# Fuel Management Strategies in 60-Year-Old Douglas-Fir/Ponderosa Pine Stands in the Squamish Forest District, British Columbia[1]

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## Abstract

The restoration of dry forest ecosystems in the Squamish Forest District in the past has focused on treating stands with no prior history of selective harvest and containing a large population of remnant historical stand structure. Many 60 to 90 year old stands that date to turn of the century selective harvest operations also exist in the district. These stands contain very high densities of Douglas-fir and ponderosa pine and few historical structures. Silviculture prescriptions were developed to thin these stands to a remnant structure that would be more resilient to future wildfires that may occur between the maintenance prescribed burn schedule. Several strategies were employed, including manual thinning only, thinning and fuel wood harvest, and thinning and mulching. All thinning treatments were followed by prescribed fire. From a strategic perspective, the treatment results indicate that options exist for creating wildfire resilient stands. The best overall option is to thin, remove the material, and then burn the site.

## Introduction

Historically, dry forests in the northern end of the Squamish Forest District, Haylmore Creek, British Columbia (BC) contained a higher proportion of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) than Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) and were structurally dominated by well-spaced, large diameter trees. Structure and species composition were maintained by a short-interval, low- to moderate-severity fire regime (Gray 2001). The historic dry forest type was located on southerly aspects at low to mid-elevations.

Forest stands in Haylmore Creek have experienced a significant increase in stand density and an increase in aerial and surface fuels in a pattern similar to many other sites in western North America (Covington and others 1994, Harrod and others 1999, Gray and others 2004). The homogenization of surface and aerial fuels means that a wildfire can travel for long distances at high-intensity levels and result in large-scale environmental damage. Fire suppression personnel, public and private property, natural resources, and local economies within these landscapes are all at significant risk from large, high intensity fire within these ecosystems. Where fire once promoted biodiversity and heterogeneity, it now threatens biodiversity and promotes homogeneity of structures and species (Martin and Sapsis 1991).

In the fall of 2001 the Squamish Forest District Small Business Forest Enterprise Program (SBFEP) began a strategic assessment of wildfire threat (Blackwell and

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others 2004) to identify high hazard areas of the landscape with significant values (biological, social and economic) at risk. This assessment was followed by a prioritization plan detailing the location and timing of restoration and fuel treatments. The second initiative was an operational study of dry forest restoration treatments in 60 year old mixed stands of Douglas-fir and ponderosa pine. Four treatment strategies were tested and included: 1) thinning combined with understory burning, 2) understory burning with no thinning, 3) thinning, fuel wood removal and understory burning, 4) thinning, mechanical mulching and understory burning. The creation of a wildfire resilient stand through the restoration of dry forest structure and composition, which more closely represents the historical range of variability (Morgan and others 1994), is the primary objective in the TERP study. More specific, tactical objectives of the study were to test the short-term and long-term effects of a range of fuel treatments on stand-level wildfire resilience.

## Study Area

The strategic assessment of wildfire threat was conducted at a larger landscape scale of 103,202 ha, and encompassed two Landscape Units (LUs) (Ministry of Environment, Lands, and Parks and Ministry of Forests 1999); the Birkenhead LU and the Gates LU. Each of these LUs lie on the east, or leeward, side of British Columbia's Coast Mountain Range and is comprised of a second order watershed. Climate, vegetation and stand structure details are outlined in *table 1*.

**Table 1**—*Study area climate, vegetation and stand structure details.*

| | |
|---|---|
| **Climate Variables** | **mean** |
| annual precipitation | 549 mm |
| monthly air temperature: January | -1.4 C |
| monthly air temperature: July | 23.7 C |
| **Vegetation Classification** | |
| biogeoclimatic subzone[1] | Interior Douglas-fir wet warm (IDFww) |
| vegetation community | Douglas-fir and ponderosa pine on warm sites; predominantly Douglas-fir with minor western red cedar (*Thuja plicata* Donn ex D. Don) and paper birch (*Betula papyrifera* Marsh.) on moist sites |
| **Stand Structure** | |
| study area | 42.3 ha total; 22.3 ha of old high-grade logging, and 20 ha of unharvested with scattered old pine and Douglas-fir |
| stand density: high-grade area | 2,600 t $ha^{-1}$ to 10,000 t $ha^{-1}$ |
| species proportions | Douglas-fir 90 pct, ponderosa pine 10 pct |
| canopy closure: total unit | >90 pct |

[1](Green and Klinka 1994)

## Methods

The first step in the strategic assessment of wildfire threat relied upon the use of a spatial threat rating model known as the WTRS (Blackwell and others 2004). A full description of the WTRS assessment used in this project can be found in Blackwell and others (2004).

