

Harvesting and Thinning Guidance for Treatments in Wildland-Urban Interface Areas of TSA 29

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Introduction

Communities throughout British Columbia are vulnerable to forest fires. At particular risk is the Wildland-Urban Interface¹ (WUI) zone. Recent interface fires in British Columbia and in other jurisdictions have provided evidence that completed fuel-reduction treatments reduce fire suppression costs, improve safety for residents and firefighters, and improve the resilience of forests subjected to fire (Safford et al. 2009, Rogers et al. 2008). However, the cost of such treatments has been high and the rate of treatments slow.

In this report we provide Best Management Practices (BMP) guidance for harvesting and thinning activities in the Wildland stands within Community Wildfire Protection Plans. The report considers areas of the Interior Douglas-Fir (IDF) biogeoclimatic zone within Williams Lake Timber Supply Area. Fuel and fire behaviour modelling, an extensive literature review, and operational experiences have been synthesized to provide guidance for fuel management. It focusses on achieving land use objectives while:

- Reducing crown closure;
- Maintaining low surface fuel loading; and
- Increasing canopy base height.

We suggest that fuel treatment rates can be increased and costs lowered if licensees undertaking harvesting and thinning treatments can be induced to modify fuels in conjunction with their other objectives. We further believe that the intensity of the fuel treatment should vary according to the proximity to values at risk.

Problem Statement

Uncontrolled fires in the WUI present a clear danger to people, property and infrastructure. The Auditor General of B.C. (2001) pointed out two factors that contribute to an increasing risk of interface fires:

- Increasing fuel accumulations resulting from decreased fire frequency; and
- More people choosing to live in or near our forests.

Added to those shifts, the impacts of climate change are expected to cause more extreme weather, with an increasing summer temperature and decreasing summer precipitation. This combination of factors creates what the Forest Practices Board (2010) describes as “...*ideal conditions for catastrophic wildfires affecting tens of thousands of people.*” As a result of the recommendations of Filmon et al. (2004) local governments have been undertaking planning and implementation of fuel reduction treatments in the WUI. Funding for that work has been available from both federal and provincial governments.

The Forest Practices Board (2010) points out the enormity of the task: 685,000 ha are considered to be at high risk of interface fire

On the peak day [of 2003], most of the southern half of the province was in extreme or high fire danger. At this point, no community could be assured they would not be the site of the next interface fire.

Filmon et al. (2004)

¹ Wildland Urban Interface is an area where human development meets or is inter-mingled with forest and grassland fuel types (FPB 2010)

in B.C., and to date only about 35,000 ha have been treated. Moreover, fuel reduction treatments are temporary, because trees in the forests continue to grow and die, accumulating biomass and contributing to a new build-up of fuel.

In 2005 a committee of interested individuals produced the Williams Lake and Area Interface Fire Plan with the aim of encouraging participation by agencies, residents, companies and land managers to address the potential impacts of fire in the interface area (Williams Lake Interface Fire Committee 2005). Following that lead, Dunlevy and Perry (2006) created a Community Wildfire Protection Plan (CWPP) for the unincorporated areas of the Cariboo Regional District. It contains community hazard assessments for 12 communities, three of which are located within Interior Douglas-fir forests and one (Alexis Creek) is located in the Williams Lake Timber Supply Area.

Fuel treatments in the WUI must be done in conjunction with citizen efforts to make private property FireSmart (Rogers et al. 2008, Williams Lake Interface Fire Committee 2005, Vickers 2003). Rogers et al. (2008) documented that fire brands that landed on or near privately owned structures led to structural fires well before the main fire front arrived. Fuel treatments on Crown Land can catalyze neighbours to treat their private property, but many property owners will require assistance or support in order to implement Fire Smart procedures.

PART 1: PRINCIPLES OF FUEL MANAGEMENT

Fuel Reduction Treatments

The purpose of treating forest fuels in a Wildland Urban Interface is to reduce the intensity of a forest fire when it occurs by limiting the energy released, so as to increase the probability of successful containment and minimize adverse impacts. Treatments are applied to stands, and stands are selected for treatment according to the impact those treatments will have on the hazard fires present to communities and values. This report is concerned with recommending fuel reduction treatments for stands that Safford et al. (2009) refer to as Wildlands. These are stands that are not adjacent to the structures and values, but are sufficiently close to the interface that aggressive fire behaviour there would threaten our communities.

Rogers et al. (2008) found that fuel reduction treatments in wildlands had significant effects on fire behaviour, even in an extreme wildfire situation in densely developed urban interface. They found that, as a result of fuel treatments:

- People were evacuated more safely;
- Fire spread was slower, fire intensity was reduced, and fire was more easily contained;
- Suppression was more effective and concentrated on controlling the spread of fire in urban areas.

Rogers et al. (2008) state that treatments were effective because they were placed in the landscape according to an integrated analysis of fuels, terrain, weather, history, access, and values at risk. The treatments were planned and implemented to achieve specific fire behaviour objectives, and the fuels along roads and powerlines were treated to enable safe public evacuation and rapid access for suppression forces.

Fuel reduction treatments in the Cariboo began slowly in the early 1990s, due to limited understanding of their importance and low financial and public support. Awareness, support, and efforts have increased such that there has been a significant increase in the area where fuels have been reduced. Treatment costs, however, remain high and the area treated is small relative to the total CWPP area. Average fuel treatment costs are approximately \$6,000 per hectare in B.C. (R. Colwell, Fuels Management Specialist Cariboo Fire Centre, Personal Communications 2009). In the Williams Lake area our experience to date shows operational costs have ranged from \$2,618/ha to \$6,400/ha depending upon stand conditions and debris disposal methods. Costs average \$3,406/ha for the most frequently used method (hand falling, skid debris to roadside for removal to bioenergy plant.)

To bring costs down so that more area can be treated, we can:

1. Identify less expensive operational methods;
2. Identify stands where treatment cost and intensity will be low, or where more merchantable timber can be removed; and
3. Incorporate fuel reduction treatments into general forest management activities.

Basic Fire Theory

This section outlines the background knowledge necessary for interpreting the results of the fuel modelling study and the rationale behind treatments recommended later in this report.

Unless stated otherwise, content in this section has been adapted from the Forest Encyclopedia Network website (<http://www.forestencyclopedia.net/p/p4>) and the Field Guide to the Canadian Forest Fire Behaviour Prediction System (Taylor et al 1997).

Measures of Fire Behaviour

Fireline Intensity and **Rate of Spread** are the two major descriptive measures of fire behaviour used in this study.

Rate of spread is the horizontal distance that the flame zone moves per unit of time (meters per minute) and usually refers to the head fire segment of the fire perimeter. Rates of spread generally increase with increasing wind speed, slope, and amount of fine fuels.

Fire intensity is a measure of the rate of heat released by a fire, and fireline intensity is the most common measure of fire intensity. **Fireline intensity**, also known as frontal fire intensity, is the rate of heat energy released per unit time per unit length of fire front, regardless of the depth of the flame zone. It is measured in units of kW/m. Because considerable burning can take place after passage of the flaming front, these figures do not describe the total energy or heat released.

Weather Effects on Fire Intensity and Rates of Spread

Wind speed has one of the greatest effects on fire intensity and rates of spread. As wind blows across a fire, it pushes the flame forward closer to the unburned fuel in front of the fire. This increases convection and radiation, which dry the fuel and increase its combustibility. In general, the higher the wind speed, the further the flame leans and the faster it dries the fuels, increasing both fire intensity and rate of spread. Wind also adds oxygen to the existing fire, further increasing combustion rates in the flaming zone (Whelan 1995).

Fuel Moisture is reduced under the influence of high temperature, low relative humidity, wind exposure, and absence of precipitation. Moisture content of fuels determines fire intensity and rate of spread, because it affects pre-heating time-lags and the availability of larger-diameter fuels.

Fire Rank

The Canadian Forest Fire Behaviour Prediction (FPB) System includes a Fire Intensity Rank System. This system includes 6 fire ranks on a continuum of fire behaviour representing increasing difficulty of control.

Table 1 provides quantitative and qualitative descriptions of Ranks 2 through 6 in the Fire Intensity Rank System. Rank 2 fires are classified by fireline intensities less than 500 kW/m and are readily controllable using direct manual attack with hand tools and water. Ranks 3 and 4 fires have fireline intensities between 500 and 4,000 kW/m and are generally only controllable with heavy equipment. Rank 5 fires are extremely difficult to control and have fireline intensities between 4,000 and 10,000 kW/m, while Rank 6 fires are generally out of control and have fireline intensities above 10,000 kW/m.

Explanation of Dead Fuel Diameter Classes

Dead fuels are categorized into fuel diameter classes named according to the “timelag principle” (Pyne et al. 1996) in the US fuel classification system. This principle is based on the fact that the moisture content of small diameter fuels can change rapidly in response to weather changes, while larger diameter fuels are slower to respond. A timelag is the time required for a fuel particle to reach 63% of the difference between the initial moisture content and the moisture content when the fuel is in equilibrium with the new weather conditions. The categories are named for the “midpoint” of the response time of each fuel category: 1-hour fuels respond in less than 2 hours, 10-hour fuels respond in 2 to 20 hours, 100-hour fuels respond in 20 to 200 hours, and 1,000 hour fuels respond in greater than 200 hours. Below are typical fuels and fire behaviour for each of these 4 time lag classes.

Table 1: Ranks 2 to 6 Fires in the Canadian Fire Intensity Rank System (Information adapted from the B.C. MoF Wild-fire Management Branch website: <http://bcwildfire.ca/fightingwildfire/firerank.htm>).

Rank	2	3	4	5	6
Rate of Spread (m/min)	<1.5	1.5-3.0	3 to 6	6 to 18	> 18
Fireline Intensity (kW/m)	10-500	500-2000	2000-4000	4000-10000	>10000
Description	Low vigour surface fire	Moderately vigorous surface fire	Highly vigorous surface fire, torching (or passive crown fire)	Extremely vigorous surface fire or active crown fire	Blow-up or conflagration, extreme fire behaviour
Qualitative Fire Behaviour	These fires produce visible open flame; have little or no spread, and have an unorganized flame front	Vigorous surface fire with a moderate rate of spread. They have an organized front and may display “candling”, which is when a tree’s fuels ignite and flare up, along the perimeter and/or within the fire	Grey to black smoke, has an organized surface flame front, and has a moderate to fast rate of spread along the ground. Short aerial bursts and short range spotting will occur with these fires	Black to copper smoke, has an organized crown fire front, moderate to long-range spotting and independent spot fire growth.	Violent fire behaviour. An organized crown fire front, moderate to long-range spotting and independent spot fire growth are characteristic of this fire type. There may be the presence of fireballs and whirls.
Response to Control Efforts	Direct manual attack at fire’s head or flanks by fire fighters with hand tools and water possible. Constructed fire guard should hold.	Hand-constructed fire guards likely to be challenged. Heavy equipment generally successful in controlling fire.	Control efforts at fire’s head may fail.	Very difficult to control. Suppression action must be restricted to fire’s flanks. Indirect attack with aerial ignition (i.e., helitorch and/or aid dispenser) may be effective.	Violent physical behaviour probable. Suppression actions should not be attempted until burning conditions ameliorate.
Photo					

- **1-hour time lag fuels (< 0.625 cm diameter)**—1-hour time lag fuels are the most important for carrying surface fires and their moisture content governs fire behaviour. One-hour fuels include fallen needle and leaf litter, grassy fuels, lichens, and small twigs.
- **10-hour timelag fuels (0.625 cm - 2.5 cm diameter)**—Common 10-hour fuels include small branches and woody stems. Due to their resistance to drying and greater heat capacity, 10-hour fuels often do not combust in low-intensity surface fires. When moisture is low, however, 10-hour fuels can carry hot fires and help ignite larger (100- and 1000-hour) fuels.
- **100-hour timelag fuels (2.5 cm - 7.6 cm diameter)**—Larger downed woody debris is common 100-hour forest fuels. These fuels take longer to dry, deterring their consumption under most conditions. Likewise, 100-hour fuels are slow to gain moisture, so they can combust after prolonged drought, even with recent precipitation. When 100-hour fuels ignite they can burn for

hours, in mixtures of flaming and smoldering combustion. Decay of 100-hour fuels can alter their response and makes them combust more readily than intact fuels.

- **1000-hour timelag fuels (> 7.6 cm diameter)**—These fuels, which include large downed branches, logs, and tree stumps, burn only under prolonged dry conditions, or when sufficiently pre-heated by adjacent fuels. Since they do not commonly burn, 1000-hour fuels can act as firebreaks and cause fire shadows. When they do burn, 1000-hour fuels are common smoldering fuels and can burn for days after ignition, creating air quality and re-burn hazards.

Thresholds of Fire Behaviour

Most forested areas have surface fuels that under most weather conditions would support at least a rank 2 fire. Section 7 of the Wildfire Act² states that prescribed activities (e.g. vegetation management) must include fire hazard assessments and, if necessary, abate the fire hazard. Up to this time government has not defined what it considers to constitute a fuel hazard beyond the following description from the Wildfire Regulation³:

“fuel hazard” means the potential fire behaviour, without regard to the state of weather or topography, based on the physical fuel characteristics, including fuel arrangement, fuel load, condition of herbaceous vegetation and the presence of ladder fuel;

Section 12 (2) of the Wildfire Regulation stipulates that a person required to abate a fire hazard must do so to the extent that fire behaviour is not increased. In the absence of more concrete direction from government on expectations for fuel reduction, it is our professional opinion that treatments should target fuel loadings that would not support greater than a Rank 2 fire.

Vegetation (Fuel) Management

Vegetation (fuel) management is the planned manipulation and/or reduction of living and dead forest fuels for land management objectives (e.g., hazard reduction). It is a critical tool in reducing fire risk. Given public concerns, vegetation management is often difficult to implement and must be carefully rationalized in an open and transparent process. Vegetation management should be strategically focused to minimize the risk of fire to values with the least ecological and financial impacts. For example, understory thinning or surface fuel removal may reduce fire behaviour, but in situations where tolerance to risk is low, a more aggressive vegetation management strategy may be necessary. Effectiveness of vegetation management depends on the longevity of treatment (vegetation grows back), treatment cost, and the resultant effect on fire behaviour.

Fuel As A Component of Fire

Fire is a chemical reaction that requires three main ingredients which make up the fire triangle:

- Fuel (carbon);
- Oxygen; and
- Heat.

If any of these three ingredients are not present, a fire will not burn.

Fuel is generally available in ample quantities in the forest. Fuel must contain carbon. It comes from living or dead plant materials (organic matter). Trees and branches lying on the ground are a major source of fuel



<http://www.wingello.rfsa.org.au/Fire-Facts/firefact2.htm>

² http://www.bclaws.ca/Recon/document/freeside/--%20w%20--/wildfire%20act%20%20sbc%202004%20%20c.%2031/00_04031_01.xml

³ http://www.bclaws.ca/Recon/document/freeside/--%20w%20--/wildfire%20act%20%20sbc%202004%20%20c.%2031/05_regulations/11_38_2005.xml#section2.1

in a forest. Such fuel can accumulate gradually as trees in the stand die. Fuel can also build up in large amounts after catastrophic events, such as insect infestations or disease.

Oxygen is present in the air. As oxygen is used up by fire, it is replenished quickly by wind.

Heat is needed to start and maintain a fire. Heat can be supplied by nature through lightning. People also supply a heat source through misuse of matches, campfires, trash fires, and cigarettes. Once a fire has started, it provides its own heat source as it spreads.

Forest Fuels

The amount of fuel available to burn on any site is a function of biomass production and decomposition. Many of the forest ecosystems within British Columbia have the potential to produce large amounts of vegetation biomass. Variation in the amount of biomass produced is typically a function of site productivity and climate. Loss of vegetation biomass is a function of decomposition, which is regulated by temperature and moisture. In wet maritime coastal climates the rates of decomposition are relatively high when compared with drier cooler continental climates of the interior. Rates of decomposition can be accelerated naturally by fire or purposely by breaking up and redistributing the biomass.

A hazardous fuel type can be defined by high surface fuel loadings: high proportions of fine fuels (<1 cm) relative to larger size classes, high fuel continuity between the ground surface and overstory tree canopies, and high stand densities. A fuel complex is defined by any combination of these attributes at the stand level and may include groupings of stands.

Surface Fuels

Surface fuels consist of forest floor, understory vegetation (grasses, herbs and shrubs, and small trees), and downed wood in contact with the forest floor (Figure 1). Surface fuel loading is a function of natural disturbance, tree mortality and/or human related disturbance.

Surface fuels typically include all combustible material lying on or immediately above the ground. Often roots and organic soils have the potential to be consumed by fire and are included in the surface fuel category.

Surface fuels that are less than 7.6 cm in diameter contribute to surface fire spread; these fuels often dry quickly and are ignited more easily than larger diameter fuels. Therefore, this category of fuel is the most important when considering a fuel reduction treatment. Larger surface fuels greater than 7.6 cm are important in the contribution to sustained burning conditions, but are often not as contiguous and are less flammable because of delayed drying and high moisture content, when compared with smaller size classes. In some cases where these larger size classes form a contiguous surface layer, such as following a windthrow event or wildfire, they

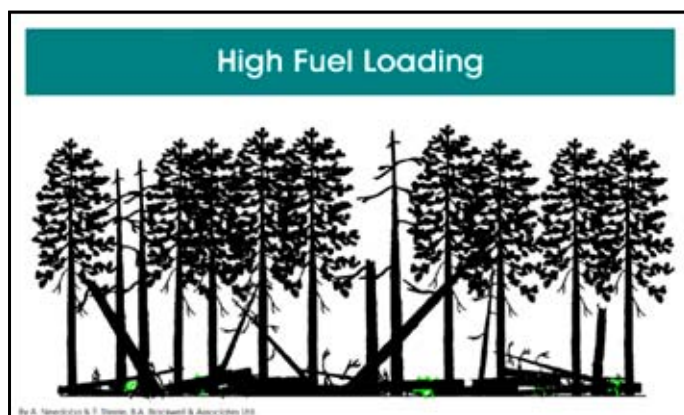


Figure 1: High fuel loading under a forest canopy. High surface fuel loads provide intense fire behaviour, while high aerial fuel loads provide fuel ladders, allowing fire access into tree crowns.

can contribute an enormous amount of fuel, which will increase fire severity⁴ and potential for fire damage.

Surface fuels are measured in kilograms per square meter. As a point of reference Figure 2 illustrates a gradient of fuel loadings from 0 kg/m² to greater than 15 kg/m². Note that the fuel loadings in Figure 2 are observation-based estimates only, and field measurements are required to validate these values.

Aerial Fuels

Aerial fuels include all dead and living material that is not in direct contact with the forest floor surface (Figure 1). The fire potential of these fuels is dependent on type, size, moisture content, and overall vertical continuity. Dead branches and bark on trees and snags (dead standing trees) are important aerial fuel. Concentrations of dead branches and foliage increase the aerial fuel bulk density and enable fire to move from tree to tree. The exception is for deciduous trees where the live leaves will not normally carry fire. Numerous species of moss, lichens, and plants hanging on trees are light and flashy aerial fuels. All of the fuels above the ground surface and below the upper forest canopy are described as ladder fuels.



