Burn Impacts In PIR CP 633, Block 1

An Analysis Of Techniques For Measuring The Impacts Of Broadcast Burning

LM FOREST RESOURCE SOLUTIONS LTD.

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INTRODUCTION

Project Objectives

The overall purpose of this project was to test the efficacy of various tools in measuring the impacts of broadcast burning on post-harvest site conditions. More specifically, the project aimed to:

- evaluate the utility of data from unmanned aerial vehicles (UAVs) in assessing burn impacts.
- evaluate the utility of information from burn modelling by comparing it to burn information obtained from burn pins and UAV imagery.
- collect baseline data that might be used to assess vegetation response on this block in the future.

Funding for the project was provided by Westfraser's Pacific Inland Resources Ltd., SERNbc, the B.C. Government's Forests Lands and Natural Resource Operations, and LM Forest Resource Solutions Ltd.

Project Timelines

Pacific Inland Resources Ltd. (PIR) logged Section A of CP 633, Block 1 in the winter of 2016, an area in the Skeena Stikine District near Mount Horetsky in the ESSFmc biogeoclimatic zone. Post-harvest slash volumes were high because the area was logged in the winter with a deep snow pack, and there were high volumes of dead sub-alpine fir in the mature stand. Gary Quanstrom, a forester with PIR, prescribed a burn treatment for the area to reduce slash levels and promote regeneration of berry plants.

In October of 2016, after logging was complete, LM Forest Resource Solutions Ltd (LMFRS) flew the area, on behalf of PIR, with their DJI S900 UAV to obtain pre-burn RGB imagery. At this time, they also installed a number of burn pins used to measure the duff consumption that might result from burning. PIR built a fire guard around much of the perimeter of the block, and the B.C. Wildfire Service prepared the site for a potential burn. Fire weather in the fall of 2016 was not favourable, however, and no burning was conducted that year. The following year, on May 29th 2017, LMFRS flew the block again with an RBG sensor (36 megapixel Sony A7R), as well as with a thermal sensor (FLIR ProVue R) on a Matrice 600 airframe, to gain a broader understanding of pre- burn conditions, and to test infrared imagery on a test burn conducted by Wildfire Services personnel. On May 30th, 2017 the area was broadcast burned by Wildfire Services personnel using an AID device on a Bell 206. The area burned well with complete coverage and pre-burn objectives were largely achieved with only a few small escapes outside the original perimeter. On May 31st, and again on June 8th, post burn thermal and RGB imagery were acquired by LMFRS for much of the area. On October 3rd, 2017 the burn pin locations were reevaluated, as well as several other plots to determine post-burn site conditions.

METHODS

Five types of analysis were used to evaluate the impacts of this broadcast burn: burn severity ratings obtained from satellite imagery, the Canadian Forest Service (CFS) Fire Effects Model (CanFIRE), UAV image analysis, actual measurements of duff consumption, and thermal imagery taken the day after burning. Each of these methods provided a unique way to evaluate the effects of fire on key site attributes.

Burn Severity Mapping From Satellite Imagery

At the broadest level of analysis, burn severity information can be calculated using the raster data sets (30 meter pixels) available from infrared bands in Landsat 8 satellite imagery. Using a Normalized Burn Ratio, or NBR, differences between values for shortwave infrared radiation (SWIR) and near infrared radiation (NIR), both before and after the burn, can be calculated using the following equation:

$$NBR = (NIR-SWIR)/(NIR+SWIR)$$

High NIR values are observed when vegetation is healthy, and high SWIR values are observed with bare soils and burned areas. NBR is calculated from the imagery just prior to the burn and immediately following the burn. Burn severity is judged by looking at the difference between these two calculations. This process was used in this project and mirrors that used by FLNRO's Wildfire Services with their BAM severity mapping.

CFS Canadian Fire Effects Model

Fire effects modelling was also tested as a general predictor of burn impacts, in this case using the Canadian Fire Effects Model (CanFIRE)[1]. Guidance on use of the model was provided by Dr. Bill de Groot, a research scientist with the CFS specializing in fire danger rating, fire behaviour, and fire effects modeling. The model incorporates CFS fire weather index values and environmental characteristics such as initial forest floor fuel loads, dead woody debris fuel loads, and standing timber fuel types, to predict the impact of a prescribed burn.