The current forest structure contains a high surface fuel load in duff, litter, and branchwood fuels, and a very high aerial fuel load. Historic surface fuels were likely 1 to 3 kg $m^{-2}$, while the current fuel load averages 9.8 kg $m^{-2}$. Canopy fuels, measured as canopy bulk density and the total weight of crown fuels, were never likely to have been high enough to sustain an active crown fire. Computing this fuel layer was achieved using the CrownMass subroutine in the Fuels Management Analyst™ (Fire Program Solutions, L.L.C. 1999). The current stand structure is highly conducive to an active crown fire, with a canopy bulk density of 1.40 kg/m³/ha (0.028 lb/ft³/ac) and 5.3 kg $m^{-2}$ (23.5 t $ac^{-1}$) of crown fuels measured as a single layer across the entire study area. The critical canopy bulk density required to sustain a crown fire is measured at 0.1 kg/m³/ha (0.006 lb/ft³/ac) (Sando and Wick 1972, Harrod and others 1998). Contemporary stands are at >1400 percent of the critical threshold value. Surface fuel load must also be reduced to a point where the convective heat from a wildfire does not result in excessive crown scorch damage (Saveland and others 1990). Therefore, creating a wildfire resilient structure is the result of reducing canopy bulk density below the critical active crown fire threshold, and reducing surface fuels to the point where a wildfire will not result in unacceptable crown scorch.

Meeting the study objectives centered on developing thinning and burning prescriptions that were easily understood and implemented. Implementation of the prescribed burn post-thinning was the most constraining element in the development of treatment prescriptions. Existing surface fuel load was high, and the various thinning treatments would increase fuel load significantly. Crown scorch, even though several of the treatment units were to be thinned, was still the most critical element in developing both the thinning and burning prescriptions. The critical step in developing a crown closure-driven thinning prescription that still met the restoration objectives relied on developing a correlation between diameter at breast height (DBH) and crown area. Prior field work in Haylmore Creek yielded a strong relationship ($r^2$=0.70) between crown area and DBH. Field crews then established fixed radius inventory plots in the portions of TERP that were to be thinned. Variables collected included stand density, diameter distribution, tree height, and crown area. A linear regression of crown area over DBH yielded an $r^2$ of 0.86.

The next most critical factor in developing the prescription was setting limits on crown scorch damage and mortality. The crown scorch model in the First Order Fire Effects Model (FOFEM) (Reinhardt and others 1995) was used in combination with professional judgment to develop a maximum canopy closure parameter for burn prescription success. A target of 40 to 60 percent canopy closure was arbitrarily set by the burn planning team based on past understory burning experience. Target canopy closure was to be achieved by summing crown area by diameter, starting at the largest DBH class recorded, and adding crown area until the target was reached (*fig. 1*). The canopy closure prescription target was theoretically met at a lower diameter limit of 20 cm and resulted in a mean retention level of 270 t $ha^{-1}$. Based on this prescription approximately 2,600 trees $ha^{-1}$ <23 cm DBH were to be felled.

It was assumed that, at a minimum, the thinning prescription would result in reduced canopy bulk density below the critical active crown fire threshold (i.e., <0.1 kg/m³/ha). This would be accomplished by using canopy closure as a surrogate for the density of aerial fuels instead of a more rigorous inventory and analysis of canopy bulk density and crown weight by species and structural characteristic. The hypothesis was that if canopy closure was reduced to 40 to 60 percent from >90 percent, there would be a reciprocal reduction in canopy bulk density. Once thinning was completed to the canopy closure target, resulting stand structure could be re-compiled in FMA™ to determine post-thinning canopy bulk density and crown weights.

A series of four thinning and fuel management treatments was applied to 20 ha of the TERP study area. The thin and mulch (Unit TM) area was conducted on gentle slopes (<30 percent), where the operation could be carried out with a small tracked forwarder. In the thin and removal (Unit TR) unit the area was thinned and fuels were either manually or mechanically removed to the roadside. The thin only (Unit TO) unit was thinned only, with no fuel removal. The last unit, burn only (unit BO), contained only natural fuels and was prescribed burned unthinned. Burn objective monitoring quantified surface fuel consumption, immediate tree mortality by probable cause, crown scorch, and understory vegetation response. Prescribed burn monitoring methodology follows the U.S. Department of Interior National Park Service Fire Monitoring Handbook and included a series of 1/10th ha plots randomly located in each treatment unit. Surface fuel inventory followed Brown and others (1982), immediate tree mortality was measured over a 100 percent sample of the study area, percent crown scorch was measured from all trees within the 1/10th plots, and vegetation response, which is not reported here, was measured using point-intercept transects in the 1/10th ha plots.

