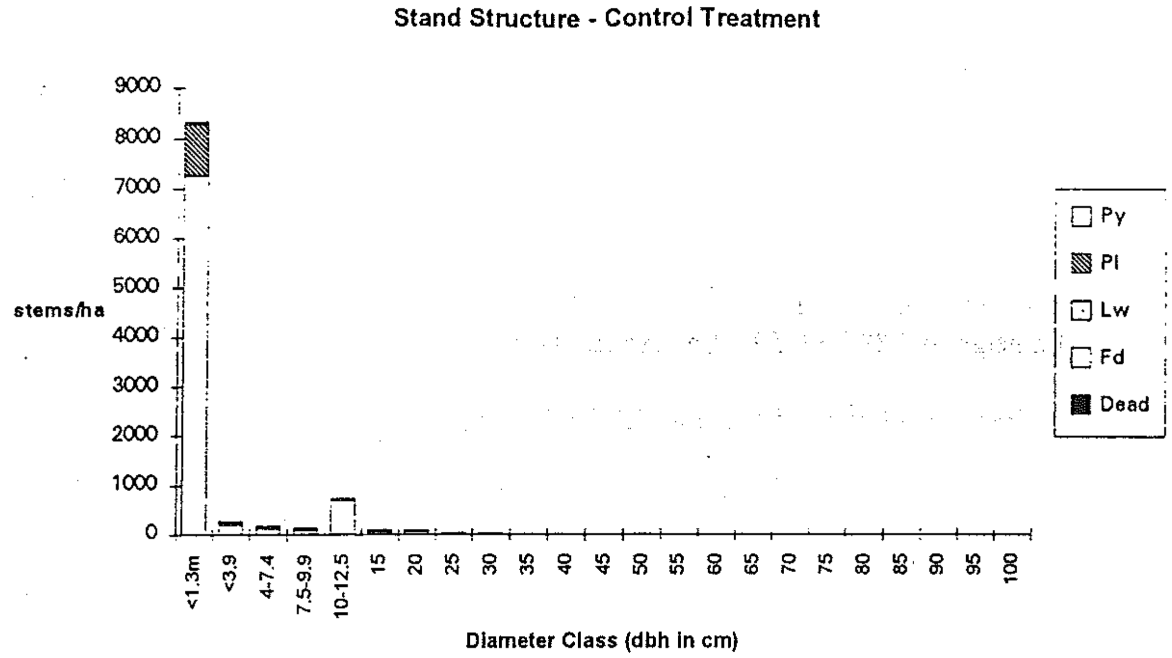

Figure 21. Stocking by diameter class, control Findlay Creek

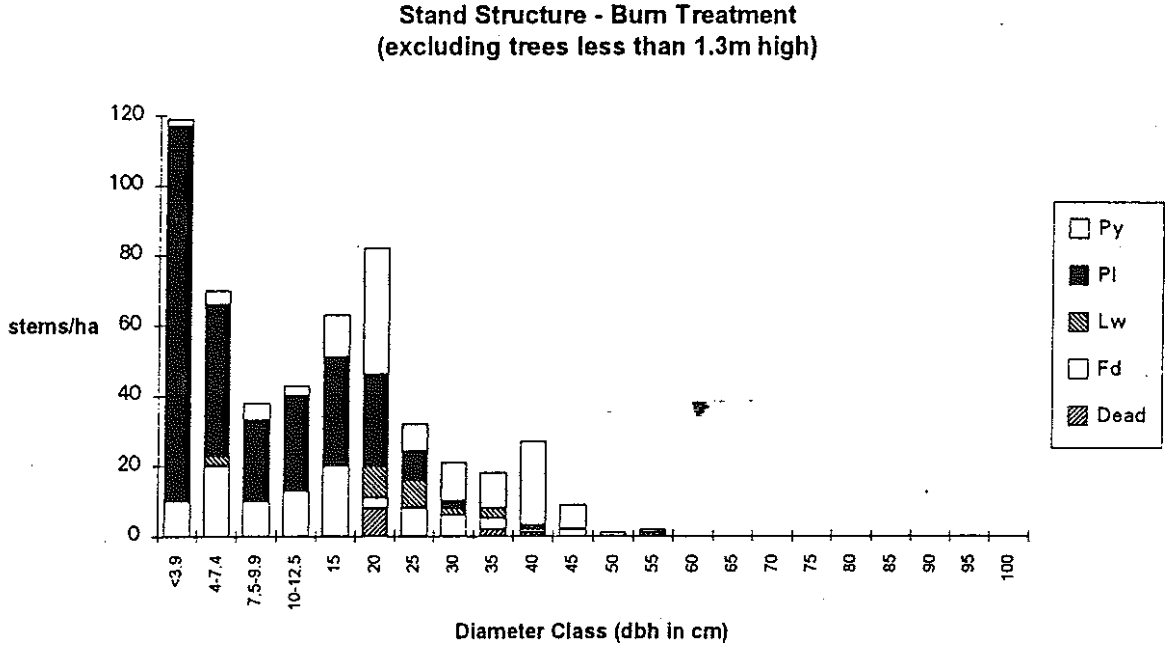

Figure 22. Stocking by diameter class (excluding trees less than 1.3 m high), burn treatment Findlay Creek

The distribution of basal area (m^2/ha) by stratum and species is shown in Table 10. Basal areas for layer 1 were calculated directly from the number of stems in each prism sweep and the factor