Fire weather index inputs were provided by Jeff Walsh from FLNRO's Wildfire Services in Telkwa, B.C. Data were obtained from a weather station located near the burn site between May 18th and July 2nd, 2017, including May 29th (the day of the burn). Fire weather indices generated from this data included:

- Fine Fuel Moisture Code (FFMC) - a measure of flammability or rate of ignition based on the amount of moisture found within the fine fuels layer of the forest floor.
- Duff Moisture Code (DMC) - the moisture content of the duff layer, including loosely compacted organic material and medium sized woody material, and provides insight into the amount of expected fuel consumption within this layer.
- Drought Code (DC) - the moisture content of compacted organic matter, found deeper within the forest floor. This rating provides insight into the smoldering effect of deep fuels, and the likelihood of long lasting hotspots.
- Initial Spread Index (ISI) - a measure of the rate of fire spread, based on the combination of wind characteristics and the FFMC rating.
- Buildup Index (BUI) - a measure of the total amount of fuel available, as a function of the DC and the DMC rating.
- Fire Weather Index (FWI) - indicates overall fire intensity, by combining indices taken from the ISI and the BUI.

Known pre-burn values were used in the model to obtain predicted impacts, in particular on forest floor and coarse woody debris consumption, and this was compared to field data, collected after the burn. Specific inputs required for the model included:

- Slash Type (S-1, S-2, or S-3)
- Stand Area (ha)
- DC Value
- Wind Speed (km/h)
- FFMC
- BUI Value
- Forest Floor Depth (cm)
- Litter and Lichen Fuel Loads (kg/m^2)
- Duff Fuel Loads (kg/m^2)

[1] Canfire Model: see http://www.glfc.forestry.ca/canfire-feucan/index.cfm

- CWD Fuel Loads (kg/m^2)
- Fine Woody Debris Fuel Loads (kg/m^2)

Methods used to determine fuel loading followed guidance in McRae et al (1979)[2]. The Canfire model default values for litter and lichen, and for fine woody debris, in kg/m^2 were used. CWD values were obtained by measuring individual pieces along various transects on pre-burn imagery (as described below under UAV Image Analysis) to obtain volume, and then converted to kg/m^2 using conversion factors in table 3 of the McRae et al report (1979). Duff fuel loading was obtained by using measured pre-burn duff depth and the graph in figure 19 in McRae et al (1979) which relates duff depth to duff fuel loading in kg/m^2.

UAV Image Analysis

Pre-Burn Slash Imagery

To get pre-burn fuel loading, RGB imagery was collected with a 36 megapixel RGB camera mounted on a S900 hexacopter in October 2016. Photos obtained were then used to create a georeferenced orthomosaic (Figure 1).

FIGURE 1: AN EXAMPLE OF RGB IMAGERY SHOWING SLASH LEVELS PRIOR TO BURNING.

Pre-burn slash imagery consisted of mostly the perimeter of the block, with some of the surrounding standing timber incorporated into the images as well. In the office, nine 30m long photo transects were randomly chosen within three different strata (low, medium, and high slash loading) using ArcGIS (Figure 2). Three transects were established in pile areas, three were placed in areas with frequent

[2] Douglas J. Mcrae, Martin E. Alexander and Brian J. Stocks. 1979. Measurement And Description Of Fuels And Fire Behavior On Prescribed Burns: A Handbook. Great Lakes Forest Research Centre, Sault Ste. Marie, Ontario, Report O-X-287

accumulations, and three were placed in areas with dispersed slash loading (Figure 3). Using the measuring tool in Arc, the intersect diameter of each piece of slash greater than 7.0 cm diameter was measured and recorded in centimeters. Volume was then calculated using the following equation:

$$Yi = (\pi^2/L)*(ID^2)$$ Where L = Transect length, and ID = Intersection diameter.

FIGURE 2: AN EXAMPLE OF A 30M TRANSECT (PINK LINE).