Figure 2: Photo gradient of surface fuel loadings. Surface fuel loading values are subjective observation-based estimates only and require some level of validation. B.A. Blackwell photos, Knife Creek Block, UBC/Alex Fraser Research Forest.

⁴ **Fire severity** is a qualitative indicator of the effects of fire on an ecosystem, whether it affects the forest floor, canopy, or some other part of the system. Like fire intensity, fire severity reflects the amount of heat released by a fire, and therefore it is also dependent on fuels and fire behaviour. But fire severity also integrates fuel and soil conditions *before* a fire, energy released during *and* after flaming combustion, and visible effects after a fire. (<http://www.forestencyclopedia.net/p/p618>)

Two measures that describe crown fire potential of aerial fuels are the height to live crown and crown closure (Figure 3 and Figure 4). The height to live crown describes fuel continuity between the ground surface and lower limit of the upper tree canopy. Crown closure describes the inter-tree crown continuity and reflects how easily fire can be propagated from tree to tree. In addition to crown closure, tree density is an important measure of the distribution of aerial fuels and has significant influence on the overall crown and surface fire conditions (Figure 5). Higher stand density is associated with lower inter-tree spacing, which increases overall crown continuity. While high density stands may increase the potential for fire spread in the upper canopy, a combination of high crown closure and high stand density usually results in a reduction in light levels associated with these stand types. Reduced light levels accelerate self-pruning of trees, inhibit the growth of lower branches, and decrease the cover and biomass of understory vegetation.

Note that in fuel modelling, the variable used to represent fuel continuity between the surface fuels and the canopy is “canopy base height”. This is similar to the height to live crown, though instead of simply being a measure of where the limbs of the canopy start it is a measure of the height above the ground where the density of the crown mass is high enough to support vertical fire movement. Canopy base height (or CBH) will be the term used in results section of this report.

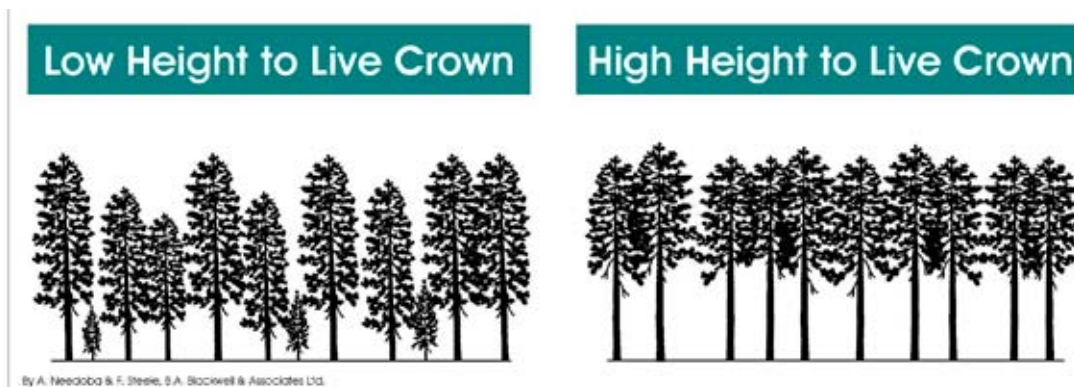


Figure 3: Comparisons showing stand level differences in the height to live crown.

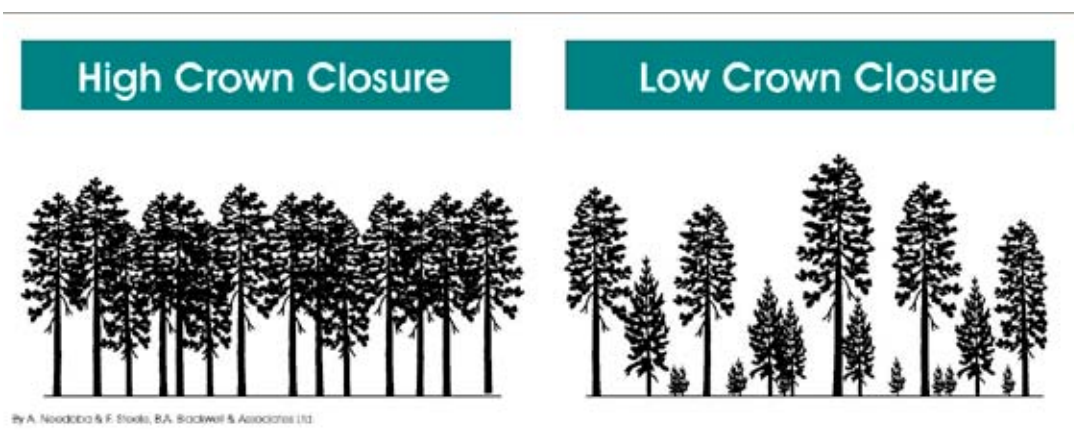


Figure 4: Comparisons showing stand level differences in crown closure.

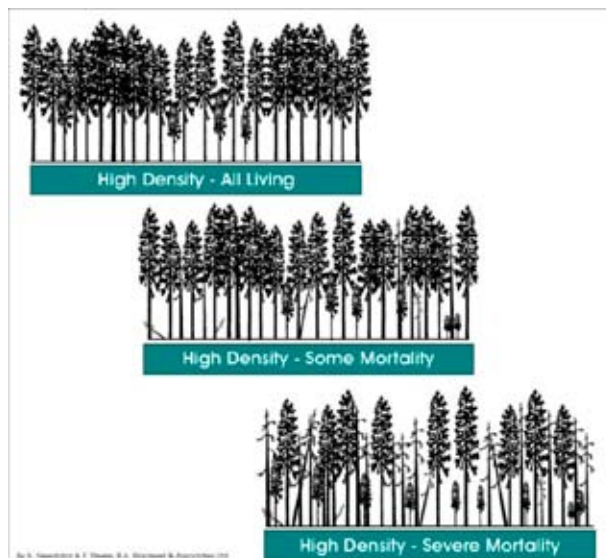


Figure 5: Comparisons showing stand level differences in density and mortality.

Stand Treatments for Fuel Modification

The goal of fuel management is to reduce potential fire behaviour, thereby increasing the probability of successful containment and minimizing adverse impacts. More specifically, the goal is to decrease the rate of fire spread, and in turn fire size and intensity, as well as crowning and spotting potential (Alexander 2003).

Thinning is a preferred approach to fuel treatment (Figure 6) and offers several advantages compared to other methods:

- Thinning provides the most control over stand level attributes such as species composition, vertical structure, tree density, and spatial pattern, as well as the retention of snags and downed wood for maintenance of wildlife habitat and biodiversity.
- Unlike prescribed fire treatments, thinning is comparatively low risk, is not constrained to short weather windows, can be implemented at any time, and has long-lasting effects on ladder fuels.
- Thinning may provide marketable materials that can be utilized by the local economy.
- Thinning can be carried out using sensitive methods that limit soil disturbance, minimize damage to leave trees, and provide benefits to other values such as wildlife, aesthetics, and recreation opportunities.

The following summarizes the guiding principles that should be applied in developing thinning prescriptions:

- Protect public safety and property both within and adjacent to the urban interface.
- Reduce the risk of human caused fires in the immediate vicinity of the urban interface.
- Improve fire suppression capability in the immediate vicinity of the urban interface.
- Reduce the continuity of overstory fuel loads and related high crown fire risk.
- Maintain the diversity of wildlife habitats by

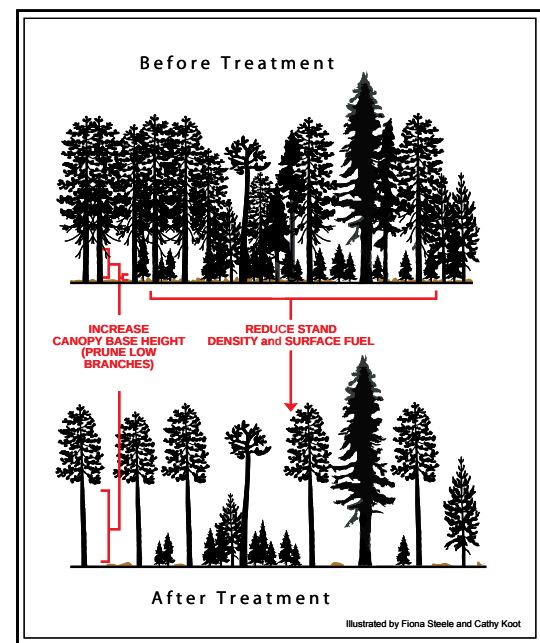


Figure 6: Schematic showing the principles of thinning to reduce stand level hazard.

1. Thinning to increase the diversity of understory plant species; and
 2. Retaining a component of dense understory in un-thinned reserves (strips 30 m wide spanning the treatment area) for hiding and thermal cover (Day 1998a, Waterhouse et al. 1990).
- Minimize negative impacts on aesthetic values, soil, non-targeted vegetation, water and air quality, and wildlife.

The main wildfire objective of thinning is to reduce crown fire potential by creating a low surface fire potential and reducing ladder fuels. In general, the goals of thinning are to:

- Reduce stem density below a critical threshold to minimize the potential for crown fire spread. Target crown closure depends on the stand type but is often less than 35%;
- Thin from below to reduce the component of ladder fuels, push the canopy base height up, and retain the most fire resistant trees in the stand;
- Prune to increase the height to live crown to between 2 and 6 meters depending on the surface fuel loading and stand density to reduce the potential of surface fire spreading into tree crowns; and
- Remove slash created by thinning and pruning to maintain surface fuel loadings below 3-5 kg/m² depending on objectives and acceptable risk.

Thinning without managing the resulting slash will increase surface fuel loads, making fire behaviour more aggressive and reducing stand resilience.

Thinning is completely supported for the management of mule deer winter range in the IDF (General Wildlife Measures for Shallow and Moderate Snowpack Zones).

The Principles of Landscape Fuelbreak Design

Fuel breaks are strategically placed strips of low volume fuel on the landscape where firefighters can make a stand against fire (e.g. indirect attack via the ignition of backfires) and provide safe access for fire crews in the vicinity of wildfires. A fuel treatment is created by reducing surface fuels, increasing height to live crown and aggressively lowering stand density through tree removal (Figure 7, Figure 8).

Landscape fuelbreaks should be located:

- Considering the direction fire would likely come from due to prevailing winds;
- Prioritizing fuel management on areas at highest fire risk;
- Linking existing fire barriers such as agricultural developments, roads, airports, lakes or other low-fuel areas such as rocky areas, ridges and bare ground;
- Outside of established mule deer winter range, or within areas of low habitat objective within mule deer winter range;
- In consultation with fire specialists, identify candidate fire break areas that could support tactical fire suppression measures or provide fire crews with safe access;

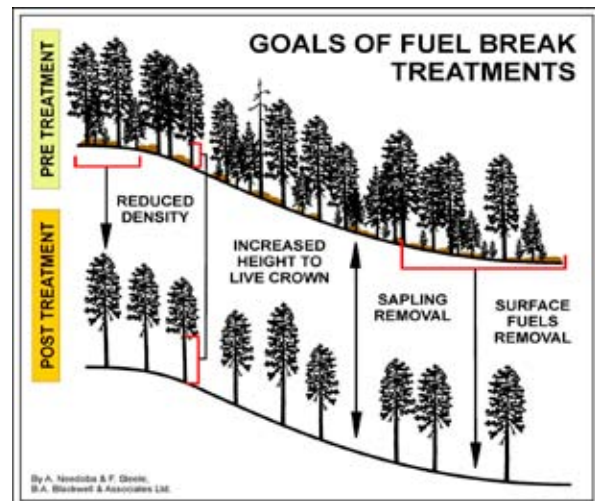


Figure 7: Conceptual diagram of a shaded fuelbreak pre treatment and post treatment.

Stand Maintenance

Fuelbreaks require ongoing treatment to maintain low fuel loadings. Following treatment, tree growth and understory development continue the process of fuel accumulation and, if left unchecked, over time the fuelbreak will degrade to conditions that existed prior to treatment. Some form of follow-up treatment is required. Follow-up is dependent on the productivity of the site, and may be required as frequently as every 10 to 15 years in order to maintain the site in a condition of low fire behaviour potential.



Figure 8: Fuelbreak conditions created by Tolko Ltd. at Anderson Road, Williams Lake. Treated 2006, photo 2006.

PART 2: FOREST MANAGEMENT FOR FUEL REDUCTION

Fuel and Fire Behaviour Modelling Summary And Discussion

BA Blackwell and Associates (2010) modelled fire behaviour in a case study stand in the Knife Creek Block of the UBC Alex Fraser Research Forest, so as to determine the threshold levels of fuel and make recommendations to guide fuel management prescriptions. The report of that work is attached at Appendix 1. We assume these modelling results are generally applicable to stands in the IDF biogeoclimatic zone in the Williams Lake Timber Supply Area. The modelling results provided several key findings discussed below.

Surface Fuel Loading

- At wind speeds of 15 km/hr and higher, regardless of stand density, modelled surface fuel loadings above 8.3 kg/m² exceeded rank 3 fire behaviour;
- At higher wind speeds (35 km/hr), regardless of stand density, modelled surface fuel loadings above 4.5 kg/m² exceeded rank 3 fire behaviour;
- At wind speeds of 15 km/hr and stand densities of 300-600 stems/ha, crown fire did not occur even at extreme surface fuel loadings, though it is expected that fire behaviour would still be difficult to control (up to Rank 5 fire) and spotting and tree scorching would still likely occur;
- At wind speeds of 35 km/hr, modelled surface fuel loadings above 7.2 kg/m² resulted in crown fire regardless of stand density.

Stand Density

When the stand density was varied in the modelling, diameter class distribution was found to be a critical stand attribute that largely affected the fire behaviour. With winds of 15 km/hr fireline intensity makes a dramatic jump between 1000 stems/ha and 1500 stems/ha for surface fuel loadings of 3.8-7.2 kg/m². This is also where the fire type changes from a surface fire to a crown fire. Small diameter trees are both surface and aerial fuels, and contribute to the continuity between the forest floor and canopy. Small trees are a critical stand component affecting fire behaviour. This is further emphasized by the lack of differences in fireline intensity (at 15 km/hr winds) between the stands with densities of 300, 600, 800 and 1000 stems/ha which all varied only in density of the larger diameter classes. At the lower fuel loading of 3.1kg/m² the jump from surface fire to crown fire happened at a higher stand density (between 2500 and 3000 stems/ha) indicating that higher stand densities can be maintained if surface fuels are lowered below a specified threshold.

Canopy Base Height

The fire rank at each canopy base height was the same for all stand densities modelled between 600-4000 stems/ha, and varied slightly for the stand modelled with 300 stems/ha.

- Canopy base height had very little influence on fire rank at low surface fuel loadings (<4.5 kg/m²) and lower wind speeds (15 km/hr);
- At high wind speeds (35 km/hr), regardless of surface fuel loading and stand density, stands with a canopy base height below 3 m exceeded rank 3 fire behaviour;
- Canopy base height had a stronger influence on fire behaviour than stand density;
- At higher surface fuel loadings, higher canopy base heights were required to maintain a low fire rank.

As a rule of thumb, it appears that stand density can be maintained as high as 2000 stems/ha where canopy base height is greater than or equal to 2 m and the surface fuels are less than 4 kg/m². However, as these conclusions vary with diameter class they need to be tested with a wider range of diameter distributions. In modelled stands where the fuel loading is above 4 kg/m² and/or the canopy base height is below 2 m, thinning has little or no mitigating effect on fire behaviour potential.

Fuel Management Recommendations

Based on fuel modelling at 15 km/hr winds we recommend the following fuel reduction actions:

- Maintain surface fuel loading below 4 kg/m² if stand resilience or fuel break conditions are desired;
- At surface fuel loading less than 4 kg/m²:
 1. Where the tolerance for risk is moderate (e.g. not within close proximity to infrastructure or other values at risk), the canopy base height should be greater than or equal to 2 meters.
 2. Where the tolerance for risk is low (e.g. within close proximity to infrastructure or other values at risk), the canopy base height should be greater than or equal to 3 meters.
- Surface fuel loadings should never exceed 8 kg/m²;
- If surface fuels cannot be maintained below 4 kg/m² and are between 4-8 kg/m² then the canopy base height must be greater than or equal to 3 meters.

Discussion

These conclusions are supported by Gray (2005) who reported potential fire effects before and after thinning treatments in Knife Creek that prescribed commercial removal of logs but not tops or unmerchantable trees. Gray (2005) indicates that thinning treatments without fuel removal substantially increased the potential fire behaviour and the difficulty of fire suppression. Thinning decreased the proportion of trees (by number) expected to be killed by a fire and reduced the probability of a crown fire by reducing stand density and increasing of canopy base height. However, fire severity and therefore ecological impacts to that study site of a post-thinning fire were expected to be much greater.

The recommendations generated by model results emphasize surface and ladder fuel reduction but, as regeneration layers contribute to fuel loading these recommendations conflict with regeneration objectives. We recommend aggregating regeneration spatially, so that small trees stand in discrete groups, without an overhead canopy into which torching would propagate.

Planning Fuel Reduction Treatments

Hirsch et al. (2001) point out that general forest management practices, implemented in a proactive and planned manner, can reduce the area burned by undesirable wildfires. Martell et al. (2004) pursue the concept further, and suggest that forest management can modify forest fuel complexes to:

- Reduce fire incidence on the landscape;
- Decrease fire spread potential; and
- Enhance fire suppression effectiveness.

The Forest Practices Board (2010) states that a CWPP is a critical first step, in order to identify priority areas for treatment and ensure that priority areas are treated first, and

Although forest managers have long recognized the ecological importance of fire, most fire management policies and practices focus on fire exclusion...

The challenge for managers is... to know where, when, and how to minimize its economic and social impacts...

Hirsch et al. (2001)

treatments fit into a strategic plan to protect a community. Fuel management treatments should be strategically arranged to:

- Take advantage of existing barriers such as agricultural developments, roads, lakes or low-fuel areas such as rocky areas, ridges and bare ground (Schmidt et al. 2008);
- Support suppression efforts (Schmidt et al. 2008, Rogers et al. 2008);
- Protect property and provide safe zones for tactical staging (Safford et al. 2009).

Community Wildfire Protection Plans for the Cariboo (Williams Lake Interface Fire Committee 2005, Dunlevy and Perry 2006, Morrow 2007, Perry 2007) provide little strategic direction on which stands to treat and in which order. Such direction is critical to achieving the best protection from limited financial resources available to support treatment operations.

Community Wildfire Protection can be approached as through forest management planning. Citing others, Zielke et al. (2010) describe good forest management as an eight-step process:

Step 1 – create terms of reference – the plan for the process.

Step 2 - defining the management area, including subdivision to clarify overlapping objectives.

Step 3 - understand the expectations: values, and associated goals.

Step 4 - understand the context for the expectations: landbase and resource analysis.