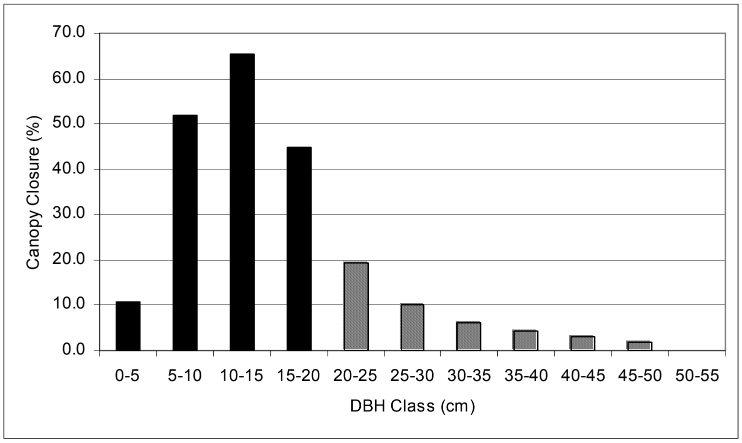

**Figure 1**—Range of canopy closure by 5 cm DBH class. The target, 50 percent, was reached by summing all trees starting at 45 to 50 cm and descending in DBH.

Prescribed burn operations took place in March and April of 2002, with fire effects monitoring carried out immediately post-burn. Surface fuel consumption focused on removing fine fuels <7.5 cm in order to reduce the short-term surface fire rate of spread. The ignition strategy for meeting this objective was driven by the need to limit overstory crown scorch.

## Results

Manual thinning treatments carried out in units TM, TR, and TO resulted in variable crown closure by subunit. The prescription target of 40 to 60 percent canopy closure was met on average, with some gaps being larger than others (*table 2*).

Variability was attributed to the spatial pattern of tree diameters, especially in unit TO where a high density of >20 cm DBH trees are located. Along the south edge of TM where the unit abuts a steep, southwest slope the density of <20 cm DBH trees was often >5,000 t $ha^{-1}$ with few trees >20 cm DBH; leading to larger post-thinning canopy gaps.

**Table 2**—*Post-thinning canopy closure by treatment subunit in the TERP study area.*

| Treatment unit[1] | N[2] | Mean (pct) | SD | Minimum (pct) | Median (pct) | Maximum (pct) |
|---|---|---|---|---|---|---|
| TM | 10 | 56.1 | 20.6 | 23.3 | 59.1 | 82.8 |
| TR | 16 | 60.1 | 15.3 | 33.5 | 59.1 | 91.3 |
| TO | 6 | 81.1 | 11.4 | 64.0 | 81.3 | 94.0 |

[1] Treatment unit abbreviations correspond to the following: TM=thin and mulch; TR=thin and remove; and, TO=thin only.

[2] Each plot involves 4 cardinal direction measurements.

The reduction in crown closure translated into a significant reduction in canopy bulk density and crown fuel load (*fig. 1*). Post-thinning canopy bulk density, measured for the entire 20 ha manual thinning area, was 0.004 $lbs/ft^3/ac$. The post-thinning stand also contained many significant gaps. Thinning reduced canopy fuel load by 84 percent, from 5.3 kg $m^{-2}$ (23.5 t $ac^{-1}$) to 0.8 kg $m^{-2}$ (3.8 t $ac^{-1}$). Unfortunately, this fuel load was added to the surface fuel load, which defeats the purpose of the prescription. However, this result was anticipated.

Fuel consumption in activity fuels was highly variable, not only in total consumption, but also in rates of consumption by fuel size class (*table 3*). The post-burn fuel inventory indicated that the highest consumption rate of the three thinned treatments occurred in the TR unit, while the only unthinned unit, BO, experienced a moderate consumption for total fuel load.