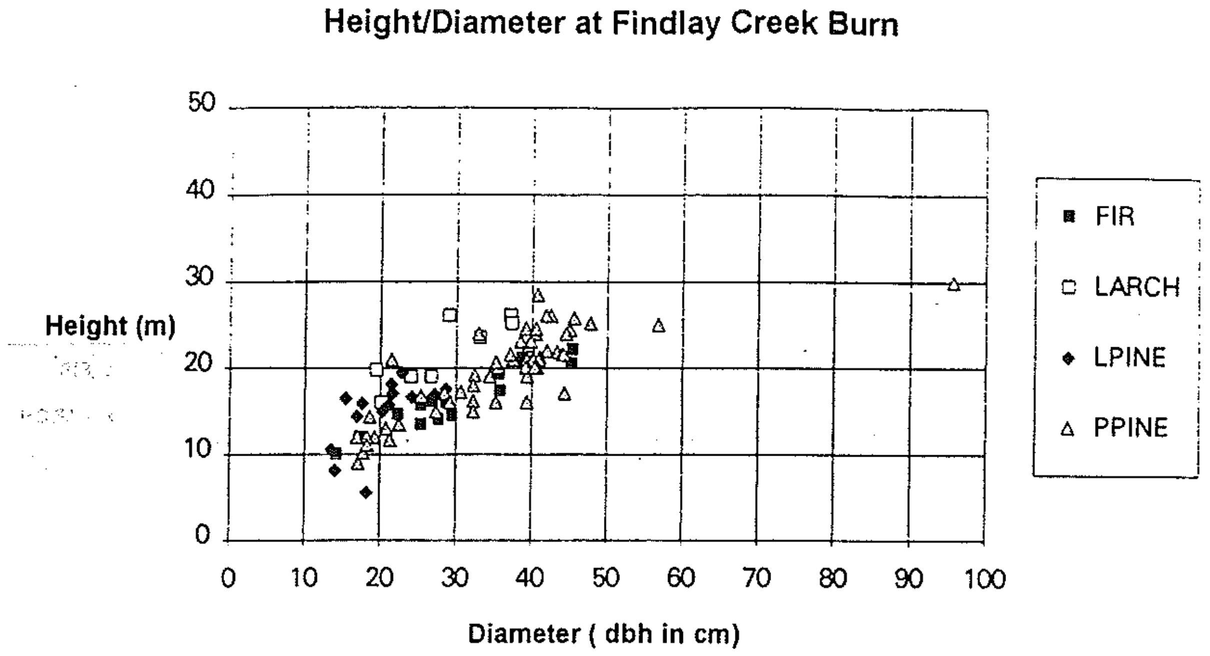

Figure 23. Height versus diameter, burn treatment Findlay Creek

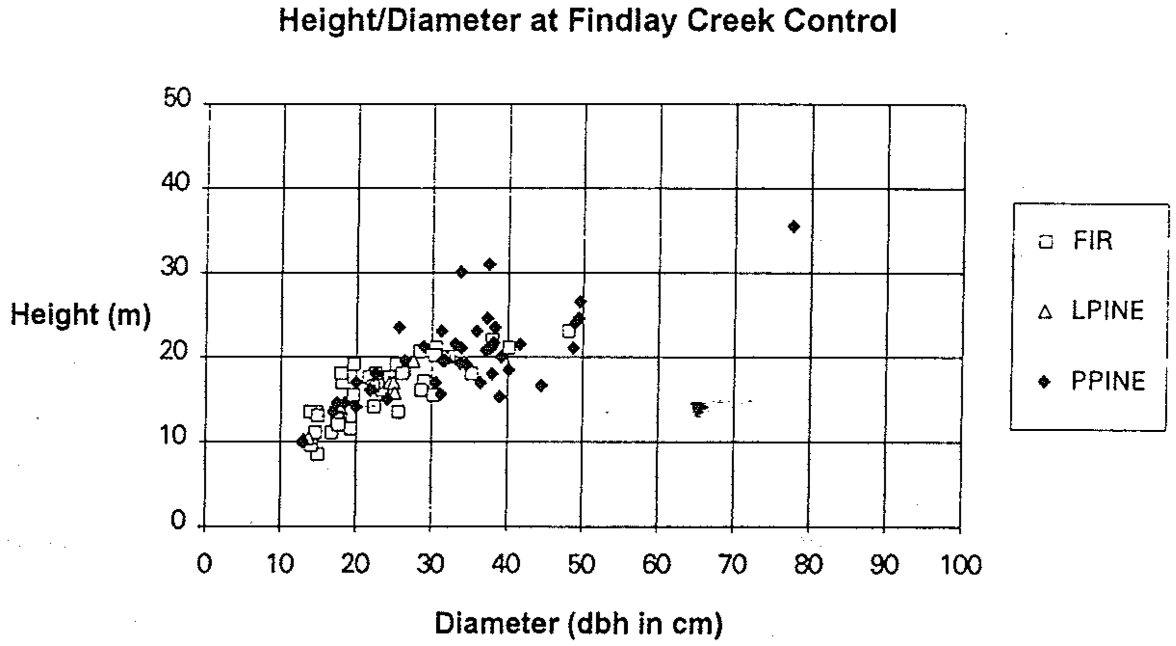

Figure 24. Height versus diameter, control treatment Findlay Creek

Height-to-live-crown was assessed only in the burn treatment, and was weakly correlated with stem diameter (Figure 25). No regressions were attempted. There appear to be differences by species, with lodgepole pine having generally greater heights-to-live-crown. Douglas-fir generally

Table 11. Total herb cover by treatment and date, Picture Valley.

Treatment	Date	Mean Total Herb Cover (%)	Standard Error	Range (%)
Control	Pretreatment	31	6.0	10-59
	1st season post treatment	25	4.0	8-46
Burn	Pretreatment	48	8.0	22-112
	1st season post treatment	26	4.0	10-53