Step 5 - create a vision for the forest future: objectives, indicators, targets and management scenario analysis.

Step 6 - translate the vision to day-to-day operations – scheduling in time and space.

Step 7 - monitor, evaluate success, and adapt management.

Step 8 - communicate with landowner(s), stakeholders and others (an ongoing process)

Step 1: Creating a CWPP

CWPPs help communities to improve fire protection in interface areas (Forest Practices Board 2010). A CWPP encourages governments, land users and residents to coordinate their activities within the plan area (Williams Lake Interface Fire Committee 2005), and therefore requires the input of the community. Creating a CWPP will need a well-defined process that will be unique for each community.

Step 2: Subdividing the Landbase of the CWPP

Effective forest management requires clear objectives that are spatially explicit across the landscape. Subdividing the landbase allows us to identify units with clearly defined land management objectives. While a primary objective within the WUI will be fuel reduction, there are overlapping objectives for land management that are important to neighbours and may be legally binding. The best way to sort out the myriad of issues is to subdivide the management area into zones based upon geographic features such as roads, ridges, creeks and private property. Those spatially explicit units can then be described in terms of their multiple land management objectives. When prescriptions are set for stands within a particular zone the required silvicultural approach is clarified.

The intensity of fuel treatment should vary depending upon the proximity of stands to the values being protected. Safford et al. (2009) found that fire behaviour is modified by fuel treatments within about 40 m of entry into the treated conditions. Fuel treatment projects can be arranged in bands of decreasing intensity as distance increases from the values being protected. The Williams Lake and Area Interface Fire Committee (2005) also recommended different activities depending on proximity to values. Consistent with FireSmart principles described by Vickers (2003) we recommend the following zones from the values out into the forest (see Figure 9):

1. Adjacent to structures, on private property:
 - This zone is equivalent to zones 1 and 2 in Vickers (2003)
 - Encourage owners and developers to implement FireSmart recommendations on their property (Province of B.C. n.d.)
2. The Urban Interface Zone, adjacent to private property, public access routes or utilities: 100 m fuel treatment zone
 - 30 m fuel-free zone, where ladder fuels and surface fuels under 7.6 cm are reduced to near zero, and canopy base height is raised to at least 3 m.
 - 70 m fuel-reduced zone, where ladder fuels are retained only in canopy gaps and surface fuels under 7.6 cm are reduced to 4 kg/m² or less and widely dispersed, and canopy base height is raised to at least 3 m.
3. The Wildland Zone within a CWPP, greater than 100 m from private property, public access routes or utilities, where Forest Stewardship Plans, Woodlot Licence Plans and Community Forest Management Plans should address fuel reduction treatments (Williams Lake and Area Interface Fire Committee 2005).
4. Tactical fuel breaks, arranged throughout the landscape to take advantage of existing natural or human-caused fuel breaks, and providing tactical opportunities during fire suppression (Schmidt et al. 2008).

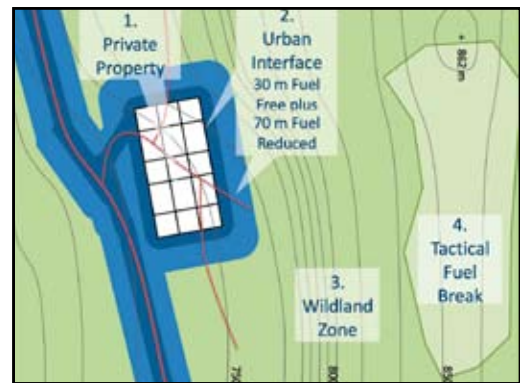


Figure 9: Fuel Reduction zones described in a fictional community. Stand treatments will vary amongst zones.

Step 3: Values In Place Within Community Wildfire Protection Plans

Citizens have an expectation that fuel reduction treatments will respect all of the values ascribed to the forests that surround their communities. These will, of course, vary from community to community, but even in small communities the values are many and often conflicting. As an example, within the WUI surrounding Williams Lake, current values include:

Public safety -- citizens expect that fuel treatment will reduce the probability of significant losses of life and property, but will also minimize the disruption to the services they are accustomed to. Furthermore, the treatments should not create hazards that decrease citizens safety.

Cultural values -- the area occupied by the present City of Williams Lake has been home to Northern Secwepemc people for millennia. Physical evidence of their living in this valley is frequently present and should be protected according to regulations and established practices. Furthermore the cultural and technological traditions of these people are tied to the landscape and forests in which we live, work and seek to treat.

Recreation trails -- trails for mountain bike riding, dirt bike and all-terrain cycle riding, horseback riding, walking, cross country running and skiing abound. User-groups utilize trails with different standards. Conflict can exist between user-groups; mountain bikers prefer a narrow single-track over wide steep trails used by dirt bikes and all-terrain cycles. Horseback riding and walking occur throughout the trail networks.

Aesthetics -- the forest surrounding our community provides the visual backdrop for every view out of the community. For many residents forests also form the principle near-ground view from their homes. Changes in those views are anticipated with resistance, and every effort should be taken to reduce the visual impact of treatments.

Wildlife Habitat -- Wildlife viewing is a popular passtime and the presence of wildlife habitat allows for this. The community is surrounded by mule deer winter range.

Biodiversity -- dead trees and coarse woody debris are an important component of the forests, providing habitat for a great diversity of life from fungi, lichens, insects, mammals, and birds. Care is necessary to avoid removing too much of this dead wood in service of the fuel reduction objective. Fuel reduction treatments will increase the diversity of plant species by reducing stand density and allowing more growing space for shrubs and forbs.

Timber -- The City of Williams Lake has been a lumber town for generations, and will continue to be so. We cannot ignore the silvicultural impact of our treatments on the value of the timber, simply because we have a different purpose for treating a stand. We expect that careful silvicultural treatments will improve the value of stands sufficiently to allow future fuel reduction treatments to be supported (at least in part) by timber revenues.

Clean Air -- There are burning restrictions imposed by several levels of bylaw and regulations, to protect human health. The net result is that burning debris is difficult within the airshed of this community.

Quiet Enjoyment -- Both the City of Williams Lake and the Cariboo Regional District have noise bylaws that will affect treatment activities.

Privacy -- People who live behind a screen of trees before treatments may find they can see neighbours they've never been able to see before.

Tresspass -- Some people living adjacent to crown land take advantage of that lack of neighbours. Fences, livestock, tree forts, play grounds, dead vehicles, buildings, yard waste and illicit crops might all be occupying land intended for treatment.

Range -- The City of Williams Lake has been a cow town longer than it has been a lumber town. Cattle grazing is a significant land-use in the wildland portions of the CWPP. Fuel reduction treatments will improve range production by reducing stand density and allowing more growing space for grasses. There is a risk that treatments will remove natural barriers to cattle movement. Cattle grazing can contribute to fuel reduction by eating off annual grass production.

Utilities -- Urban areas are served by many utilities that must be protected during operations. Electricity, telephone and cable services are carried in overhead wires that restrict falling and forwarding operations. Gas, water and sewer lines restrict forwarding operations. Paved streets, ditches and driveways, and public traffic restrict decking and loading operations.

Step 4: Landbase And Resource Analysis

Within a CWPP the landscape and forest cover combine to create an arrangement of fuel hazard classes. When those are combined with proximity to urban development and fire-fighting resources, they create a mosaic of fire hazard conditions that help to plan fuel treatments. However, overlaying the fire hazard analysis is a set of resource management objectives established by other processes.

Important resource management objectives established in the Cariboo Chilcotin Land Use Plan should be mapped within the CWPP. As examples, Ungulate Winter Range, Wildlife Habitat Areas, Old Growth Management Areas, or Visual Quality Objectives will be mapped within the WUI, and may cause a variation of the prescription for treatment. Other values important to the community should also be mapped to understand their impacts on proposed treatments.

Important resource features will exist within a CWPP, and features such as cultural and archaeological sites, stick nests, dens, mineral licks and recreation trails should be identified

on maps to the extent their presence is known. These features will affect the way treatments are accomplished and should be incorporated into spatially explicit management objectives.

Historical Stand Structures Have Changed

E.G. McDougall (1913) conducted reconnaissance surveys of the Cariboo and Lillooet Land Districts in 1913 and 1914 and provided a wonderful description of the San Jose Valley (McDougall 1913).

“The timber is distributed in belts along the sides of the main valley, and behind those belts lies the burned country, which [is] covered with a patchy Black Pine stand, from ten to fifty years [old]. The persistence of the old stands in positions so exposed to fire [must] be due to the former periodical removal of undergrowth and litter [by] light burning, and to some extent by the pasturing of horses and []. Away from those influences, the forest would come into an extremely flammable condition, and when, at longer intervals, fire did reach [them], the result would be total destruction.”

The following discussion from Day (2007a) presents a succinct discussion of changes in disturbance regimes with respect to the Knife Creek Block of the UBC Alex Fraser Research Forest, which is located within the Williams Lake and Area Interface Fire Plan.

This is a dry forest, and forest fires are a major concern. Researchers are in unanimous agreement that fire interval has increased since approximately 1900. Writing in 1955, Benteli comments that:

“It seemed as if there had been a maximum of fire occurrences in the past 50 years, with a sudden decrease in the past 20 years.”

This change coincides with settlement history in most studies, and Steele et al. (1986) attribute it to the:

- 1. cessation of aboriginal use of fire as First Nations communities were moved to reserves and reservations and use of fire was stopped by European settlers intent on protecting buildings, livestock and timber;*
- 2. beginning of organized wildfire suppression; and*
- 3. unregulated grazing by livestock which reduced fuel loads.*

In a study on the Knife Creek block, Daniels et al. (1995) found that two stands in the IDFdk3 demonstrate a pre-settlement fire interval of 16.6 to 18.0 years, which ceased in 1915. Parminter (1978) found, in his study nearby at Riske Creek (in the IDF biogeoclimatic zone⁵), a fire interval of 9.8 years, which ceased in 1926. Further work in the IDFdk3 by Feller and Klinka (1998) and Iversen et al. (2002) indicates that mean fire intervals have been extended in the last century.

There is little doubt that cessation of natural fires has led to significant changes in stands and forests. Parminter (1978), Kilgore (1981), and Arno (1991) all conclude that cessation of fires in uneven-aged forests has resulted in an increase in the proportion of smaller stems. Iversen et al. (2002) conclude that these changes have resulted in increased densities of saplings, reduced diversity and abundance of understory vegetation, increased forest floor and standing fuels, and increasing fire severity when fires do start.

The change in fire regime and stand structure has significant implications:

- a community of species adapted to the ecosystem is displaced;*
- accumulation of fuel and changes in fuel structure create a much higher risk of crown fire;*
- crown fire would have a catastrophic effect on the mule deer winter range, and could potentially cause significant property loss to adjacent private-land owners.*

The dominant disturbance regime in these forests was stand-maintaining fire. Higher severity fires tended to develop stands with higher components of lodgepole pine and aspen in the dry cool subzones of the IDF. Grasslands were a frequent component of the natural landscape.

⁵ Parminter classified the area as the Cariboo Aspen Lodgepole Pine zone after Krajina. This area has now been included in the IDF (Hope et al. 1991).

Current Stand Structures

Within the Interior Douglas-fir biogeoclimatic zone in the Cariboo, we have two broad classes of stand structures, being uneven-aged stands with Douglas-fir leading, or even-aged stands with lodgepole pine leading. There are, of course, many intergrading conditions. Farnden et al. (2003) classified 17 different stand structural conditions, of which eight were uneven-aged and Douglas-fir dominated, while 11 were even-aged lodgepole pine dominated.

Stands develop from their present structure to a future condition depending upon growth and disturbance, and there are myriad pathways from present to future structures. Growth continues and competition between plants intensifies, until disturbance releases growing space. Survivors rapidly respond by both growing and regenerating themselves (Oliver and Larson 1996).

We presume that stands which are presently even-aged and dominated by lodgepole pine can eventually be uneven-aged and dominated by Douglas-fir, given:

- Appropriate disturbances;
- Sufficient overstory shelter to protect young Douglas-fir trees from growing season frost; and
- Sufficient time to allow new generations of trees to grow.

Even-Aged Lodgepole Pine Stands

Since the middle of the 1990s we have experienced unprecedented levels of mortality in lodgepole pine caused by mountain pine beetle. Nearly all of the pine trees over 40 years of age have been killed, and many of the younger trees down to 10 cm DBH have also been killed by bark beetles. These dead trees provide a great deal of standing fuel at the present time, and an increasing surface fuel load in the near future as the trees die and fall to the ground. Residual stands will typically be composed of Douglas-fir, aspen and spruce from the overstory, plus Douglas-fir, lodgepole pine and spruce from the understory, and a well-developed shrub and forb community. Since the original stand was a mosaic of species composition, the post-beetle stand will also be a mosaic of open space and forested conditions.

Uneven-Aged Douglas-fir Stands

Uneven-aged Douglas-fir stands generally contain minor components of lodgepole pine, aspen, spruce, and occasional birch and cottonwood. The understory densities are very high, leading to a stand dominated by tall and slender Douglas-fir trees that have not attained sawlog dimensions. This understory provides a low canopy base height and close crowns, providing significant risk of crown fires.

Hot and dry slopes often contain a significant component of Rocky Mountain juniper and a shrub layer of common juniper. Both juniper species are highly flammable and are likely much more frequent now than they would have been in the historic stand conditions. Juniper provides significant risk of fire brands, and the shade-tolerant nature and spreading but upright growth habit make Rocky Mountain juniper a significant ladder fuel. However, juniper (particularly Rocky Mountain juniper) is culturally important and relatively rare regionally.

Large dead trees in the overstory are frequent, caused by recurring outbreaks of Douglas-fir bark beetle. These large dead trees are important for a wide range of biodiversity and wildlife values, and are long-lasting in the ecosystem. However, they also present a risk of firebrands if they burn. In recent years an outbreak of spruce budworm has caused significant mortality and top dieback in both overstory and understory trees. Over-topped understory trees are likely to be heavily defoliated for several years, and mortality in the understory is now high. Early indications are that the budworm populations are collapsing in some areas, and we may see improvement in the quality of the understory over the next few years.

The tall slender nature of much of the stand volume means that ice and snow damage are frequent. A significant ice and snow event in December 2008 damaged significant areas of uneven-aged Douglas-fir stands in the area around Williams Lake, leaving stands tangled and broken over sizable patches within stands.

Step 5: A Vision For The Future Wildland Forest

Long Range Stand Structure Targets for Wildland Fuel Treatments

We have a vision for the Wildland stands within the IDF of the Williams Lake Timber Supply Area. Douglas-fir is the species most resilient to fire because of its thick bark. Since Douglas-fir trees are more resilient to fire than other species, our target stand structure for WUI stands is uneven-aged Douglas-fir with components of aspen, lodgepole pine and spruce, and inclusions of grassland and open forest. We recognize that this vision will take many years to fully implement, but we believe it can be achieved with patience and careful silvicultural practise. The elements of our vision are:

1. Stands are dominated by Douglas-fir, but contain significant components of aspen that are clumps sufficiently large to create a forest floor dominated by deciduous litterfall. Rocky Mountain juniper is maintained as a frequent component of the stand in those ecosystems where it occurs naturally.
2. Most trees have present or potential value for forest products, and the timber produced from these stands will be highly desirable for wood products.
3. Trees are growing in even-aged cohorts that are approximately 300-500 m² in area (up to one tree-length across).
4. Mid-diameter (DBH) cohorts are sufficiently dense to suppress the understory vegetation, but large diameter cohorts are open with grass-dominated understory.
5. Large diameter cohorts have a minimum of 3 individuals on 300 m².
6. Open grass and shrub-dominated areas form up to 10% of the area within a stand, and trees gradually regenerate naturally to occupy those areas.
7. Stands are dominated by large trees with maximum tree diameter between 60 and 70 cm DBH, although larger trees can be reserved for habitat and biodiversity purposes.
8. Minimum average stand density after thinning is between 16 and 22 m²/ha. That density is distributed on 350 to 400 stems/ha over 7.5 cm DBH. Minimum density will vary depending upon site quality and management objectives applicable to the particular site. Lower densities will make more open stand conditions with greater understory productivity and higher diameter growth rates. Higher densities will make a more closed stand with lower shrub and forb biomass and lower productivity of regeneration. Higher minimum density implies more frequent harvest entries, to ensure sufficient growing space for younger cohorts.
9. Surface fuel loading is generally less than 4 kg/m² but in all cases less than 8 kg/m². The majority of that surface fuel is in pieces larger than 15 cm lying flat on the ground and discontinuous.
10. Canopy base height is always more than 2 m, and generally more than 3 m. In areas of conifer regeneration, live branches will be pruned to 3 m or half of the live crown depth, whichever is less.

Wildland Stands within Mule Deer Winter Range

The Province of B.C. (2007) has provided General Wildlife Measures that have the force of regulation and apply to Wildland stands within identified mule deer winter ranges. The General Wildlife Measures provide specific recommendations that will limit prescribed post-treatment stand

density. Each mule deer winter range has been mapped according to habitat class objective. Our vision for Wildland stand structure (above) is consistent with those measures for Low or Moderate Habitat Class objectives. Table 2 shows the minimum basal area and distribution of basal area amongst size classes for mule deer winter range depending upon habitat class objective.

Table 2: Residual basal area targets for stands in established mule deer winter ranges. Note that these targets stipulate both total and large-tree basal area. Copied from Dawson and Armleder (2000).

Habitat Class	Biogeoclimatic Unit	Minimum Residual Basal Area Immediately Post Harvest		Other Criteria Applicable to All IDF Zone Mule Deer Winter Range Prescriptions
		Total Basal Area ≥ 12.5 cm. (m ² /ha)	Basal Area in stems ≥ 37.5 cm. (m ² /ha)	
Low	IDFxm and IDFdk3	≥ 16	≥ 6	• Create canopy gaps 0.3-1 tree height, averaging 0.5 • Minimize residual damage
Moderate	IDFxm (A)	≥ 22	≥ 8	• Harvest non-Douglas-fir species first
	IDFxm (B)	≥ 22	≥ 11	• Maintain clumpy stem distribution
	IDFdk3	≥ 22	≥ 11	• Distribute harvest in relation to micro-topography
High	IDFxm	≥ 27	≥ 15	• Maintain or promote multi-storied stands
	IDFdk3	≥ 29	≥ 16	
Note: Special recommendations are provided for warm, steep slopes in the IDFxm because these sites are common and because good habitat management will require that some of them be managed as moderate crown closure habitat even though they may not be capable of being managed with a residual large tree basal area of 11 m ² /ha. Warm slopes >60% will only have the capability to produce low crown closure habitat.				

Where High Habitat Class is mapped within WUI, there is a conflict between the mule deer winter range plan and the long-range stand structure targets for Wildland stands described above. Since the General Wildlife Measures have the force of regulation, the fuel reduction treatments must accommodate the higher stand density required by the mule deer habitat objective on those sites. This has the following implications:

- The high stand density will result in increased competition, reducing overall stand vigour and reducing taper, making losses to windthrow and snow or ice breakage more prevalent;
- A dense canopy will result in increased litter (branches) accumulating as surface fuels through wind abrasion between crowns (a management objective of mule deer winter range); and
- More of the stand area will be occupied by mid-sized and large trees, with less area in the forb-shrub and regeneration communities.