FIGURE 3: AN EXAMPLE OF EACH OF THE 3 STRATA TYPES: A PILE AREA, A CONCENTRATION AREA, AND A DISPERSED AREA

Post-Burn Slash Imagery

On both May 31st and June 8th 2017, additional RGB imagery was captured using a UAV and orthomosaics were created from the photos to showcase the post-burn landscape, and to determine slash levels after the fire (Figure 4). Using the same nine 30m transects used on the pre-burn imagery, slash loading was determined using the same methods used in the pre-burn slash analysis (Figure 5).

FIGURE 4: AN EXAMPLE OF THE RBG IMAGERY ASSOCIATED WITH THE POST-BURN LANDSCAPE, ONE DAY AFTER THE BURN.

FIGURE 5: ONE OF THE 30M TRANSECTS ON THE POST-BURN IMAGERY.

In addition to the nine pre- and nine post-burn transects, three 30m transects were chosen from the photos and then measured on the ground as a way of validating photo interpreted volume estimates (Figure 6). Each of these lines was measured both on the ground and on the photos to compare volumes. All pieces with an intersection diameter greater than 7.0 cm were measured.

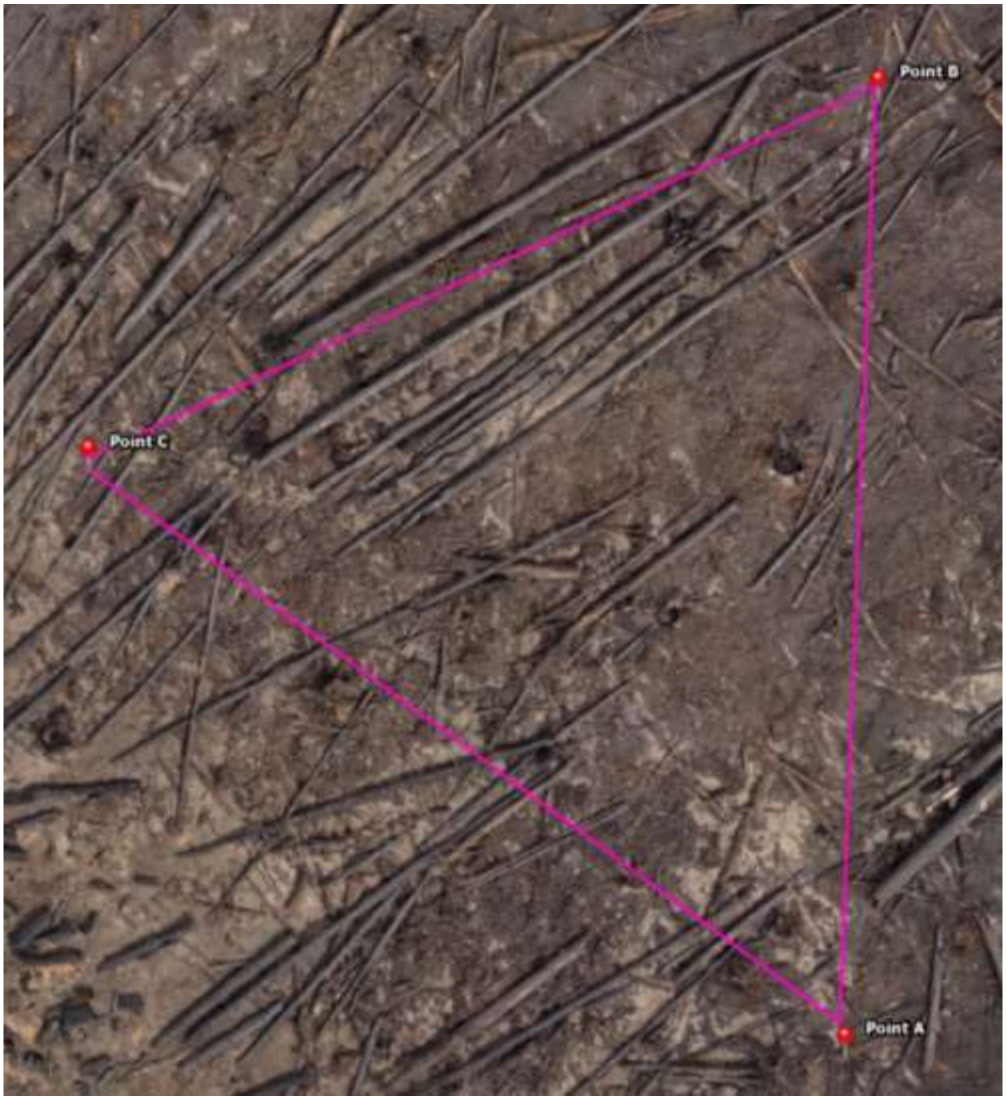

FIGURE 6: PHOTO VALIDATION TRANSECTS USED TO COMPARE VOLUMES CALCULATED FROM IMAGE ANALYSIS WITH VOLUMES CALCULATED FROM GROUND MEASUREMENTS

Burn Pin Data and Post Burn Forest Floor Consumption

Prior to the burn, 11 depth-of-burn pins were inserted into the forest floor as a way to measure the total amount of duff reduction after the burn. Pins were inserted so that the metal crossbar was level with the pre-burn duff levels, so that pre and post duff levels could be compared.

In addition to the 11 pin locations, 16 additional post-burn plots were chosen (each with a radius of 5.62 meters), to obtain a more comprehensive understanding of how prescribed burns can affect environmental characteristics such as duff abundance, soil exposure, and vegetation composition. These additional plot locations were distributed so that comparisons could be made between burned and unburned clearcuts, as well as burned and unburned forested locations. Unburned clearcut plots were established in an adjacent cut block, while all forested plots were established in adjacent forested areas In each of the 27 plots, the following data was collected:

- humus depth (cm)

- humus type
- depth of burn (only applicable for the 11 plots with pre-burn pins)
- % mineral soil exposure
- % CWD cover (pieces greater than 7 cm in diameter)
- % fine fuel coverage (pieces less than 7 cm in diameter)
- % cover of shrubs, herbs, and mosses.

Post-Burn Infrared Imagery

During image acquisition on May 31st 2017, infrared imagery along the perimeter and north end of the block was captured using a UAV equipped with a radiometric thermal camera to detect hotspots (Figure 7). This part of the project was not directly related to the assessment of burn impacts but did reveal where the fire was hottest (and therefore likely to have the greatest impacts). The radiometric camera provides temperature data for each pixel in the image which could be useful in correlating temperature with impacts.