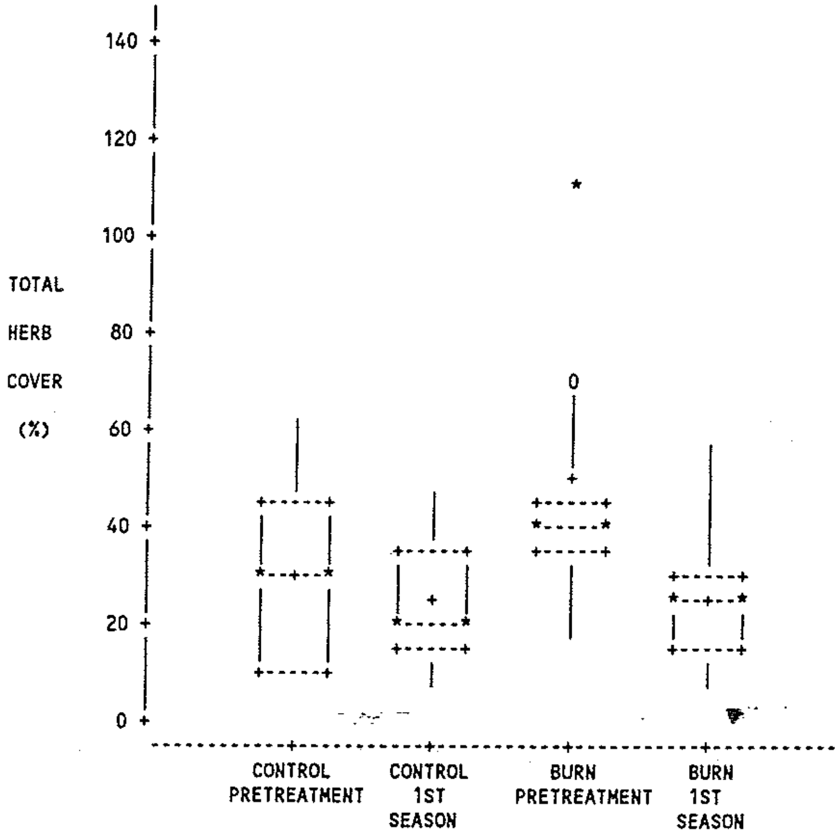

Figure 26. Box plot[a] of total herb cover by treatment and measurement date for Picture Valley

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[a] The interpretation of box plots is as follows: the bottom and top edges are the sample 25th and 75th percentiles; the centre horizontal line is the sample median and the central + is at the sample mean; the central vertical lines, called whiskers, extend from the box as far the data extend, up to 1.5 interquartile ranges (an interquartile range is the distance between the 25th and 75th percentiles); any more extreme value is marked with a zero if it is within three interquartile ranges, or an asterisk if it is still more extreme (SAS Institute Inc. 1988)

Table 13. Major herb species cover, Picture Valley

Species	Treatment	Measurement date	Mean Cover (%)	N	Range (%)
Calamagrostis rubescens	Control	Pretreatment	12	10	0-40
		1st Season	7	10	0-25
	Burn	Pretreatment	26	10	5-50
		1st Season	4	10	0.5-10
Agropyron spicatum	Control	Pretreatment	4	9	0-30
		1st Season	2	9	0-10
	Burn	Pretreatment	0.5	6	0-2
		1st Season	1	6	0-5
Festuca scabrella	Control	Pretreatment	2	9	0-15
		1st Season	1	9	0.5-3
	Burn	Pretreatment	1	9	0-5
		1st Season	1	9	0-2
Arctostaphylos uva-ursi	Control	Pretreatment	1	9	0-4
		1st Season	1	9	0-3
	Burn	Pretreatment	3	10	0-15
		1st Season	1	10	0-5
Stipa occidentalis	Control	Pretreatment	0.5	10	0-1
		1st Season	1	10	0-3
	Burn	Pretreatment	1	10	0-3
		1st Season	2	10	0.5-10
Phlox diffusa	Control	Pretreatment	1	7	0-5
		1st Season	1	7	0.5-5
	Burn	Pretreatment	1	6	0-2
		1st Season	0.5	6	0.5-1
Koeleria macrantha	Control	Pretreatment	0.05	6	0-0.5
		1st Season	0.5	6	0.5-1
	Burn	Pretreatment	1	7	0-5
		1st Season	0.5	7	0.5-1

6.3.1.2 Shrubs

Total shrub cover, as estimated on ten 10m radius plots per treatment (same plots used for herb estimation), is presented in Table 14 and Figure 27 Total shrub cover is very similar both between treatments and dates.

Table 15. Major shrub species cover, Picture Valley

Species	Treatment	Measurement Date	Mean Cover (%)	Range (%)	N
Symphoricarpos spp.	Control	Pretreatment	1.8	0.5-5	9
		1st Season	1.7	0.5-5	9
	Burn	Pretreatment	3.2	0.5-20	7
		1st Season	1.8	0.5-10	9
Amelanchier alnifolia	Control	Pretreatment	0.4	0-1	6
		1st Season	0.5	0.5-1	9
	Burn	Pretreatment	2.1	0.5-10	7
		1st Season	1.6	0.5-5	7
Rosa acicularis	Control	Pretreatment	0.6	0.5-1	9
		1st Season	0.7	0.5-2	10
	Burn	Pretreatment	1.1	0.5-5	8
		1st Season	1.2	0.5-7	8

6.3.2 Findlay Creek

6.3.2.1 Herbs

Herb cover was assessed only after one growing season after the burn treatment. A pretreatment measurement was not feasible given the timing of site selection. Seven plots were assessed on each the burn and control areas. Total herb cover is presented in Table 16 and Figure 28.