As a result, more frequent fuel reduction treatments will be necessary in areas with high habitat objectives to maintain surface fuels at low levels. Significantly, many high-habitat-class areas have been designated as Old Growth Management Areas (OGMAs) where timber harvesting is limited and accumulations of dead wood are a desired outcome.

Silvicultural Approach for Wildland Fuel Reduction Treatments

Uneven-aged management is traditionally approached by one of three methods:

- Single Tree Selection systems that prescribe a mathematical distribution of tree diameters to regulate stand structure (e.g. Day 1998a);
- Group selection systems (e.g. Smith et al. 1997); or
- Irregular shelterwoods forming a two-aged stand (e.g. Matthews 1991).

Each of these systems have both challenges and merits with respect to the objective of maintaining low surface fuels and minimizing ladder fuels. The basic problem is that they represent “inside the box” thinking to address a very complicated problem. Tappeiner et al (2007) have reminded us that silvicultural systems are not unique and unrelated methods, but a spectrum of overlapping approaches. Puettman et al. (2009) advocate managing complex stands for non-timber objectives by setting aside the traditions of silvicultural practices and “managing forest[s] as complex adaptive systems.”

Graham and Jain (2005) described their use of a silvicultural approach they call “Free Selection” that they successfully applied to complex conifer stands with fuel reduction objectives in Idaho. This is a multi-entry uneven-aged system suited to maintaining high cover and variable composition and structure. It allows the practitioner the freedom to vary the pattern of cutting in consideration of the quality of the existing trees, their health status, and their contribution towards the management objectives. In their lexicon, Graham and Jain (2005) use the word “free” to imply that the frequency, kind, and intensity of treatments are dependant on the development of the stand. Instead of describing the rules of the treatment (as in single-tree selection systems) the manager sets out the post-treatment conditions required, the long-term objectives that are pursued, and the triggers that indicate that a treatment is required.

The Free Selection system described by Graham and Jain (2005) seems to mesh well with other authors cited above. More-over, it appeals to us in that it is objective-driven and it allows us to explicitly recognize the variability that makes the rigid application of the single-tree selection method so difficult in the dry Douglas-fir forests.

The application of the Free Selection system may conflict with the General Wildlife Measures (Province of B.C. 2007) in terms of the frequency of entries. Province of B.C. (2007) requires that “forest practices involving the clumpy single tree selection method of Douglas-fir harvesting over a series of passes will result in a minimum cutting cycle of 30 years or greater.” It is our opinion that this re-entry cycle will result in levels of ladder fuels and surface fuels that are incompatible with the fuel management objectives within a CWPP.

Post Treatment Target Stand Structure

Each entry into a Wildland stand will be a step towards the long-term target condition. The post-treatment condition will be more strongly influenced by the pre-treatment condition than the long-term vision. A site plan, prepared by forest professionals, is an important and required step to ensuring that the treatment contemplates all the values in place, and sets out a sensible step towards achieving the long-term vision while respecting current values.

Even-Aged Lodgepole Pine Stands

Stands currently dominated by lodgepole pine will be quite open after treatment, as the majority of dead pine will be removed. Overstory Douglas-fir, spruce, and aspen may be quite exposed to damage by wind after the removal of the pine. Understory live pine will be tall and slender and may have significant disease or insect damage. Poorly formed or damaged understory pine should be cut during the treatment. Understory Douglas-fir and spruce may be quite tall and slender, but are now in the process of improving their height-to-diameter ratio and becoming more mechanically stable, since the death of the pine overstory has released growing space to them. Shrubs and forbs will be dominant in the understory and may create regeneration difficulties. Aspen clumps will regenerate

vigorously after treatment, and aspen should be an important component of the post-treatment stand. The aspen will, over time, provide suitable nurse-crop conditions to support Douglas-fir regeneration. Preferred species for regeneration include aspen and Douglas-fir, and suitable species include lodgepole pine and spruce. Post-treatment stand conditions will maintain the social values that apply to the stand before treatment.

Uneven-Aged Douglas-fir Stands

Stands currently dominated by uneven-aged Douglas-fir will generally remain quite closed, with relatively high density of mid-sized trees remaining. This is because much of the stand density before harvest is concentrated in the size classes between 12.5 and 30 cm DBH. For trees less than 12.5 cm DBH, inter-tree distance between trees will vary by tree size within a cohort. Trees greater than 12.5 cm DBH should be managed by residual Basal Area, such that the basal area of the stand does not fall below the lower stocking limit shown in Figure 10.

Post-Treatment Fuel Conditions

Understory fuels will be reduced by treatment, either by removing fuels to roadside for bioenergy, or by burning on site (either broadcast or after piling) where smoke control regulations allow. Chipping and distributing the material on site is also a useful treatment to increase the decay rate of surface fuels, but does not actually remove the fuel from the site. Chipped fuel in contact with the ground stays moist longer, but is still available for ignition sites and slow but intense fires at the soil surface. Based on fuel modelling (see Appendix 1) we recommend the following fuel reduction actions:

- To create stand resilience or fuel break conditions, maintain surface fuel loadings below 4 kg/m²;
- At surface fuel loading less than 4 kg/m²:
 1. Where the tolerance for risk is moderate (e.g. not within close proximity to infrastructure or other values at risk), the canopy base height should be greater than or equal to 2 meters.
 2. Where the tolerance for risk is low (e.g. within close proximity to infrastructure or other values at risk), the canopy base height should be greater than or equal to 3 meters.
- Surface fuel loadings should never exceed 8 kg/m². If surface fuels are between 4-8 kg/m² then the crown based height must be greater than or equal to 3 metres.

Step 6: Scheduling Fuel Treatments In Time And Space

The CWPP should set out a clear framework that allows each stand to be assessed a priority for treatment. This priority will consider the fire hazard conditions assessed in Step 4, the cost of treatment, and the potential of achieving the target conditions described in Step 5. These priorities should guide the allocation of scarce funding to carry out projects.

Step 7: Monitoring Progress Towards Target Stand Conditions

Day (1998b) calibrated a Gingrich Stocking Chart (Ginrich 1967) for the IDFdk3 subzone at the Knife Creek Block of the Alex Fraser Research Forest, following methods described by Gingrich (1967) and Ernst and Knapp (1985). Gingrich stocking charts are a means of examining the density of a stand with regard to the range of acceptable stocking, with an upper limit describing the onset of competition-induced mortality, and a lower limit at which a stand is understocked by trees. The chart shown at Figure 10 could be used to describe the pre-treatment stocking status of the stand, and compare it to the long-range target stocking. Notations made on the chart before and after each entry can track the progress towards the target. Figure 10 shows stocking targets for high, medium and low habitat classes for mule deer winter range in the IDFdk3, based upon BDq regulation (Day 2007a).

Gingrich Chart IDF Knife Creek

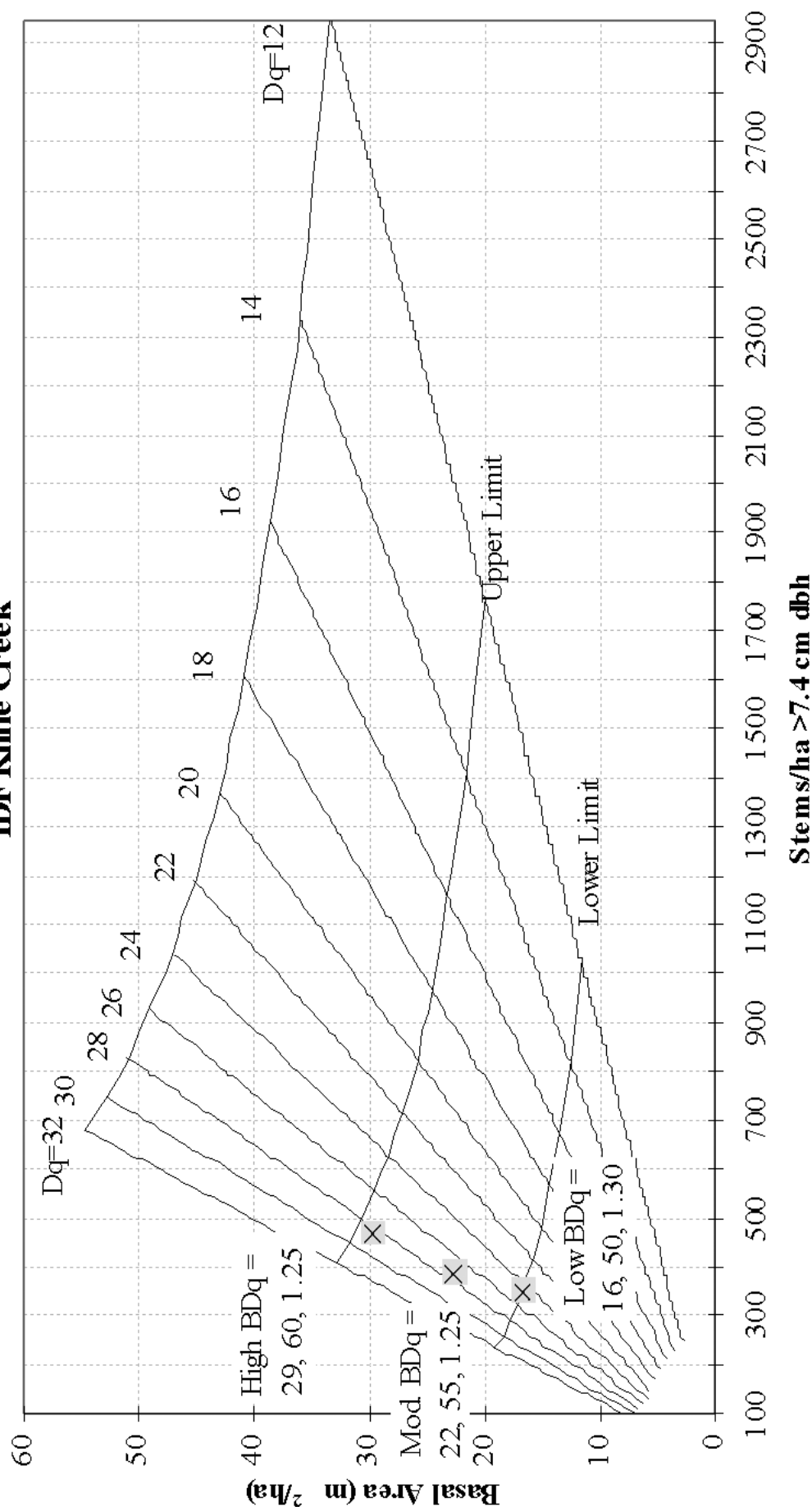


Figure 10: A Gingrich Stocking Chart calibrated for the IDF Knife Creek Block of the UBC Alex Fraser Research Forest (adapted from Day 1998). The Upper and lower limits represent the management zone for Douglas-fir stands, and within that zone the trees will occupy the site but will not be suffering competition-induced mortality. Dq represents the quadratic mean diameter of the stand, which is the diameter of the tree of mean basal area. High BDq, Med. BDq and Low BDq represent the stocking of a stand with a high, medium, or low habitat objective for mule deer winter range, as described by the Province of BC (2007), using the noted parameters of Basal Area, maximum Diameter, and diminution quotient described in Day (2007a).

PART 3: IMPLEMENTATION AND COSTS

Case Studies

Over the past decade in the Williams Lake area, we have been implementing projects that provide directly relevant implementation and cost experience. These are described as a series of case studies below.

1: Block 217 Knife Creek Fuel Reduction

Proponent: UBC Alex Fraser Research Forest

Funding: Union of BC Municipalities Pilot Project

Report: <http://fire.feric.ca/36112001/AdvantageVol9No4.pdf>;
<http://www.forestry.ubc.ca/resfor/afrr/Fuel%20Reduction%20Block%20217%20RP%2005-17%202006.pdfDescription>

Description

Block 217 is a narrow strip of land between the urban interface at the west boundary of the Knife Creek Block and the Big Meadow Road, the primary access road into the Research Forest. The block has a gross area of 4.3 hectares and a net area of 3.8 hectares excluding roads. The ecosystem is a circa-mesic site within the Interior Douglas-fir (IDFxm). The site is used extensively by neighbours for bike riding, walking, dirt biking, and horseback riding. The area was previously pre-commercially thinned in 1994 for reduction of fuel ladders.

The area was harvested by hand-falling and line skidders during winter months in 2006. All felled trees, including those that were non-commercial in size, were forwarded to landings where merchantable logs were processed for sale and debris was burned. Total merchantable logs sold from the operation was 58.7 m³ (15.5 m³/ha) which was less than the original plan called for, as a result of input from immediate neighbours.

Pruning was conducted by breaking dead branches to 3 m height. Surface fuels remaining after skidding were piled by hand and burned, with subsequent re-piling and re-burning. Actual project costs are summarized in Table 3.

Table 3: Activity cost summary from fuel reduction treatment at Block 217, adapted from Day and Mitchell (2006).

Function	Activity	Cost/ha	Total Cost/ha
Planning	Community	\$375.79	
	Marking	\$212.00	
	Prescription	\$115.82	
	Planning Total		\$703.61
Log&Pile	Brokerage, Stumpage	\$25.88	
	Falling	\$546.05	
	Piling	\$631.58	
	Skidding	\$1,425.99	
	Supervision	\$110.53	
	Timber Receipts	(\$733.82)	
	Trucking	\$197.32	
	Log&Pile Total		\$2,203.53
Burn and Re-pile	Manual light, re-pile, re-light	\$467.63	
	Machine re-pile	\$59.21	
	Burn and Re-pile Total		\$526.84
Grand Total			\$3,433.98



Figure 11: Photos from Block 217 clockwise from upper left: Pre-harvest stand condition with trees marked for removal; Felled and awaiting skidding; Contractor Rolf Scheutze with ATV with skidding arch, used for skidding non-merchantable trees; Hand piles burned on-site; sawlogs loaded out by self-loading truck. (Copied from Day and Mitchell 2006).

2. Block 224, Knife Creek Grassland Restoration

Proponent: UBC Alex Fraser Research Forest

Funding: UBC and Grassland Conservation Council

Report: Koot, C. 2008. Grassland Benchmark Restoration at the Knife Creek Block: RP #07-14 Implementation Report. Unpub. Cont. Rep. UBC Alex Fraser Research Forest.

Description

The Knife Creek Block of the UBC Alex Fraser Research Forest (AFRF) contains 4.14 gross hectares of Grassland Benchmark. A net area of 3.75 ha was developed (including Wildlife Tree Patch), with forest encroachment removed from 2.5 ha. Grassland restoration for this site was identified in the AFRF Management and Working Plan #3 (2007) pending financial feasibility. In October 2007, Harry Jennings, Team Leader for the Ecosystem Restoration Team, Cariboo-Chilcotin Range Branch, Ministry of Forests and Range approached AFRF about completing a tree removal

phase in early 2008. The area was felled by hand, with 220 m³ of logs forwarded to a landing by line skidder. Non-commercial trees and debris were accumulated with a tracked log-loader and removed to a landing by a forwarder. Final debris removal was accomplished by a farm tractor and trailer with manual and tractor loading. The site was broadcast burned the following spring. 1375 loose cubic metres of landing debris was ground and producing 130 Green Metric tonnes (80 Oven Dry tonnes) of ground material trucked to the bio-energy plant. Treatment costs are shown in Table 4.

Table 4: Costs per hectare for grassland restoration operations over net 3.75 ha at Knife Creek

Operation	Cost /ha
Planning, Layout, Admin and Supervision	\$1,012*
Logging, Skidding, Bucking, Loading	\$3,120
Debris Removal: Loader/Forwarder	\$1,008
Debris Removal: Tractor/Trailer/Manual	\$616
Trucking, Stumpage, Brokerage	\$538
Debris Burning (to be done in next phase)	N/A
Controlled Burn of Site (not incl. Unit Crew)	\$1,331
Subtotal Operational Costs per Hectare	\$7,625
Log Revenues	-\$2,772
Total Operational Costs per Hectare	\$4,853

*These costs are proportionately high due to the small area of the block. These are fixed planning costs that would average out much lower per hectare on a larger sized block.



Figure 12: Block 224 grassland restoration at Knife Creek, clockwise from top left: Handfelling; line skidder to landings on trails planned to avoid large woody debris; 220 m³ of logs of good quality were recovered; 1,375 loose m3 of debris were piled at the landing; log loader accumulated debris; forwarder carried debris to landing pile.

3. Williams Lake Municipal Airport

Proponent: City of Williams Lake

Funding: Natural Resources Canada

Report: Day, K., D. Skea and B. Carruthers. 2009. Mitigating the Effects of Mountain Pine Beetle on Wildfire Hazard within the City of Williams Lake. Unpub. Cont. Rep. UBC Alex Fraser Research Forest.

Description

In the winter of 2009, 9.4 hectares of a bark beetle-affected stand was treated to reduce the risk of fire at the Williams Lake Municipal Airport. The *Williams Lake and Area Interface Fire Plan* deems the municipal airport to be a critical spot because it is the location of the Cariboo Fire Centre and the Air Operations base for fire fighting. The fuel reduction project was undertaken by the City of Williams Lake, with funding from Natural Resources Canada Mountain Pine Beetle Program. The project resulted in 1,613 Green Metric tonnes of potential fuel being cut for disposal. Due to the sensitivity of air operations and environmental benefits, the trees cut during from this project were piled at roadside for removal as biomass to local industrial users.

The stand being treated was significantly affected by mountain pine beetle and snow press. Two approaches were tried: handfelling and line skidding with small skidder and ATV with a skidding arch; and single-grip harvester and forwarder. Handfelling was extremely slow due to heavy snow loads, and many trees were under significant tension. Harvester and forwarder was much more successful, but still very slow. Debris was forwarded to a landing for grinding and removal to the bioenergy plant, with no operational cost attributed to the cost of this project. Pruning to 3 m height or more was completed with the harvester head on residual trees.

Due to constraints of the funding agreement, no logs were merchandized from this operation. Instead all the debris went as biomass, ground on site. The project did bear some implementation costs for the grinding and trucking logistics. This was a first effort with fuel reduction for the harvester/forwarder contractor, and production was slow as a result. Costs for the treatment are shown in Table 5. Costs for Planning and Prescriptions reflects only operational planning, since the site plan for the whole property was established under separate funding.

Table 5: Treatment cost for 9.4 ha of fuel reduction at the Williams Lake Municipal Airport in 2009.

Data	Total	Cost/ha
Planning / Prescriptions	\$ 7,167	\$ 762
Falling, Forwarding, Stacking	\$ 69,519	\$ 7,396
Supervision and Contract Admin	\$ 10,941	\$ 1,164
Communication	\$ 1,974	\$ 210
Total	\$ 89,600	\$ 9,532

A second year of treatment at the Williams Lake Municipal Airport is just finishing as this report is written, and it appears that treatment costs have improved significantly. The same contractor and operational approach has been used, and all-found costs experienced in our second year have fallen to \$ 6,209/ha.