**Table 3**—*Fuel consumption rate by treatment unit and fuel size class.*

| Treatment Unit | 0 to 0.6 cm | 0.6 to 2.5 cm | 2.5 to 7.5 cm | <7.5 cm total | >7.5 cm sound | >7.5 cm rotten | Total |
|---|---|---|---|---|---|---|---|
| **Pre-burn ($kg/m^2$)** | | | | | | | |
| Thin and mulch | 1.62 | 0.74 | 1.37 | 3.73 | 3.41 | 0.00 | 7.14 |
| Thin and removal | 1.73 | 0.56 | 0.40 | 2.69 | 0.00 | 0.04 | 2.73 |
| Thin only | 1.82 | 0.27 | 0.63 | 2.72 | 6.06 | 0.07 | 8.85 |
| Burn only | 1.77 | 0.18 | 0.54 | 2.49 | 0.00 | 1.42 | 3.89 |
| **Post-burn ($kg/m^2$)** | | | | | | | |
| Thin and mulch | 0.92 | 0.49 | 1.24 | 2.65 | 3.35 | 0.00 | 6.00 |
| Thin and removal | 0.18 | 0.18 | 0.27 | 0.63 | 0.00 | 0.00 | 0.63 |
| Thin only | 0.76 | 0.20 | 0.56 | 1.52 | 4.78 | 0.07 | 6.37 |
| Burn only | 0.25 | 0.07 | 0.34 | 0.66 | 0.00 | 1.21 | 1.87 |

The level of scorch damage in the treatment units was variable, ranging from none in the TM unit to widely scattered but low-level scorch in the TR and TO units, to more consistent but still scattered scorch in the BO unit. There are several small patches (<1 ha) of either moderate or high crown scorch, especially in the TO and BO units. From a pool of approximately 5,500 live trees in the treatment units, <200 trees were killed outright in the burn. It is expected that subsequent tree mortality will occur as Douglas-fir beetles (*D. pseudotsugae* Hopkins) and red turpentine beetles (*D. valens* LeConte) attack fire-damaged trees.

## Discussion

At the stand level, the use of thinning, mulching and prescribed fire reduced fine surface fuels, and therefore the short-term threat of fire spread, but left a long-term large fuel legacy that must be dealt with through subsequent burns. The period of reduced fire spread risk is currently unknown and is dependent on the development of a fine fuel complex. Considering that these sites were depauperate prior to thinning, many of the herbs and grasses that would contribute to a future fine fuel complex will have to invade the site. The rate of invasion and accumulation of cured material is part of ongoing monitoring in the study site. Once a consistent fine surface fuel complex is developed, subsequent burns used to incrementally reduce the remaining unnatural fuel accumulation can be more easily carried out.

The TO treatment left a problematic fuels legacy as did the TM treatment. The significant difference between TM and TO treatments lies in the arrangement of fuels. Mulching in the TM treatment resulted in residual fuel lying flush with the ground, providing some opportunity for microbial and fungal decay between follow-up burns. Most, if not all, residual fuels in the TO treatment remain suspended off the ground and air dried. The breakdown of fuel will be prolonged by this effect. However, invasion of a fine fuel complex consisting of grasses and herbs is likely to occur at a rate comparable to the TM treatment unit. This could create a significant fire threat before optimum conditions present themselves for subsequent fuel reduction burns. Once conditions become favorable, burning will still need to be carefully conducted in order to limit overstory damage and minimize risk of escape.

The TR treatment provided the best results for creating a long-term, wildfire resilient stand structure that would serve as a wildland-urban interface prescription model. The post-thinning, pre-burning fuel complex was light and relatively easy to manage from a prescribed burning perspective. Surface fuel reduction and crown integrity objectives were also easy to achieve due to the low volume of pre-burn fuels. The TR treatment area is more likely to survive a wildfire occurring prior to any future maintenance burning.

The BO treatment resulted in a low post-burn fuel load, but unlike any of the other treatments this unit will likely see a substantial increase in surface fuels in the short-term due to fire-caused overstory mortality. The rate of input of these fuels varies by species and diameter (Everett and others 1999); however, within 10 to 15 yr, this treatment unit is likely to have a higher surface fuel load than it did prior to treatment. The BO unit also had the highest overall rate of crown scorch, which could lead to additional bark beetle caused overstory mortality.

## Conclusions

From a strategic perspective, the treatment results indicate that options exist for creating wildfire resilient stands. The best overall option is to thin, remove the material, and then burn the site. Because one of the primary objectives in the study was the fire effects resulting from a range of stand treatments, the option of thinning and removal and no follow-up prescribed burn (a burn control unit) was not considered. While economic indicators were not tracked in detail during this study, it is abundantly clear that thinning overstocked, young Douglas-fir, forwarding the material to a road, giving it away at no cost, and then prescribed burning the site is likely to be expensive.

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