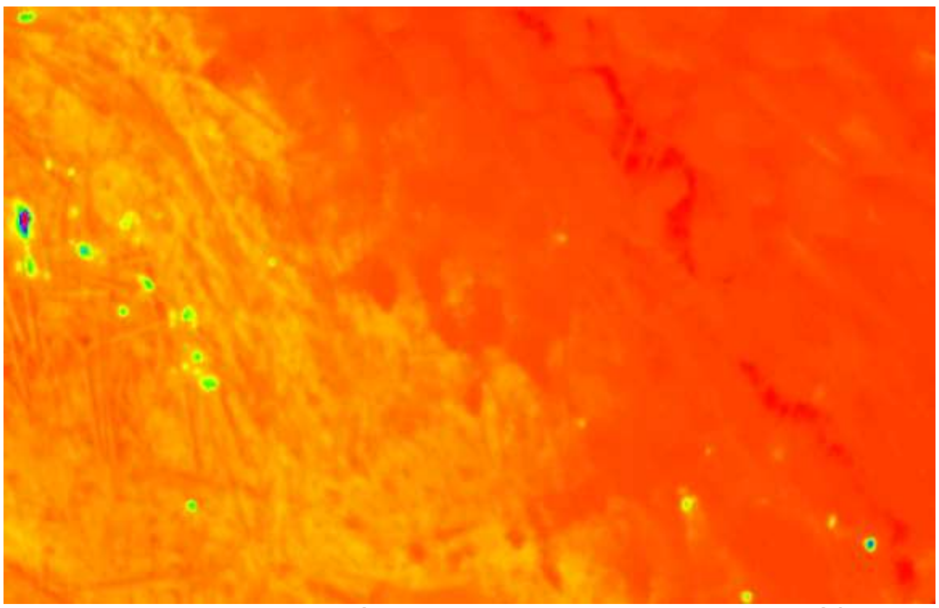

FIGURE 7: AN EXAMPLE OF INFRARED IMAGERY: GROUND TEMPERATURES AVERAGED ABOUT 20 DEGREES CELSIUS (ORANGE AREAS) WHILE HOT SPOT TEMPERATURES VARIED FROM 80 TO 255 DEGREES CELSIUS (GREEN AND PINK AREAS) ONE DAY AFTER THE BROADCAST BURN.

The thermal values were validated with a combination of temperature probes placed on the surface of the block and a hand held infrared thermometer.

RESULTS

Satellite Burn Severity Ratings

The results of the Landsat 8 burn severity mapping indicated that overall, this cutblock had a relatively high burn severity (Figure 8). Pixels with high burn severity ratings (dark red) tended to be located near the center of the block or where piles were burned, whereas lower rated pixels were located along the road where there were no piles, and along block edges. These results were consistent ground based measurements and the UAV-based infrared imagery.