Figure 13: Williams Lake Municipal Airport fuel reduction in 2009, when 9.4 ha were treated. Clockwise from top left: Rolf Scheutze unhooks a turn from ATV with skidding arch; Nilsson Select Contracting with a forwarder-load of debris for stacking at landing; Nilsson Select Contracting harvester falling dead pine and damaged understory Douglas-fir; Pat Huska's grinder starting work on piled debris.

4. Anderson Road Fuel Break Treatment

Proponent: Tolko Industries Ltd.

Funding: UBCM Pilot Project

Report: Meisner, S. 2006. Report on pile and burn treatment FLA20018 CP 207. Unpub. File Rep. Tolko Industries Ltd.

Piling was conducted in October and November, 2006, on 13.3 ha after harvesting by a feller-buncher and grapple skidder. Piling was conducted by an excavator with a clean-up bucket and a forestry thumb. Fuels treated included recent activity fuels and pre-existing surface fuels, and some advanced regeneration too small for felling in the logging phase. Piling cost averaged \$912/ha, but ranged from \$503/ha to \$1,695/ha, with the most expensive part being the first unit with an inexperienced operator. Piles were subsequently burned in the fall using a drip torch on foot, but the burning costs are not available.

5. District of Elkford Fuel Reduction - Mechanical Treatments

Proponent: B.A. Blackwell & Associates Ltd. And Apex Fire Services

Funding: UBCM

Report: District of Elkford, BA Blackwell and Associates Ltd. 2009. 2009 Operational Fuel Treatment for the District of Elkford. Prepared for: Union of BC Municipalities and Ministry of Forests and Range.

Description

In 2009 fuel treatments were implemented on Crown and Municipal Land within the District of Elkford covering a total area of 21.0 ha. The treatment area was comprised of fourteen treatment units throughout the district, all of which were within the Montane Spruce dry cool biogeoclimatic subzone (MSdk) and on zonal (01) site series. Pre-treatment density in the highest risk stands was estimated to be as high as 8,000 stems/ha. Generally, the stands were in the pole-sapling stage of development, crowns were interlocking, branches reached to the ground, and tree heights were greater than 3 metres. Surface fuel loadings were all below 5 kg/m².

The treatments included thinning, pruning, and overstory removal. The prescription targeted removal of smaller trees in the understory and sub-canopy to reduce density and fuel loads. Lodgepole pine and hazard trees were targeted for removal from the overstory, with other species thinned if densities would otherwise be above post-treatment density targets. Larger diameter, non-pine trees were prioritized for retention.

Operations spanned 9 weeks between September 20, 2009 and November 19, 2009. Apex Fire Services ran crews of 4 – 7 members with one certified faller per crew. Falling operations were completed almost entirely with a fellerbuncher, except for some handfelling that was required in close proximity to homes and in areas of high risk. In areas adjacent to hydro distribution lines, a utility arborist was on site during operations. The timber was grapple skidded and decked in a central location. Final site treatments were done by hand with rakes, pruning shears, and small burn piles where necessary. Trees were pruned to 3 metres, where specified in the prescription.

Table 6: Total fuel reduction costs for 21.0 ha in the District of Elkford in 2009.

Description	Cost/ha
Operational Fuel Treatments	\$ 12,800
Project Planning and Management	\$ 864
Terrain Stability Assessment	\$ 198
Badger Assessment	\$ 334
Total	\$ 14,196



Figure 14: Pre (left) and post treatment (right) photos from the Elkford fuel treatments in 2009.

6. Mt. Currie Fuel Reduction - Hand Treatments

Proponent: B.A. Blackwell & Associates Ltd.

Funding: Natural Resources Canada, Canadian Forest Service - MPBP First Nations Element

Report: None

Description

In 2009 fuel reduction treatments were carried out in three units in the Mount Currie Indian Reserve #6. The total treatment area was 13.2 ha. All treatment units were within the Interior Douglas Fir wet warm biogeoclimatic subzone (IDFww). Fuel reduction treatments included tree removal to a residual stand density of 400-500 trees/ha, pruning to an average height of 5 m, and piling and burning or chipping of roadside materials. All treatments were carried out by hand by local

residents. Piling was the most expensive component of the treatments as the amount of debris generated by dense stands requires extensive and arduous manual labour.

Table 7: Total Costs for fuel reduction treatments on 13.2 ha in Mt. Currie IR 6 completed in 2009.

Treatment	Cost/ha
Pile and Burn	\$ 2,113
Falling*	\$ 1,810
Pruning	\$ 2,073
Total	\$ 5,999
	Cost/km
Roadside Chipping	\$ 9,037

* Falling costs include danger tree assessment and falling.



Figure 15: Mt. Currie IR 6, clockwise from top left: pre-treatment stand condition; example of surface fuel reduction; example after thinning, pruning and burning.

Operational Questionnaire and Responses

In February 2010, a set of open questions was posed to thirty individuals selected from local contractors, local Woodlot and Major Licensees, provincial consultants and Fuel Management Specialists with the Ministry of Forests and Range. Twenty responses were received, and their responses have been summarized below.

Questionnaire Context

Suppose that you are treating a cutblock in the Wildland Urban Interface.

- The stand is a multi-layered Douglas-fir stand with dead lodgepole pine included.

- Assume that you are more than 100 m from private property.
- You have the objective of reducing stand density; you can cut commercial trees for sale.
- You cannot add to the surface fuels on the ground, and should work to remove any sound surface fuel.
- Your objective is to thin the stand from below, removing the ladder fuels and raising the crowns of the residual trees to at least 2 metres and preferably 3 metres.
- You will leave a stocked stand of the largest and best-formed trees.

Based upon your experience, how would you go about that?

Question 1: What Logging System Would You Use?

- Many respondents answered that the appropriate logging system depends upon the nature of the terrain and stand being treated, particularly the ratio of merchantable to non-merchantable trees being cut.
- Trails should be laid out in before logging to ensure retention of a healthy component of the understory.
- There is a clear desire to use small equipment, to minimize the amount of trail created and match the size of the wood being cut.
- Feller-buncher/grapple skidders were favored by most.
- Feller-bunchers have the advantage of cutting understory fuel efficiently, but present a greater risk to residual trees and cannot selectively thin understory trees.
- Hand falling with a line skidder is suitable only if a small portion of the trees being cut are of commercial size and the balance will be hand-piled or hoe-piled for burning on site.
- Three respondents indicated that single-grip harvesters with a multi-stem felling head and a long felling boom coupled with a forwarder would make a suitable system.
- Many respondents suggested ATVs with skidding arches or winches to skid non-commercial stems to a central landing, or to main trails for removal by grapple skidders.
- One respondent suggested an excavator with a power grapple and a cut-off saw is helpful for piling debris at roadside.
- In general, respondents want to remove the whole tree to the landing during the skidding phase to gain the efficiency of piling debris at the landing, but some note the inherent conflict between whole-tree skidding and quality and density of the residual stand.

"... the experience and integrity of the supervision and machine operators has a large impact on the ... success of any fuel mitigation project."

Question 2: How would you manage the surface fuel?

a) the new fuel resulting from your activities?

b) the existing fuel on the ground before you start?

- All respondents indicated that the new fuel and the fuel existing before thinning should be treated together.
- Retain a prescribed amount of coarse woody debris for ecological values. Retain old coarse woody debris on site.
- Minimize addition of new fuels by whole-tree skidding.
- If there is a market for the biomass, pile the material for removal to roadside with ATV, grapple skidder, or forwarder.
- If there isn't a market for the biomass,

"Hand piling and proper open burning should be your first option whenever possible, it is the least intrusive and most cost effective method of treatment."

1. Buck and pile on site in canopy gaps for burning.
2. Chip and disperse on site, or chip and disperse green material in combination with piling and burning dry material.
3. Masticate (grind) the fuel on site using an excavator-mounted grinder, then follow with a prescribed burn.
4. Use a small excavator to handle larger debris, ground crew to add smaller fuels to piles for burning.
5. Burning on site is the least expensive method. Chipping will multiply the total cost by 1.5, while removing to an air-curtain burner will double the cost.

Question 3: How would you carry out the pruning?

- Hand crews can break dead branches off with a hand tool or a sturdy stick, and cut large dead or green branches with pruning tools.
- Pruning height is measured to the part of the limb closest to the ground -- perhaps the branch tip.
- Pruning height should be higher on sloping ground.
- Chainsaws are preferred by some because of their efficiency, but others suggest only hand-tools should be used to ensure that branches are cut flush without wounds to the tree.
- “Raking” the residual trees with other trees during falling can complete much of the pruning.
- A single-grip harvester head can mechanically prune residual trees during the falling and processing.
- Establish damage allowances in the site plan -- allowable scarring, length of pruned branch stub, etc.
- Consider if the thinning treatment has increased canopy base height sufficiently without pruning.

“This is a huge cost driver for the treatment...”

Question 4: How would you dispose of the resulting debris?

- Merchandize anything you can find a market for.
- Sell debris as hog fuel.
 1. Forward to roadside bins for transport to power plant.
 2. Grind/Chip on site and haul away for hog fuel.
- Pile and burn debris at roadside.
- Pile and burn in canopy gaps.

Question 5: Could you see an opportunity to carry out this treatment funded only on the value of the timber?

If not, how would you structure the government program that would support your work?

- Unanimous agreement from all respondents that there is little chance a fuel reduction treatment could be properly conducted based on the value of the timber alone, given the present market.
- Several respondents suggested that a bid proposal system would allow contractors to pull volume that they can sell, and treat the stand at a net cost. One respondent suggests that a well-described target condition for the stand after treatment would allow a contractor to use whatever novel approaches make economical sense at a given time. Another respondent is using this approach:

1. Contractors tender with the understanding that they will contribute the margin from the log sales to the project.
 2. Contractors hire workers who qualify under Job Opportunity criteria to deal with the fuel treatment component.
- Another respondent suggested that the WUI be withdrawn from the working forest to be operated under unique objectives and standards, allowing more flexible approaches to tenure and obligations.
 - Wood can be decked and auctioned by B.C. Timber Sales, with the proceeds of the sale covering the cost of extracting the decked logs.

"Given that we are thinning from below removing the low-value fibre, I cannot see this [as being] viable given our current economic situation."

"We have not yet done a project that had no funding and was totally dependent on the revenues from the targeted fibre."

"In general, our experience has been that these projects need some form of funding in order for the prescription to succeed and reputable ... contractors to remain in business."

PART 4: BEST PRACTICES FOR WILDLAND FUEL TREATMENTS WITHIN COMMUNITY WILDFIRE PROTECTION PLANS

Recommendation #1: Revisit CWPPs To Provide Strategic Direction To Support Fire Suppression Efforts And Minimize Risk

An overall tactical plan for the CWPP area should be created, and then supported by an operational plan that puts treatment units into an optimal arrangement across the landscape and through time.

Recommendation #2: Incorporate Principles Of Fire Resistance Into Forest Management

Agee and Skinner (2005) summarize the basic principles of forest fuel reduction in their seminal article.

- Not every forest is a candidate for treatment -- concentrate in forests that have long dry seasons and easily combusted forest floors.
- Develop context of place to assess risk and hazard. Dry site series in dry ecosystems with important values should receive highest priority for treatment.
- Treat to maintain resilience of post-fire stands:
 1. Reduce surface fuels to reduce potential flame length;
 2. Increase canopy base height to reduce torching of overstory trees;
 3. Decrease crown density to make crown-to-crown spread less probable and reduce crown fire potential;
 4. Keep big trees of fire-resistant species to reduce mortality.
- Manage for fire resistance and resilience in all forest management decision-making by considering the implications of the following activities (Hirsch et al. 2001):
 1. Stocking standards
 2. Reforestation
 3. Brushing and pre-commercial thinning
 4. Harvesting
 5. Road maintenance

Recommendation #3: Improve The Quality And Value Of The Stand At Each Entry

We are managing fuel as a first priority, but we are also managing timber values. Our efforts to reduce fuels and manage the myriad of social objectives applied to a stand should not preclude improving the value of the growing stock. Improvements to timber values may allow future timber revenues to contribute to future fuel reduction treatments, and we should not consign future managers to a poorer financial prospect than we currently face. Employ good silvicultural techniques throughout all operations to protect and improve timber values.

Recommendation #4: Treat Wildland Stands By Thinning both Commercial and Precommercial Components

Thinning from below decreases stand density and increases canopy base height, which both decrease the probability of torching and crown fire. Thinning of non-commercial trees significantly reduces ladder fuel density, and improves the resilience of the residual stand. Thinning of the larger

commercial trees reduces crown density and reduces the risk of snow and ice or wind damage in the stand, and returns a positive cash flow to the project through timber sales.

- Thin to cut portions of a stand that are dead, at risk or growing inefficiently, freeing up growing space for the residual stand. In order to develop the stand towards the long-range target stand described earlier, retain the best-formed trees according to the following preference order:
 1. Douglas-fir
 2. Aspen
 3. Spruce
 4. Lodgepole pine
- The spatial distribution of the stand should be clumpy. Our long-term target is a stand where cohorts of similar size and age stand together in groups that measure about one tree-length in diameter, or approximately 0.03 ha in area. Small trees growing under the crowns of larger trees should be cut, because they have no future growing space and contribute to ladder fuels.
 1. Trees less than 1.3 m in height will be left uncut.
 2. Trees between 1.3 m in height and 7.5 cm DBH should average 2.0 m inter-tree distance with a range from 1.0 to 2.5 m.
 3. Trees between 7.5 cm and 12.5 cm DBH should be from average 3.0 m inter-tree distance with a range from 1.0 to 3.5 m.
 4. Trees larger than 12.5 cm DBH should be left at a prescribed target residual basal designed to keep the stand above the lower stocking limit Figure 10 above.
- Leave trees of the species best adapted to the light environment of the cohort. Douglas-fir and spruce are more tolerant of shade than aspen and lodgepole pine, and are therefore more suitable for cohorts in a smaller size class.
- Do not create gaps large enough to allow growing-season frost to form. Regeneration of Douglas-fir and spruce require shelter from growing-season frost. If a gap is large enough to cause frost accumulation, it should also be large enough to support a pine or aspen nurse crop.
- Large trees that are growing in a clump and sharing a root mass should all be either cut or left because a pair of trees sharing a stump will become unstable if one is cut, and the fresh stump will invite bark beetles to the remaining tree.
- Leave trees will be selected based upon their quality and their vigour, as described in Table 6.
- Thinning activities can be separated in time. Thinning of the commercial portion of the stand (greater than 12.5 cm) can precede precommercial thinning and fuel disposal, if that makes the total operation most efficient. Our experience leads us to believe that integrating operations provides the lowest total cost.

Table 8: Vigour classes for selection of Douglas-fir leave trees. (Excerpt from Day 2007b).

Vigour Class	Judgement Criteria					
	Crown Position*	Height/Diam Ratio (m/cm)	Crown Shape	% Live Crown	Bark Characteristics	Form Problems or Damage
Good	D, CD	<0.8	Sharply pointed	>30	Reddish, big plates, Smooth light grey upper bole	None
Med.	CD, I	0.8-1.0	Pointed	25-30	Big plates, smooth upper bole	Fork, sweep, crook
Poor	I, S	>1.0	Rounded	<25	Dark grey, rough, flat	Cracks, conk, canker

*D=Dominant, CD=Co-dominant, I=Intermediate, S=Suppressed

Recommendation #5: Remove Or Reduce Surface Fuels

Thinning must be accompanied by fuel reduction -- failing to do so adds significant surface fuels, which increases the fire behaviour and fire severity, leading to more difficult suppression and more significant ecological impacts. The Forest Practices Board (2010) was critical of harvesting in the WUI without managing the resulting debris.

- Manage the fuel resulting from thinning, by either:
 1. Removing it for bio-energy;
 2. Burning it on site, with or without piling;
 3. Reducing it by chipping and spreading on site; or
 4. A combination of any or all of the above.
- Find ways to combine operations. For example, if the operational plan calls for removing fuels to roadside, then consider forwarding the fuel and merchantable material by the same methods, e.g. whole-tree skidding with roadside processing, provided the requirements for protection of the residual stand can be achieved.

Fuel and fire behaviour modelling (at 90th percentile fire weather and 15 km/hr wind speeds) suggests that the following fuel reduction efforts be taken to reduce risk of wildland fire in the IDF of the Williams Lake TSA:

- To create stand resilience or fuel break conditions, maintain surface fuel loadings below 4 kg/m²;
- At surface fuel loading less than 4 kg/m²:
 1. Where the tolerance for risk is moderate (e.g. not within close proximity to infrastructures), the canopy base height should be greater than or equal to 2 metres.
 2. Where the tolerance for risk is low (e.g. within close proximity to infrastructures), the canopy base height should be greater than or equal to 3 metres.
 3. Surface fuel loadings should never exceed 8 kg/m²;
 4. If surface fuels cannot be maintained below 4 kg/m² and are between 4-8 kg/m² then the canopy base height must be greater than or equal to 3 metres.

Of note:

- Maintaining low levels of surface fuel loading should be a primary management concern.
- Stand density or basal area as a sole measure of canopy fuel loading is not sufficient. Ladder fuels and surface fuels (affecting canopy base height) have large influences on fire behaviour.
- A high basal area or a high number of trees (up to 2000 stems/ha) can be maintained with little risk of crown fire if the advanced regeneration and small diameter class trees are removed, if canopy base height is greater than or equal to 2 metres, and if surface fuels are kept below 4 kg/m².

Recommendation #6: Retain Dead Wood On Site

- Retain dead standing trees that are neither danger trees nor contributing significantly to ladder fuels. Large dead veteran Douglas-fir can generally be retained. Dead lodgepole pine (5-10 trees/ha) can be stubbed as high as feasible for the equipment employed. Dead trees and stubs add to the structural complexity of the residual stand. Danger-tree assessment criteria apply.

- Retain up to 40 m³/ha of fresh downed wood in pieces larger than 15 cm and up to 6 m long. Arrange logs so they lie flat on the ground and do not touch each other. Retain existing decayed woody debris.