Table 16. Total herb cover by treatment one growing season after treatment, Findlay Creek

Treatment	Mean Total Herb Cover (%)	Standard Error	Range (%)
Control	31	3.7	13-43
Burn	11	1.5	7-16

Kinnikinnick (*Arctostaphylos uva-ursi*) and pinegrass (*Calamagrostis rubescens*) are the only herb species to occur with 5% or greater cover on any plot and occur on more than half the plots. Their cover is presented in Table 18.

Table 18. Major herb species cover, Findlay Creek

Species	Treatment	N	Mean Cover (%)	Range (%)
Arctostaphylos uva-ursi	Control	7	14	2-18
	Burn	7	4	1-6
Calamagrostis rubescens	Control	6	5	0-11
	Burn	7	2	.5-6

6.3.2.2 Shrubs

Shrub cover was assessed on 5 plots pretreatment and an additional 2 plots were measured post treatment. Total shrub cover is presented in Table 19 and Figure 27.

Table 19. Total shrub cover, Findlay Creek

Treatment	Measurement Date	Mean Cover (%)	Standard Error	Range (%)
Control	Pretreatment	1.1	1.0	0-5
	1st Season	0.8	0.7	0-5
Burn	Pretreatment	2.0	1.1	0-6
	1st Season	0.6	0.3	0-2

Table 21. Total shrub density by treatment and measurement date, Findlay Creek

Treatment	**Measurement Date**	**Shrub Density (stems/ha)**	**Standard Error**	**Range (stems/ha)**
Control	Pretreatment	2400	1691	0-9000
	1st season	2429	1462	0-11 000
Burn	Pretreatment	24 600	12 568	0-62 000
	1st season	14 000	8104	0-55 000

6.4 Pretreatment Insect and Disease Incidence

6.4.1 Findlay Creek

Both the burn and control blocks were generally free of serious insect problems. Only very low (endemic?) levels of bark beetle activity were noted in the burn block, and none in the control block. No root disease was recorded in either block (Table 22).

Foliage diseases were common in both blocks. The cyclical needle cast *Lophodermella concolor* was common on lodgepole pine in both blocks, probably reflecting generally high levels of this disease in the Nelson Forest Region in 1993 and 1994. The foliage disease *Elytroderma deformans* occurred at low levels on ponderosa pine in both blocks.

Dwarf mistletoe (*Arceuthobium americanum*) was present in both blocks, and at significant levels in the burn block. Lodgepole pine occurred at approximately the same density in both blocks, however stand density (all species) was much higher in the control block, and this has probably impeded mistletoe spread. Nearly 18% of layer 3 lodgepole pine was infested with mistletoe in the burn block, but only 3 % of that layer was infested in the control block.

The long-term effects of fire on the occurrence of these diseases, particularly *E. deformans* and *A. americanum*, will be important to note.

Some aphid activity, possibly *Adelges* spp., was noted on Douglas-fir in the control block.

6.4.2 Picture Valley

Armillaria root disease was present on both the burn and unburned blocks, however incidence was much higher in the burn block (Table 23). The relatively high incidence of mountain pine beetle (*Dendroctonus ponderosae*) in the burn block may have been correlated to this high level of root disease, although no *Armillaria* was noted on the beetle attacked ponderosae pine. The bark beetle noted in the control block was Douglas-fir beetle (*Dendroctonus pseudotsugae*), but no root disease was noted in direct association.

Table 23. Pre-burn pest incidence (percent of live trees affected), Picture Valley, June, 1994.

	Pest incidence (% of live stems) by stand layer[a]							
	Control block				Burn block			
Damaging agent Layer	1	2	3	4	1	2	3	4
Root disease	0.8	-	1.5	-	3.0	33.9	18.8	-
Stem diseases	-	2.6	0.8	-	-	-	1.1	-
Tree competition	-	-	5.4	-	-	-	-	-
Snow press	-	-	-	-	1.5	18.8	9.9	-
Aphids	0.8	-	-	0.1	-	-	-	-
Bark beetles	0.8	-	-	-	4.5	-	-	-
Defoliators	-	-	-	0.1	-	-	-	-

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[a] Percent of live basal area (all tree species) for layer 1, and percent of live stems per ha (all tree species) for layers 2 -4. Layer definitions are found in section 3.5.2.

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APPENDIX 1 PLOT LOCATION MAPS

APPENDIX 2 SILVICULTURE SURVEY DAMAGE AND CONDITION CODES REFERENCE F.S. 747 FORM

APPENDIX 3 SMOKE PLUME MAPS