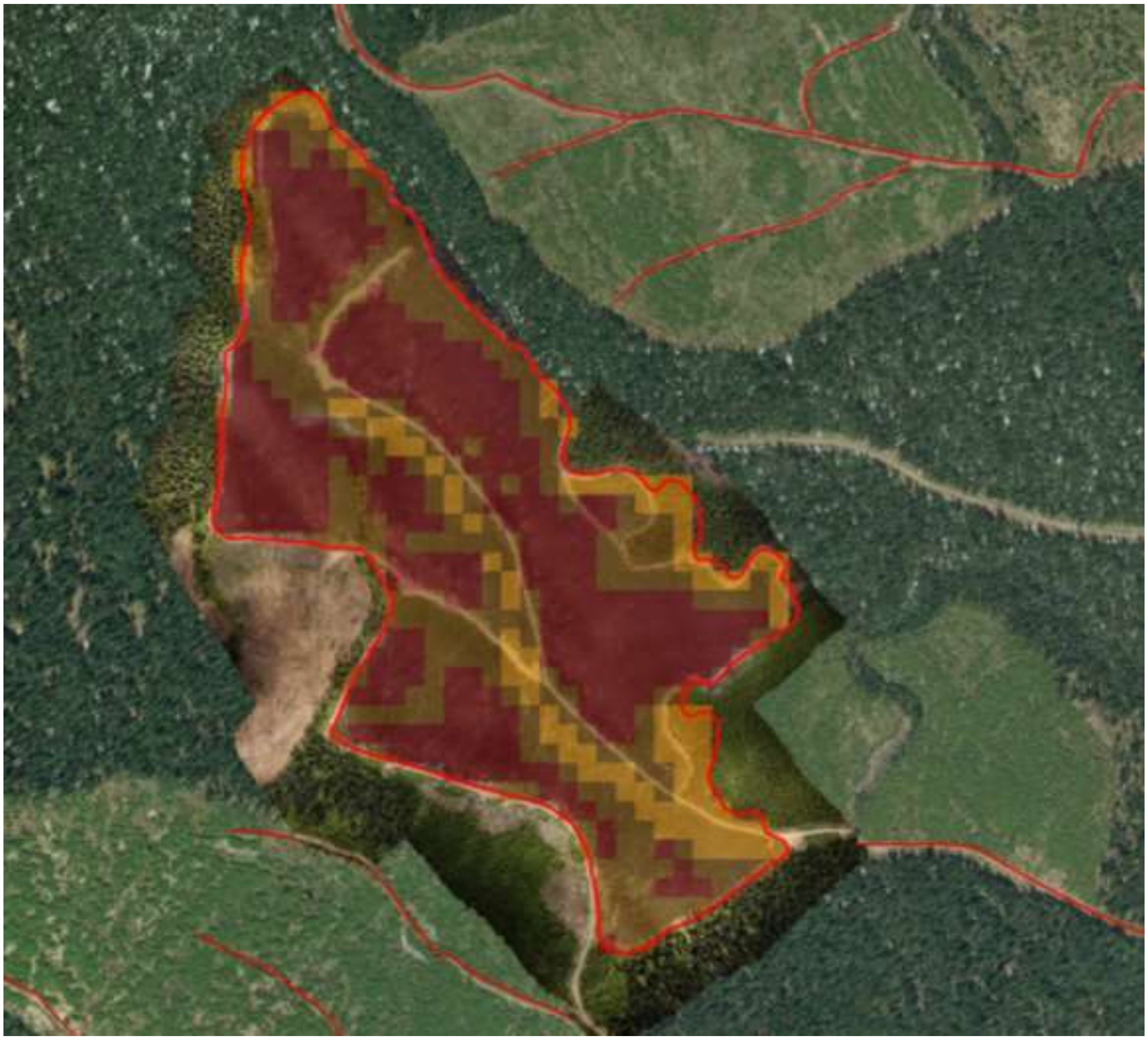

FIGURE 8: BURN SEVERITY MAP FOR CP 633, BLOCK 1: RED PIXELS REPRESENT A HIGHER SEVERITY BURN, BROWN PIXELS REPRESENT MEDIUM SEVERITY, AND YELLOW REPRESENTS LOW SEVERITY.

The burn severity mapping provides a tangible example of potential burn impacts and it is something that is relatively easy and fast to complete. It is important to understand, however, that severity does not necessarily equate to burn intensity. Intensity, broadly speaking, refers to the overall characteristics of the fire itself, in terms of heat, duration, and energy levels associated with the burn. Severity, on the other hand, refers to the relative difference in infrared values, and the thresholds for severity classes are somewhat subjective. To be useful, severity classes must be correlated with burn impacts through on the ground sampling, or other methods discussed above, that more directly address burn impacts.

Impacts Predicted By The CFS CanFIRE Model

The CanFIRE Model simulates the consumption of litter, upper and lower duff, dead woody debris (CWD), total forest floor, and total surface fuels when an area is burned. In this study we focused on consumption of dead woody debris and duff. Table 1 shows that the CanFIRE simulation predicts substantially lower coarse woody debris and forest floor consumption than what was observed in the field. The pre-fire data (based on image analysis) indicated that there was, on average, 11.1 kg/m^2 of CWD greater than 7 cm in diameter