Recommendation #7: Protect The Residual Stand From Mechanical Damage Through Careful Work Practices

- Damage to residual trees is a normal consequence of thinning and harvesting, but work habits substantially influence the extent of the damage (Nyland 1996). Day (1998a) describes three types of damage:
 1. Top damage, where falling trees break the top or shear branches from a leave-tree. Controlled by careful falling practices, particularly in cold weather.
 2. Basal scarring, where skidding equipment or moving logs bump into residual trees and remove bark and perhaps wood from the stem. These wounds weaken the tree, allow the entry of stem decay, and degrade the value and volume of the largest log in the tree.
 3. Root damage, where repeated traffic either compacts the soil around fine roots or mechanically damages roots by breakage or abrasion. These wounds weaken the tree, subject it to windthrow, and introduce stem decay into the heart of the tree.
- Day (1998a) presents a discussion of logging guidelines for harvesting and thinning in the IDFDk3 at Knife Creek, which is summarized by Day (2007a) as follows:

In order to protect the residual stand and the productive capacity of the land we manage, it is important to establish skid trails in an efficient manner, according to the following guidelines and the concepts presented in Figure 12:

- *Aim for a target density⁶ of 10% of the productive area of a stand to be occupied by trails;*
- *Re-use existing trails;*
- *Lay out and mark trails in advance of logging to minimize trail density and reduce skidding damage (Nyland 1996);*
- *Minimize trail width;*
- *Maximize inter-trail distance;*
- *Trail junctions at angles of 35° or less;*
- *Utilize ghost trails to reduce the density of skid trails;*
- *Avoid soil compaction by armouring skid trail surface with non-merchantable logs, limbs and tops; or use under dry or frozen conditions;*
- *Retain rub trees at trail junctions, and leave uncut if the next harvest entry will be in less than 10 years.*
- *Plan skid trail location to avoid wet soils, and if it is necessary to cross wet ground prepare temporary crossings at the best locations with corduroy and/or snow.*
- *Plan skid trail locations to avoid shallow soils with a high risk of soil displacement.*
- Additional considerations will be necessary as changes in logging methods are proposed. Bunch size, limbing and bucking in the woods, equipment size and forwarding methods all have significant implications to the work practices employed.

⁶ Measured by the outside edges of the travelled area of the trail, and counting only those trails that have been used to skid or forward logs (i.e. ghost trails used for felling only do not contribute to trail area). Trails with a running surface 4 m wide and spaced 40 m apart occupy 10% of the productive area.

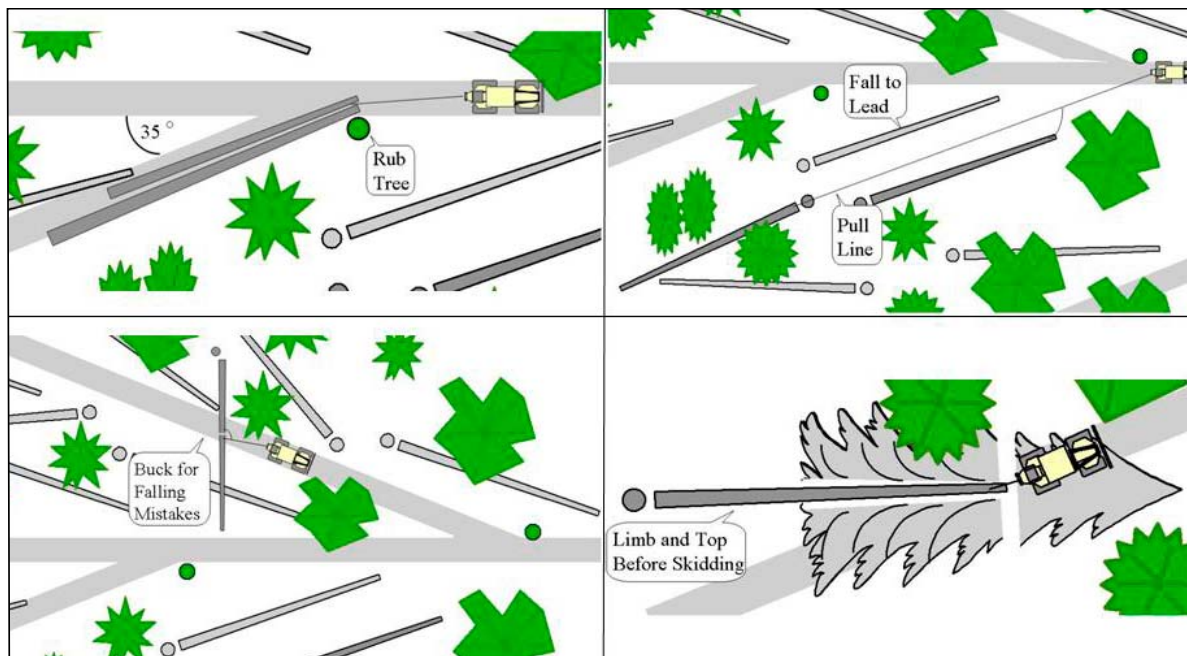


Figure 16: Logging work practices to reduce damage to the residual stand (from Day 1998), assuming a hand-felling/line skidder operation.

Recommendation #8: Create Tactical Fuel Treatments Across the Landscape

Tactical fuel treatments should be designed primarily to improve the effectiveness and safety of fire suppression tactics. Designed within the context of a CWPP, placement of these fuel breaks will consider the fuel, weather conditions and prevailing winds that are likely to occur during aggressive fire behaviour so as to yield the best protection to the community.

- During the preparation of a CWPP, identify stands that that:
 1. Enlarge or link existing low-fuel conditions;
 2. Provide safe access for suppression forces;
 3. Serve a tactical purpose for direct suppression activities;
 4. Are located outside established mule deer winter range, or within areas of low habitat objective within mule deer winter range.
- Create Landscape Fuel Breaks within those stands by:
 1. Thinning from below to retain an open stand of the largest Douglas-fir trees, with a target of 16-20 m²/ha on 300 to 500 stems/ha;
 2. Reducing surface fuel to 4 kg/m² or less, by piling and burning or by removal to roadside;
 3. Maintaining a low-fuel condition through time.

Recommendation #9: Maintain Roads At A Standard That Will Provide Access To Fire Suppression Forces During Dry Weather.

Good fire suppression capability requires sufficient access to allow fire-fighters to effectively arrive at a fire and implement their tactics. Roads should provide a network of access that is available to fire-fighters during dry weather. This includes tanker trucks for the delivery of fire-fighting water.

Recommendation #10: Protecting Public Values Through Site Plans And Operational Plans.

The many values in place in the WUI can be seen as being two different types: those values that have regulatory protection, and those that do not.

Those values that have regulatory protection include archaeological and cultural resources, smoke control, worker safety, and environmental protection. We recommend that all fuel management treatments be conducted within the regulatory requirements that apply.

Many values are widely held in the community but do not have regulatory protection. These should be addressed as objectives in a Site Plan. Examples include aesthetics and sight lines, public safety, and protection of recreational opportunities.

Other values are unique to individuals and are not widely known. These should be discovered on the ground, or through discussion with interested public. Examples include play areas, pet graves, or favorite viewpoints. These values should also be protected as objectives in a site plan or as adjustments to the operational plan.

Treatments will be perceived as successful if the process incorporated input from interested individuals, and was open to input throughout the implementation phase. Public meetings, door-to-door letters and newspaper articles are all helpful, but the most important ingredient is an honest response to input and a willingness to vary the activity.

Recommendation #11: Manage Treatment Cost And Timber Harvest Value

The preceding discussion shows that fuel treatments are expensive, particularly if there is no commercial harvest value attributed to the project. All-found costs, including planning and supervision, can range from \$2,000 to \$10,000 per hectare.

Treatment costs must be controlled, in order to ensure that scarce funds complete as much high-priority treatment as possible. Selection of operational methods has a significant impact on treatment costs. In general, operators favour whole-tree removal of target trees, with piling at roadside for burning or for removal as hog fuel. Whole trees delivered to roadside containing merchantable logs, should be ideally merchandised for that purpose and not burned or chipped for biofuel.

It seems unlikely in the near term, however, that the log market that will support treatment costs without additional program funding. Simple arithmetic shows that a net margin (selling price less logging cost) of \$25/m³ and a harvest volume of 50 m³/ha would provide \$1,250/ha net to the project. Our present market, however, is providing a negative net margin, and few fuel treatment projects will yield 50 m³/ha, indicating that fuel treatments will rely on government funding for the foreseeable future, perhaps until the first pass of treatments has been completed.

The Forest Practices Board (2010) reported a conflict between the production of merchantable timber and the government funded programs that support interface fuel treatments, because of concerns about providing subsidies to buyers of logs. However, the public expects that merchantable timber will be put to good use at a fair market value.

Harvesting and stumpage costs may exceed the value of the wood in present depressed markets, but the incremental cost of bringing to market a log already at roadside might justify the sale and reduce treatment costs. Government must find a way to allow log sales from interface fuel treatments.

Potential approaches include:

- Tender a net-cost treatment contract, where the successful bidder agrees to complete a project to an agreed standard, and the value the contractor can find in the timber designated for removal can

be realized by the contractor. This is similar to Stewardship Contracting⁷ which is being used in USDA National Forests where fuel treatments are being conducted.

- Another potential approach is to simply declare the gross log revenues against the bottom line costs of the funded project work. See Table 3 and 4 above for an example. This is likely the best arrangement for inducing the participation of Woodlot Licensees and Community Forests.
- A third option for crown land projects would be to put the wood at roadside for sale by BC Timber Sales.

Recommendation #12: Necessary Policy Accommodations

General Wildlife Measures for ungulate winter range in shallow and moderate snowpack zones within the Cariboo Chilcotin Land Use Plan (Province of BC 2007) restrict cutting cycles in particular types of harvesting to 30 years or more. In our opinion this is inconsistent with the fuel reduction objective within a CWPP, because such a long re-entry period will contribute to the development of significant surface and aerial fuels. The resolution of this conflict could be via an exemption application as provided in the General Wildlife Measures.

The Open Burning and Smoke Control Regulation and its Code of Practice are very restrictive because they limit both broadcast and slash burning to brief periods (weather windows) when venting conditions are adequate to prevent accumulating smoke in the community airshed. The regulation and code also restrict the location, frequency and duration of open burning. There is a conflict in government's objectives to:

- Reduce hazardous forest fuels using the cheapest methods, while maximizing the area treated and limiting program treatment dollars; versus
- Minimizing smoke in communities to reduce negative human health effects.

In the Cariboo, good venting conditions occur during the fire season when open burning is curtailed by fire hazard, or in the fall and spring. Good venting conditions are infrequent during the winter. Piles therefore need to be left for burning at a later time during fall or spring, resulting in:

- Inefficiencies of personnel deployment;
- Burning in a different fiscal year from the year of fuel treatment, compromising contractual arrangements.

In concentrating all pile burning into a short window when venting permits, the sheer volume of burning may lead to abundant smoke in the airshed in spite of good venting. This can be exacerbated if fuel piles are snow-covered or wet from snowmelt or rain.

Resolution of this conflict could result from a variety of measures:

- During periods of poor or fair venting, burn few but very hot fires to minimize smoke production. Feed a single fire for a prolonged period concurrently with fuel reduction treatments to keep the fire hot, limiting smoke and fine particulate matter. Use a burning sloop⁸ to allow the fire to move and burn throughout the day. This will require exemption from or amendment to the regulation.
- Remove fuel to roadside for use elsewhere. Find ways to manage the fuel removal to minimize the cost of the feedstock to the receiving plant.
- Encourage biofuel receiving plants to be a partner in community fuel treatments.
- Leave material at roadside for local firewood use, since suitable firewood at roadside disappears very quickly. Consider the implications of firewood permits from Ministry of Forests and Range, and potential liabilities created by providing wood and a workspace for firewood cutters.

⁷ See for further details -- <http://www.fs.fed.us/forestmanagement/stewardship/index.shtml/index.shtml>

⁸ A large container skidded through the woods in which a fire can be continuously fed

Approved Stocking Standards do not contemplate the fuel reduction objective, and therefore may not allow the preference of non-flammable species such as aspen. Forest District staff should support the amendment of stocking standards to reduce fire intensity and improve fire resilience.

Coarse Woody Debris Targets are poorly defined. The same woody material that is important for habitat, biodiversity and soil productivity also forms surface fuels and receptive ignition points for interface fire. Clarity on targets would help to ensure that fuel reduction treatments leave enough coarse woody debris but not too much surface fuel.

Authority to Damage or Destroy Timber and Tenure for Removal should be standardized across Forest Districts. We understand that significant delays occur in some Forest Districts as the tenure model gets worked out. The tenure model in place in the Central Cariboo Forest District functions well and provides significant flexibility:

1. A letter of authority under Section 52(1)(b) of the Forest and Range Practices Act allows a proponent to cut and deck or destroy timber from a project area in accordance with a Site Plan.
2. If timber is to be removed, a Forestry Licence to Cut is issued to allow the removal.

Scaling and Stumpage Assessment of biomass products is onerous and out of proportion with the value of the product. Government has established that a tonne of biomass has the same value to the crown as a tonne of grade 4 sawlogs, but a large portion of the material from fuel reduction treatments is actually lumber reject (tops, branches, needles). Government should review the method of assessing the value of biomass and change the procedures to more-correctly assess the inherent value of the product, and rationalize the cost of collecting stumpage with the actual stumpage paid.

Summary

Best Management Practices are recommended for planning and implementing fuel reduction treatments in the Wildland Urban Interface within the Interior Douglas-fir biogeoclimatic zone of the Williams Lake Timber Supply Area. Fuel and fire behaviour modelling, a review of relevant literature and local experience provided a basis for establishing recommendations for thinning and surface fuel reduction, along with strategic establishment of fuel breaks throughout the wildland portions of the CWPP areas. Modelling suggests that stand resilience to surface fire will occur when surface fuels are less than 4 kg/m² and canopy base height is greater than or equal to 2-3 m, depending on risk tolerance for a given stand. Fuel removal must accompany thinning and stand density reduction for fuel treatments to be effective at reducing forest fire intensity should a fire occur. Surface fuel loading should not exceed 8 kg/m².

Managers should plan for fuel treatments using forest management principles. The CWPP area should be subdivided into workable treatment zones such that community values and legislated management objectives are recognized. Wildland stands then need to be prioritized according to proximity to infrastructure. Treatment prescriptions should be planned according to short- and long-term target stand structures and in accordance to General Wildlife Measures if on identified mule deer winter ranges. Operational plans need to put treatment zones into optimal arrangements across the landscape and over time. Monitoring treatment effectiveness will ensure that stands in the Wildland-Urban Interface continue to provide ongoing resilience to fire and opportunities for fire-fighting tactics into the future.

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Appendix 1: Fire Behaviour and Fire Effects Modelling

FIRE BEHAVIOUR AND FIRE EFFECTS MODELING

*A study on fuel loading and fire behaviour to support
recommendations on Fuel Treatments*



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1.0 Introduction

Forest management operations in the Wildland Urban Interface should be conducted with reference to the anticipated impacts on fire behavior and fire effects. This report documents the results of fire effects modeling. Modeling work was undertaken to support recommendations for Best Management Practices in undertaking fuel reduction treatments in the Wildland Urban Interface in the Interior Douglas-fir zone of the Williams Lake Timber Supply Area.

2.0 Methodology

Fire behaviour modeling is a valuable tool in fire management planning though it is important to have an understanding of its limitations. Please note the following points when considering the model outputs presented in this document:

- Fire behaviour outputs calculated by fuel models provide a representation of potential fire behaviour. They provide a means of comparing different fuel profiles but do not indicate “real time” fire behavior.
- Fire behaviour models predict fire behaviour based on a wide range of inputs. For the sake of determining the contribution of individual components many inputs are kept constant during model runs. In reality it is important to note that forest ecosystems are dynamic and that their many components interact making no two forests alike.
- All fire behaviour models are based on specific assumptions that may not always represent true fire behaviour which is naturally dynamic and can behave in unpredictable ways.

2.1 Fire Behaviour Modeling

Fire behaviour modeling was used in this study to understand the potential of various fuel complexes to determine thresholds of potentially damaging wildfires. Although there are many fire behaviour models available from both the United States and Canada many do not incorporate both surface and crown fuels.

Fire behavior was modeled in Fuels Management Analyst (FMAplus 3) which uses stand inventory data, pre-set surface fuel models and environmental data to create custom fire behavior scenarios.

This model was developed by Fire Program Solution LLC. More information on FMAplus 3 can be found at: <http://www.fireps.com/fmanalyst3/index.htm>.

2.1.1 Model Inputs

In developing fire behavior scenarios the following inputs were kept constant:

- Intermountain Equation Set for calculating Canopy Bulk Density;

- 90th percentile weather conditions from the IDFdk3 (29°C and 24% Relative Humidity);
- 100% fuel moisture content;
- Site Index of 18;
- All standard default values from the model for canopy fuel loading assumptions;

To determine the effects of various surface and crown fuel loadings, windspeeds and canopy base heights, on fire behaviour the following inputs were varied:

- Surface fuel models;
- Stand density (tree inventory inputs);
- Canopy base heights;
- Windspeeds (15 and 35 km/hr)

Surface Fuel Inputs

Nine surface fuel models of varying total fuel loadings were used. These fuel models were selected from FMAplus 3.0 and are variations on 3 of the original 13 FBPS surface fuel models (Anderson, 1982). The fuel models used are described in Table 1. Images of the 3 baseline surface fuel models used are included in Figure 1. From this point on the fuel models will only be referred to according to their total surface fuel loadings.

Table 1: Surface fuel models used in FMA3.0 fire behaviour modeling.

Surface Fuel Model Name	Fuel Model Variation	Total Surface Fuel Loading (kg/m ²)	1-hour Surface Fuel Loading (kg/m ²)	10-hour Surface Fuel Loading (kg/m ²)	100-hour Surface Fuel Loading (kg/m ²)	Fuel Bed Depth (m)
FB11-Light Slash	FBPS-X-Avg. Depth	3.1	0.4	1.2	1.5	0.37
FB11-Light Slash	High-Y-Avg. Depth	3.8	0.5	1.5	1.8	0.45
FB11-Light Slash	High-Z-Avg. Depth	4.5	0.6	1.8	2.1	0.53
FB12-Medium Slash	Low-B-Avg. Depth	5.8	0.7	2.4	2.8	0.53
FB12-Medium Slash	Low-C-Avg. Depth	6.5	0.8	2.6	3.1	0.59
FB12-Medium Slash	FBPS-D-Avg. Depth	7.2	0.8	2.9	3.4	0.65
FB12-Medium Slash	FBPS-X-Avg. Depth	8.3	1.0	3.3	4.0	0.74
FB12-Medium Slash	High-Z-Avg. Depth	9.6	1.1	3.9	4.6	0.87

FB13-Heavy Slash	FBPS-D- Avg. Depth	12.3	1.5	4.9	5.9	0.87
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Figure 1. Photographs 32, 35 and 38 from Anderson 1982 (From left to right: FB11-Light Slash, FB12-Medium Slash, FB13-Heavy Slash).

Crown Fuel Inputs

Crown fuel loading inputs to the model came from stand inventory collected by the UBC Alex Fraser Research Forest staff. The example stand used for the modeling was Cut Block 208 (CB208) on Jones Creek Road at the Knife Creek site and was selected due to its high fuel loading (Figure 2).



Figure 2. Cut Block 208 on Jones Creek Road - Knife Creek Site

In order to model variations of stand density, the inventory data from this stand were input into Forest Vegetation Simulator EC Variant (FVS-EC) using Landscape Management System (LMS) (see <http://lms.cfr.washington.edu/> for details on these programs). These programs were then used to thin the stand from below to varying densities (removing trees from the advanced regeneration and 5 and 10 cm DBH class categories). As a point of comparison the Alex Fraser prescribed and target stand inventories were also modeled in FMAplus 3.