at the point of intersection prior to the burn (see also the section below on Impact on Fuel Loading Based On Image Analysis). Post-burn image analysis showed there were, on average, 6.1 kg/m^2. Using actual fire weather indices and pre-burn slash conditions, the model predicted post-burn CWD levels of 9.7 kg/m^2. The model also predicted lower levels of forest floor consumption than what was observed, although the difference between predicted and observed was lower than for coarse woody debris. Pre-burn forest floor levels were measured to be approximately 7.5 kg/m^2, with post burn levels measured at 4.0 kg/m^2, while the model simulation indicated there would be roughly 6.1 kg/m^2.

TABLE 1: MEASURED PRE-AND POST BURN CWD AND DUFF LEVELS VERSUS LEVELS MODELLED IN CANFIRE.

	Pre-Burn (kg/m²)	Post-Burn Model Predictions (kg/m²)	Post Burn Measured (kg/m^2)
CWD	11.1	9.7	6.1
Forest Floor (litter + duff)	7.5	5.7	4.0

Per Bill de Groot, a CFS expert on CanFire, the model is a reasonably good predictor for large fires at the landscape-level, but is less reliable at the site level, particularly with deep-burning fires. Based on findings in this study, the tool is sufficiently accurate to obtain a rough estimate of burn impacts (within about 50% of measured values) if data on fire weather and environmental conditions at the site of interest are available. More examples will be needed over time to calibrate the model to local fuel types and weather conditions to obtain more reliable estimates.