2.1.2 Model Outputs and Calculations

The outputs from FMAplus 3.0 included a measure of whether the stand would experience “surface fire” or “crown fire” in addition to predicted flame lengths and rates of spread. Flame length was used to calculate fireline intensity according to Equation 1:

$$I = \frac{L^{2.174}}{0.00384863} \quad \text{Where } I = \text{fireline intensity (kW/m) and } L = \text{flame length (m)}$$

Equation 1: Fireline Intensity Equation obtained from www.forestencyclopedia.net

3.0 Results and Discussion

When the various stand densities, surface fuel loadings and canopy base heights were modeled a number of observations were made about each component. Though all stand components interact in combination to drive fire behaviour, each one will be discussed separately in the following sections.

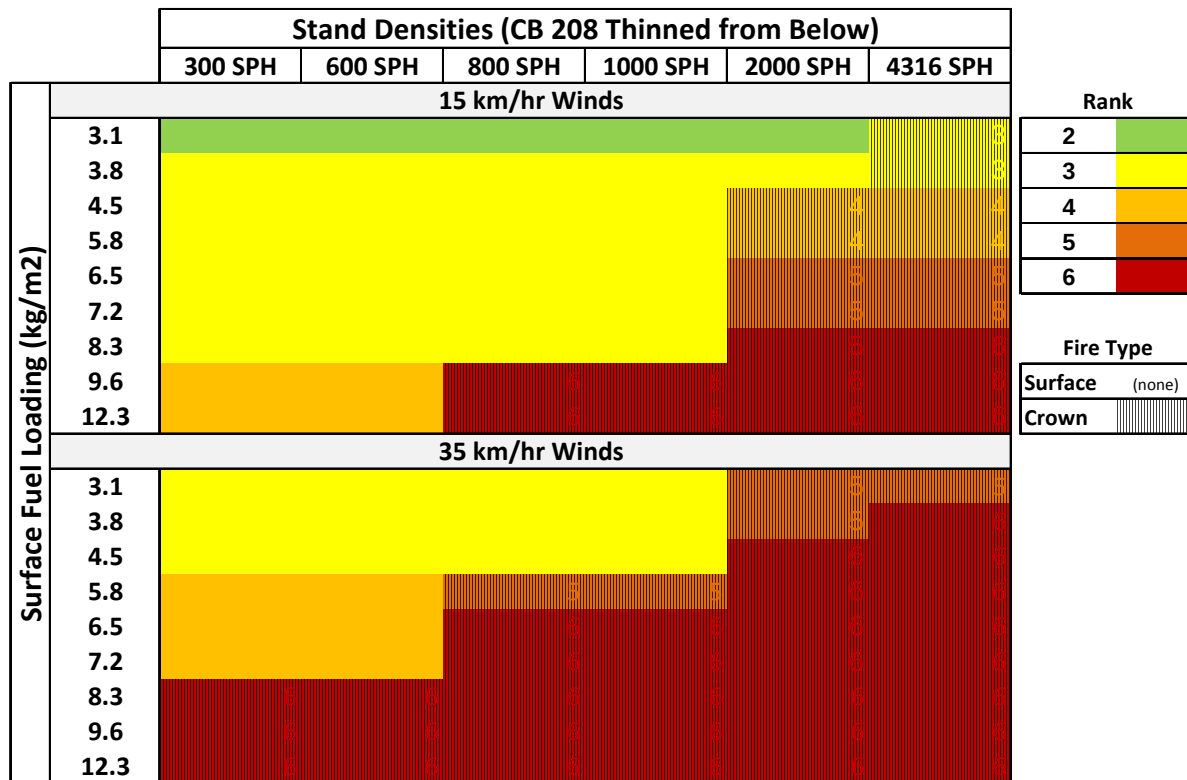
3.1 Surface Fuel Loadings

A dominant observation noted during modeling was that surface fuel loadings were a major driving force in determining head fire intensity and subsequently the Fire Rank. Table 2 shows Fire Rank (2-6) and fire type (surface/crown) by fuel loading and stand density when modeled in FMAplus 3 at 15 and 35 km/hr winds.

Key findings regarding surface fuel loading illustrated in Table 2 include:

- At both wind speeds, regardless of stand density, modeled surface fuel loadings above 8.3 kg/m² exceeded rank 3 fire behaviour;
- At higher wind speeds (35 km/hr), regardless of stand density, modeled surface fuel loadings above 4.5 kg/m² exceeded rank 3 fire behaviour;
- At low wind speeds (15 km/hr) and low modeled stand densities (300-600 SPH) crown fire did not occur even at extreme surface fuel loadings, though it is expected that fire behaviour would still be difficult to control (up to Rank 5 fire) and spotting and tree scorching would still likely occur;
- At higher wind speeds (35 km/hr), modeled surface fuel loadings above 7.2 kg/m² resulted in crown fire regardless of stand density.

Table 2. Fire Rank and Fire Type for given stand densities and surface fuel loadings at 15 and 35 km/hr winds.



3.2 Stand Density

When the stand density was varied in the modeling, diameter class distribution was found to be a critical stand attribute that largely affected the fire behaviour. Figure 3 and Figure 4 show fireline intensity for various surface fuel loadings and stand densities, modeled at 15 and 35 km/hr winds respectively. In these figures the various stand densities represent CB208 thinned from below. Due to high density of small diameter fuels in CB208, the thinning treatments only removed trees in the advanced regeneration and 5 cm DBH class categories until stands were below 1000 SPH. At 1000 SPH and above, stem counts in all the other diameter classes remained constant. Figure 5 shows the diameter class distributions and stand visualizations for the 1000 SPH, 1500 SPH model scenarios and of the untreated stand. Note that the visualization tool SVS randomly locates the trees in the visualizations. The images therefore depict the stand density but do not illustrate the “real-life” spatial distribution of trees.

Figure 3 illustrates that with winds of 15 km/hr fireline intensity makes a dramatic jump between 1000 SPH and 1500 SPH for surface fuel loadings of 3.8-7.2 kg/m². This is also where the fire type changes from a surface fire to a crown fire. The 500 stems removed between the stand modeled at 1000 SPH and 1500 SPH were all in the 5 cm DBH class (Figure 5). Small

diameter trees contribute to the continuity between the surface fuels and canopy and are a critical stand component affecting fire behaviour. This is further emphasized by the lack of differences in fireline intensity (at 15 km/hr winds) between the stands with densities of 300, 600, 800 and 1000 SPH which all varied only in density of the larger diameter classes. At the lower fuel loading of 3.1 kg/m² the jump from surface fire to crown fire happened at a higher stand density (between 2500 and 3000 SPH) indicating that higher stand densities can be maintained if surface fuels are lowered below a specified threshold.

It is important recognize in the analysis of these results that that when tree inventories are input into FMAplus 3 the fire behaviour is modeled as though the trees are evenly distributed throughout the stand. Note, that in reality clumping of understory small diameter trees may alter the fire behaviour as there would not be a continuous layer of ladder fuels.

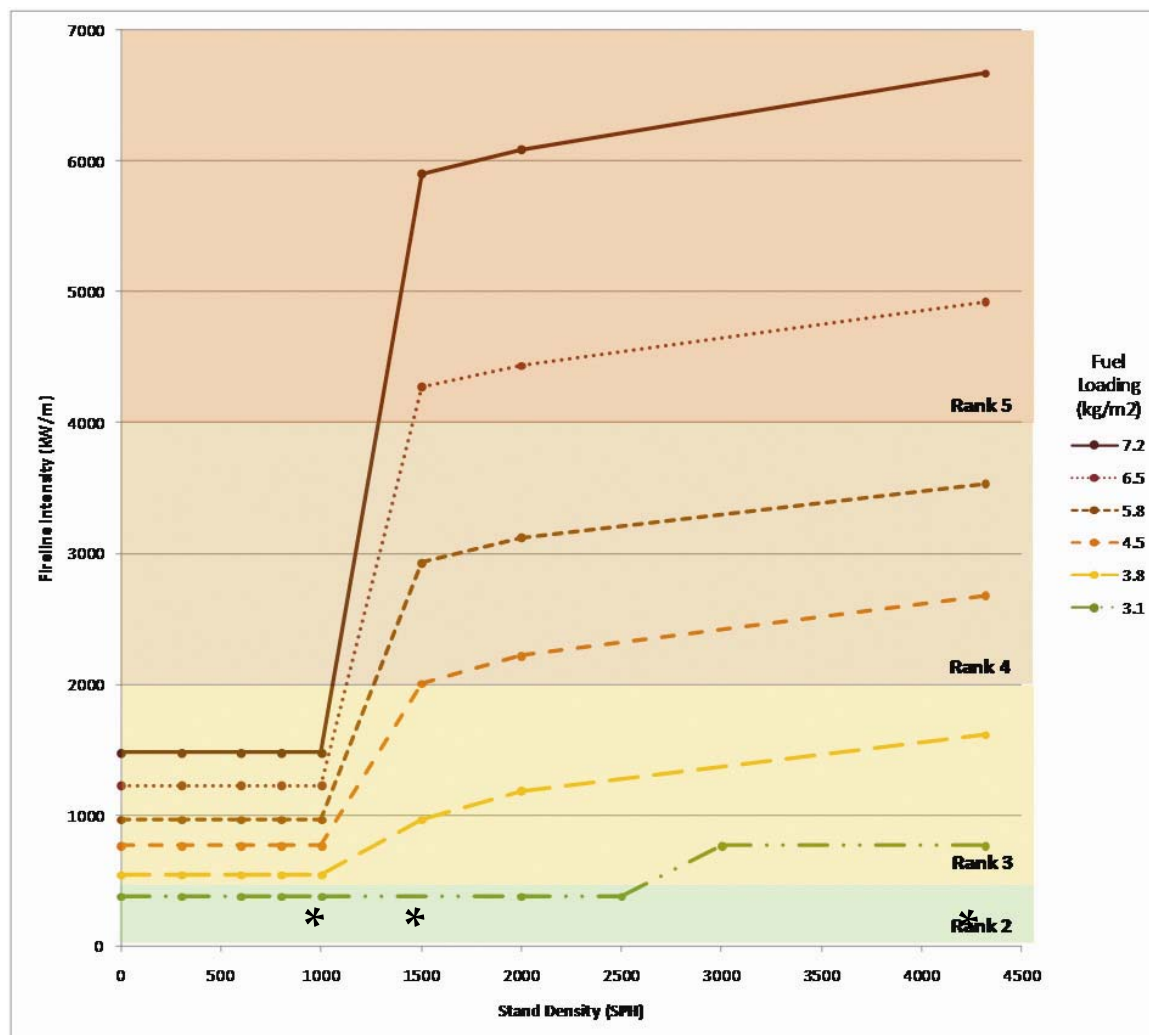


Figure 3. Fireline intensity given various surface fuel loadings and stand densities (thinned from below), modeled with 15 km/hr winds. (*Refer to Figure 5 for diameter class distributions and visualizations)

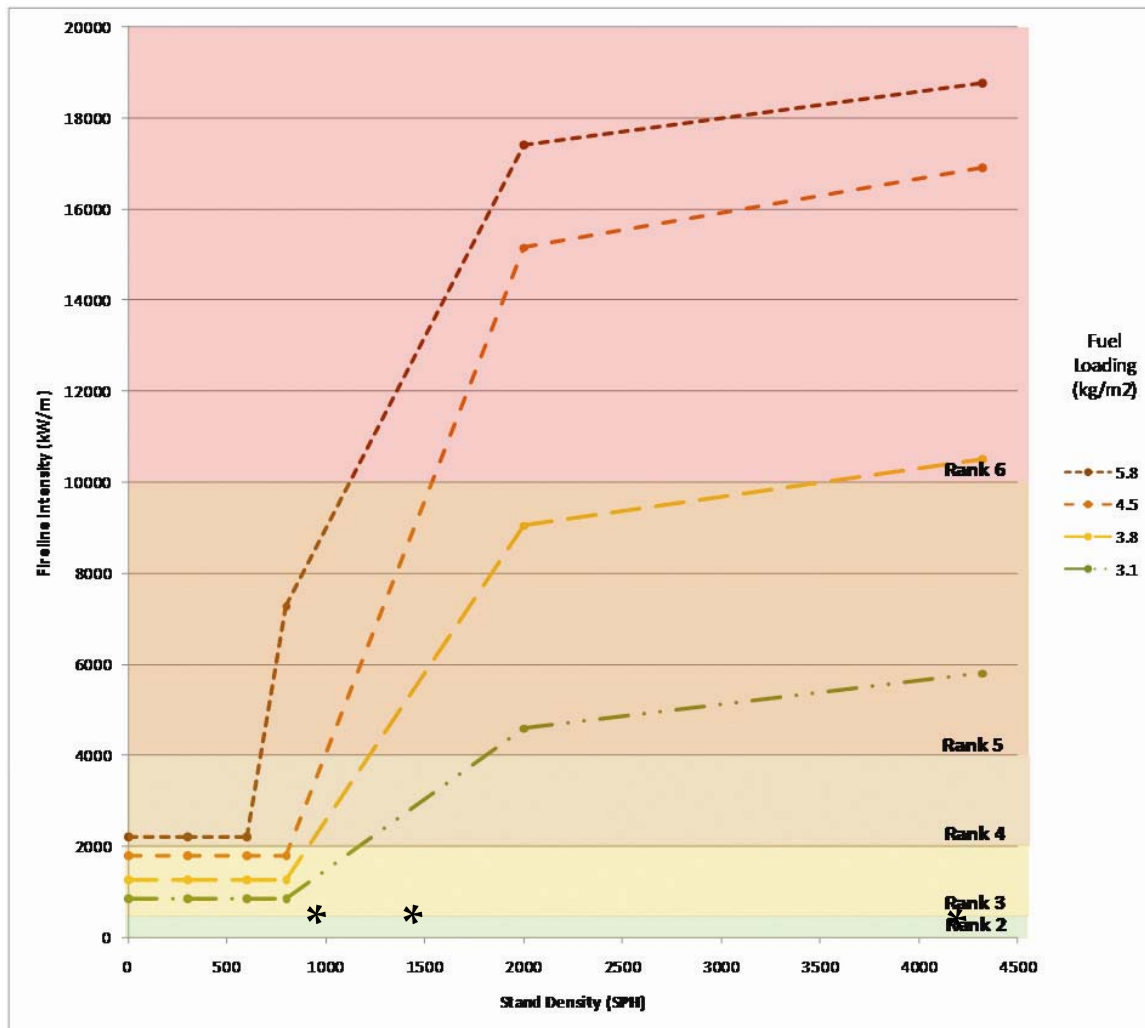


Figure 4. Fireline intensity given various surface fuel loadings and stand densities (thinned from below), modeled with 35 km/hr winds. (*Refer to Figure 5 for diameter class distributions and visualizations)

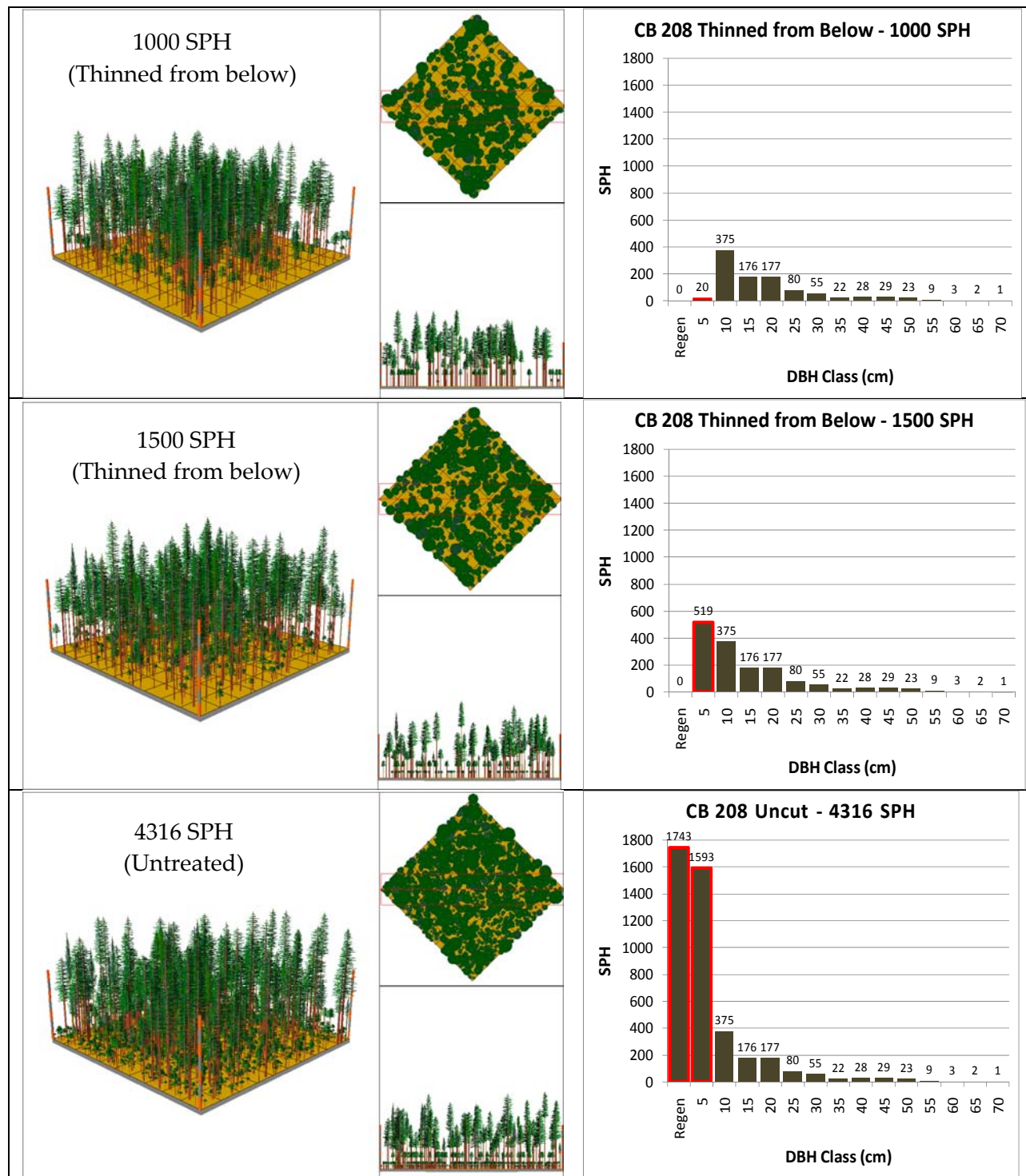


Figure 5. Stand visualizations (created in SVS) and diameter distributions that correspond to SPH (*) values in Figure 3 and Figure 4.

As a point of comparison the Alex Fraser thinning prescription and target stands were also modeled in FMAplus 3. Figure 6 and Figure 7 show fireline intensity for various surface fuel loadings and the CB208 untreated, prescribed, and target stand densities, modeled at 15 and 35 km/hr winds respectively. Note that in these graphs the fireline intensities jump at lower diameter class thresholds as the thinning prescriptions removed stems from all diameter classes and not just the small trees (Figure 8). In reality the retention of small trees in these prescriptions is intended to be done in a clumpy distribution. Recall, as mentioned above, that when tree inventories are input into FMAplus 3 the fire behaviour is modeled as though the trees are evenly distributed throughout the stand.

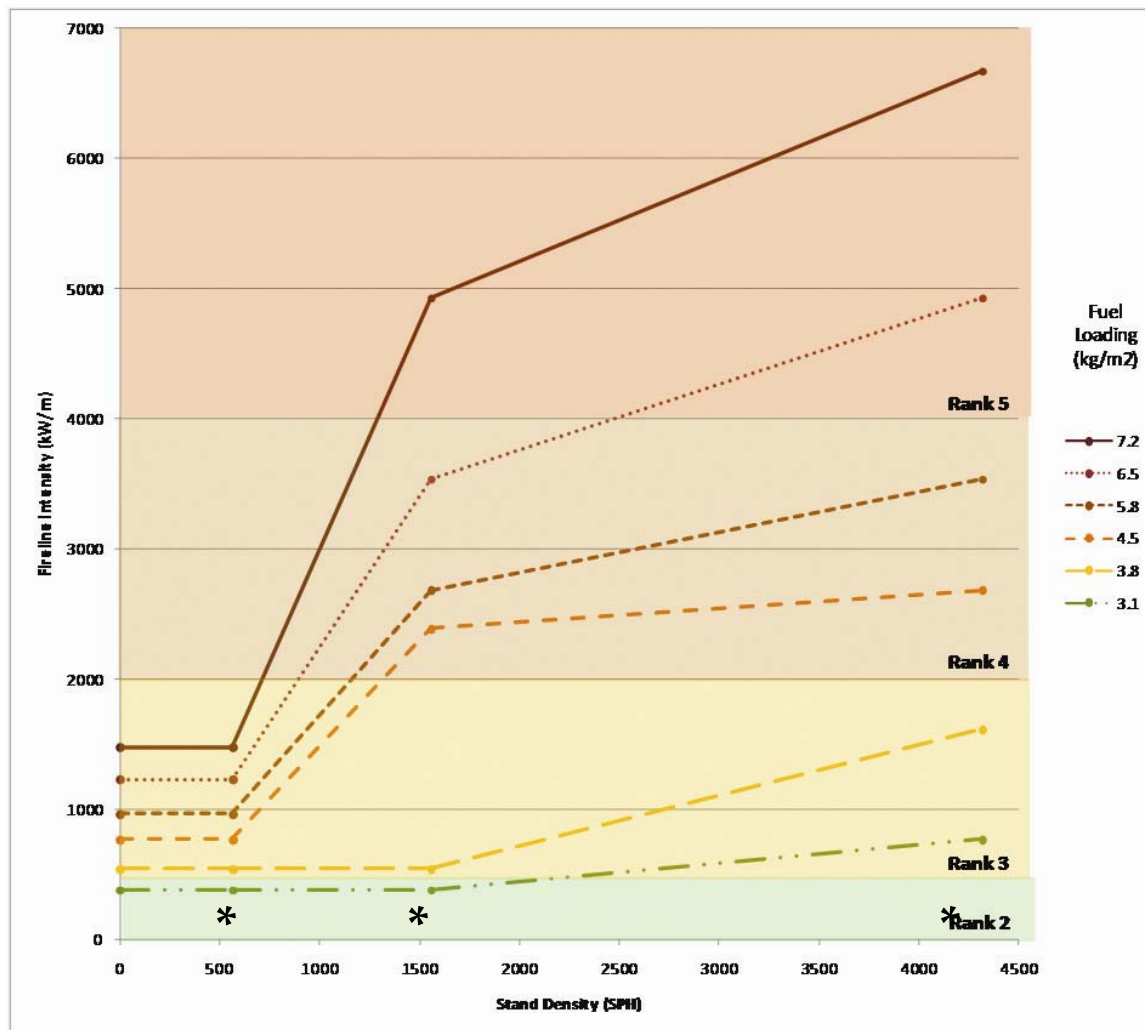


Figure 6. Fireline intensity given various surface fuel loadings and stand densities (thinned from all DBH classes), modeled with 15 km/hr winds. (*Refer to Figure 8 for diameter class distributions and visualizations)

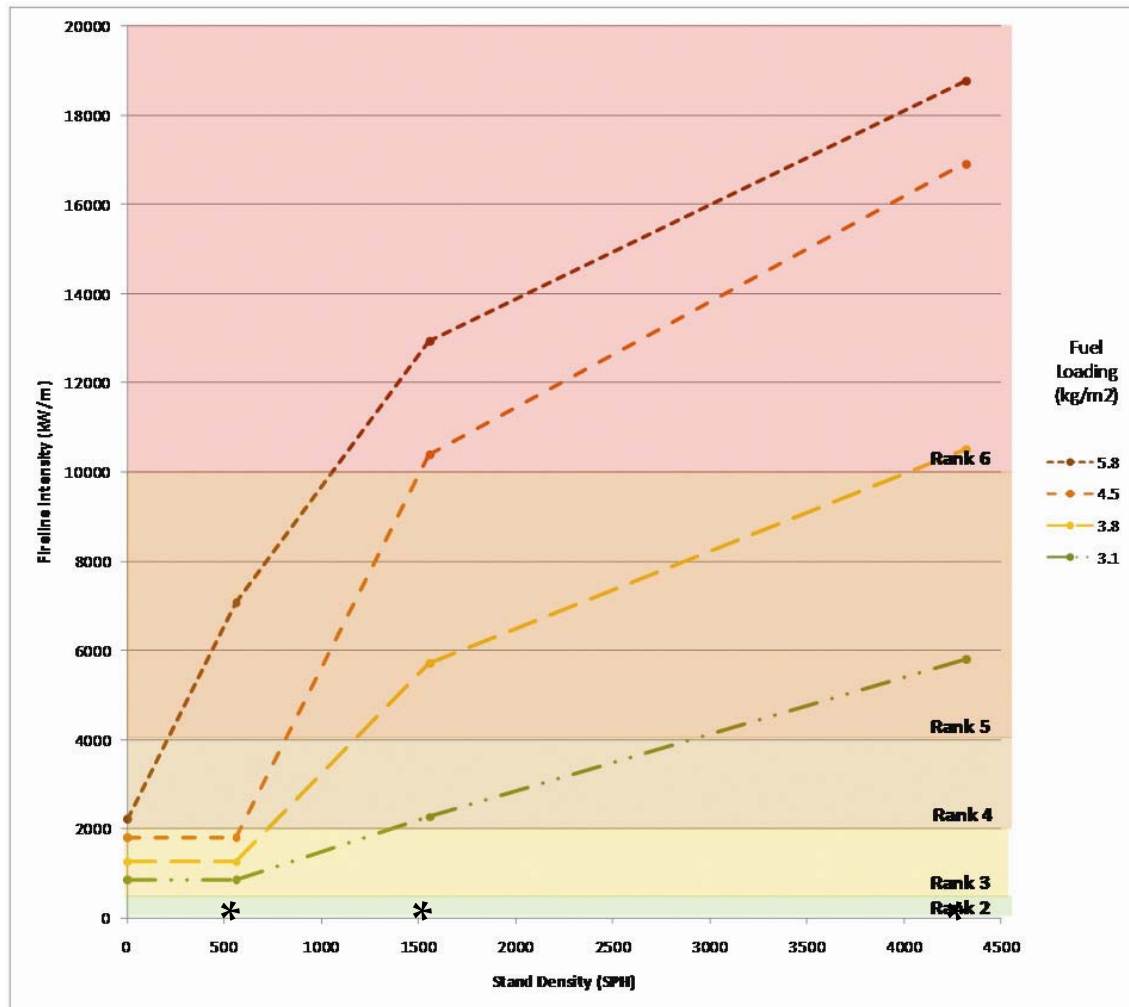


Figure 7. Fireline intensity given various surface fuel loadings and stand densities (thinned from all DBH classes), modeled with 35 km/hr winds. (*Refer to Figure 8 for diameter class distributions and visualizations)

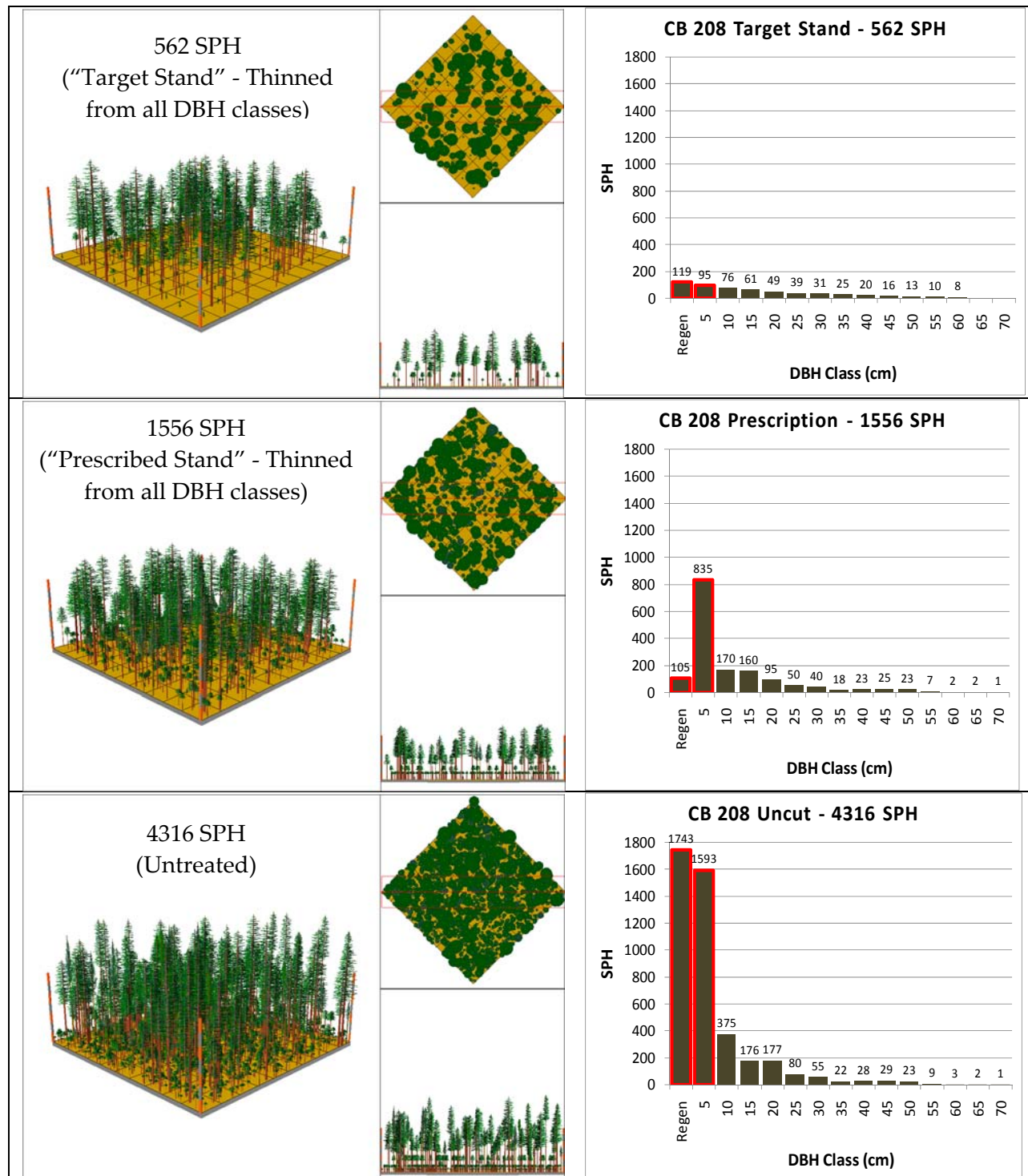
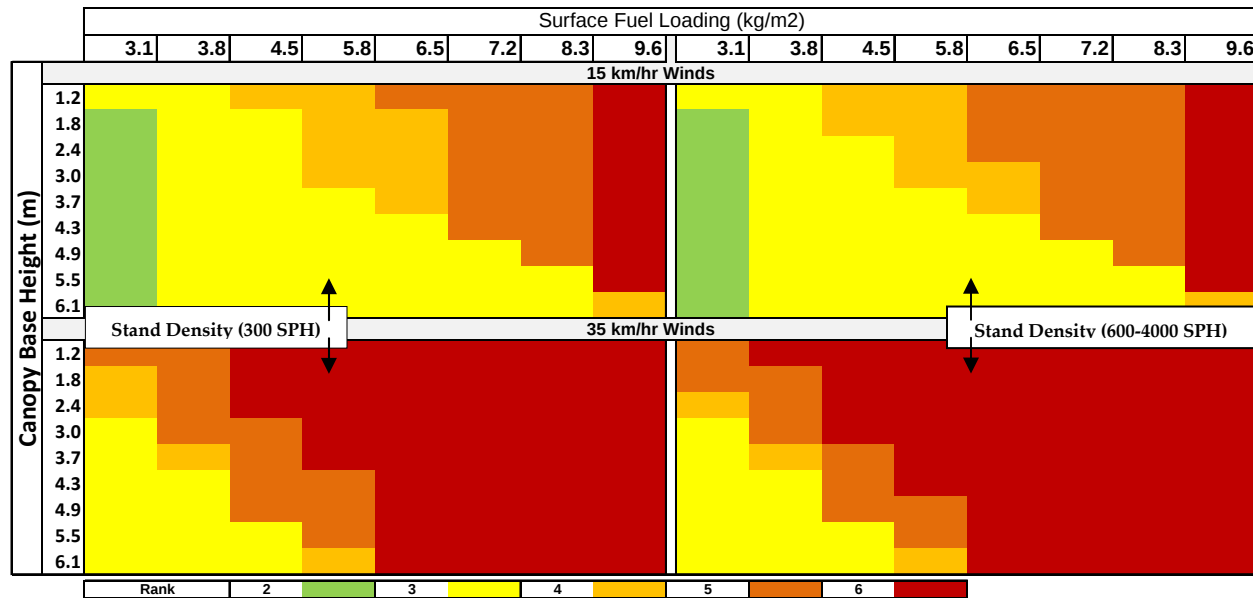


Figure 8. Stand visualizations (created in SVS) and diameter distributions that correspond to SPH (*) values in Figure 6 and Figure 7.

3.3 Canopy Base Height

Canopy base height was another important factor affecting fire behaviour. Table 3 shows how fire rank decreases as you increase the canopy base height. The fire rank at each canopy base height was the same for all stand densities modeled between 600-4000 SPH, and varied slightly for the stand modeled with 300SPH.

Table 3: Fire Rank for various surface fuel loadings and canopy base heights at 300SPH (Left) and 600-4000SPH (Right), 15km/hr winds (Top) and 35km/hr winds (Bottom).



Some key findings regarding canopy base height, as illustrated in Table 3 include:

- Based on 15km/hr winds...
- Canopy base height had very little influence on fire rank at low surface fuel loadings (<4.5 kg/m²) and lower wind speeds (15 km/hr);
- At high wind speeds (35 km/hr), regardless of surface fuel loading and stand density, stands with a canopy base height below 3 m exceeded rank 3 fire behaviour;
- Canopy base height had a stronger influence on fire behaviour than stand density;
- At higher surface fuel loadings, higher canopy base heights were required to maintain a low fire rank.

3.4 Summary

Table 4 and Table 5 summarize the recommended fuel treatments to maintain ≤ rank 3 fire or alternately a surface fire, given a range of surface fuel loadings at 15 and 35 km/hr winds respectively.

Table 4: Summary of stand component thresholds to maintain $\leq$ Rank 3 Fire or to maintain a surface fire at 15km/hr wind speeds.

15 km/hr winds				
Total Surface Fuel Loading	To Maintain $\leq$ Rank 3 Fire		To Maintain a Surface Fire	
	SPH	CBH (m)	SPH	CBH (m)
3.1	All	All	≤ 2500	≥ 2
3.8	All	All	≤ 1000	≥ 2
4.5	≤ 1500	≥ 2	≤ 1000	≥ 3
5.8	≤ 1250	≥ 4	≤ 1000	≥ 4
6.5	≤ 1100	≥ 4	≤ 1000	≥ 4
7.2	≤ 1000	≥ 5	≤ 1000	≥ 4
8.3	≤ 1000	≥ 6	≤ 1000	≥ 6
9.6	N/A	N/A	≤ 600	≥ 7

Table 5: Summary of stand component thresholds to maintain $\leq$ Rank 3 Fire or to maintain a surface fire at 35km/hr wind speeds.

35 km/hr winds				
Total Surface Fuel Loading	To Maintain $\leq$ Rank 3 Fire		To Maintain a Surface Fire	
	SPH	CBH	SPH	CBH
3.1	≤ 1200	≥ 3	≤ 1000	≥ 3
3.8	≤ 900	≥ 4	≤ 1000	≥ 4
4.5	≤ 800	≥ 6	≤ 1000	≥ 6
5.8	N/A	N/A	≤ 600	≥ 6
6.5	N/A	N/A	≤ 600	≥ 7
7.2	N/A	N/A	≤ 600	≥ 8
8.3	N/A	N/A	N/A	N/A
9.6	N/A	N/A	N/A	N/A

The results of fire behaviour modeling in this study indicate that maintaining low levels of surface fuel loading should be a primary management concern. It was also shown that stand density or basal area as a sole measure of canopy fuel loading is not sufficient. Ladder fuels (affecting canopy base height) have a large influence on fire behaviour. A high basal area or a high stand density can be maintained with little fire risk if the advanced regen and small diameter class trees are removed, if a moderate canopy base height is maintained, and as long as surface fuels are kept low.

Some specific conclusions include:

- As a rule of thumb, it appears that stand density can be maintained as high as 2000 SPH where crown base height is **greater than or equal to 2 meters** and the surface fuels are **less than 4 kg/m²**. However, as this varies with diameter class it needs to be tested with a wider range of diameter distributions.
- In stands where the fuels loadings are maintained **above 4 kg/m²** and/or the crown base height is **below 2 meters** there is little or no effect of thinning treatments on mitigating fire behaviour potential.

4.0 Fuel Management Recommendations

Based on fuel modeling at 15 km/hr winds we recommend the following fuel reduction actions:

- Maintain surface fuel loadings below **4 kg/m²** if stand resilience or fuel break conditions are desired;
- At surface fuel loading less than **4 kg/m²**:
 - Where the tolerance for risk is **moderate** (for example, in forest stands that are not within close proximity to infrastructure or other values at risk), the crown base height should be **greater than or equal to 2 meters**.
 - Where the tolerance for risk is **low** (for example, in forest stands that are within close proximity to infrastructure or other values at risk), the crown base height should be **greater than or equal to 3 meters**.
- Surface fuel loadings should never exceed **8 kg/m²**;
- If surface fuels cannot be maintained below 4kg/m² and are between **4-8 kg/m²** then the crown based height must be **greater than or equal to 3 meters**.

5.0 References

Anderson, H.E. 1982. Aids to determining fuel models for estimating fire behavior. Gen. Tech. Rep. INT-122. Ogden, UT: U.S> Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 22p.