Measured Impact On Surface Conditions

The impact of the burn on surface features such as humus horizons, slash composition, and vegetation was measured at the burn pins and in separate plots within and adjacent to the burn block. Because no pre-burn vegetation sampling was completed for the area, some plots were established in ecologically similar areas adjacent to it. Within the block, the area was mostly transitional between the ESSFmc and SBSmc2/06 and 09 site series (relatively rich and wet). Table 2 shows that the depth of duff consumption was less than half the original depth at, on average, only 3.1 cm. In forested areas, with lower pre-burn slash levels, duff consumption was even lower at 1 to 2 cm. It is apparent that there are some carbon and nitrogen losses through volatization during burning but much of the organic capital remains after buring.

TABLE 2: COMPILED RESULTS OF MEASUREMENTS TAKEN IN THE FIELD, AFTER THE BURN.

	Current Average Humus Depth (cm)	Average Depth of Burn (cm)	Average Mineral Soil Exposure (%)	Average CWD Coverage (%)	Average Fine Fuel Coverage (%)	Average Shrub Coverage (%)	Average Herb Coverage (%)	Average Moss Coverage (%)
BURNED Clearcut	4.3	3.1	4.6	13.9	6.4	11.6	10.5	0.0
BURNED Forest	5.5	1.5	0.0	10.0	8.3	30.0	38.3	20.0
UNBURNED Forest	6.1	N/A	0.0	7.0	3.3	61.7	45.0	23.3

Based on the relatively low levels of duff consumption, one could also assume that shrub species with root systems that extend into the mineral soil will likely survive. Rhizomatous species, including many of the berry species should resprout although, the above ground parts of the plant would be killed with a burn of this intensity. Post-burn observations indicate that significant resprouting did occur within the burn area just a few weeks after burning (primarily thimbleberry – Figure 9), although shrub and herb cover were lower in the burned block than in adjacent unburned areas. It is probable that vegetation cover will be greater in burned areas in the future with further resprouting and open stand conditions, although it is too early to form any definitive conclusions about percent cover.

FIGURE 9: POST-BURN VEGETATION RESPONSE.

Table 2 also shows that there is more mineral soil exposure in the burned area than in the unburned areas but field observations indicate that this most likely resulted from mechanical disturbance of the burned block rather than burning. As one would expect, the average percent cover of course woody debris and fine fuels also decreased between the burned and unburned areas, although such a comparison is of limited utility given the potentially different fuel loads on these different areas prior to burning.

Impact on Fuel Loading Based On Image Analysis

The results of the image analysis indicate that fuel loads can be reduced dramatically through broadcast burning. Table 3 summarizes the total volume of fuels greater than 7 cm in diameter at the butt in three different fuel loading strata. Areas where slash had been piled at the roadside had the greatest reduction in volume, followed by accumulation areas within the block, while areas with dispersed slash experienced the least change. It can be expected that the hottest burn would have occurred in areas with higher slash loads although this is not always the case. In a less intense fire, where some areas do not burn well, or there are no fine fuels to stoke the fire, larger coarse woody debris may not burn. Table 3 also reveals a minor anomaly for transect 9, in which post burn volume was slightly higher than pre-burn volume. This was likely caused by an abundance of fine woody debris obscuring some pieces in the pre-burn imagery.

TABLE 3: PRE AND POST BURN FUEL LOADING IN THREE FUEL STRATA.

Horetsky Photo Fuel Loading Summary			
Transect	**Stratum**	**Burn Timing**	**Volume (m^3/ha)**
1	**Pile Area**	**Before**	2356
		After	396
2	**Pile Area**	**Before**	1075
		After	421
3	**Pile Area**	**Before**	1197
		After	128
4	**Area Of Accumulations**	**Before**	779
		After	470
5	**Area Of Accumulations**	**Before**	414
		After	244
6	**Area Of Accumulations**	**Before**	284
		After	243
7	**Dispersed Area**	**Before**	183
		After	134
8	**Dispersed Area**	**Before**	260
		After	257
9	**Dispersed Area**	**Before**	394
		After	399

Although some pieces can be missed, and there is potential for inaccuracies in georeferencing imagery, making measurements inaccurate, this study shows that image analysis of slash loading can be quite accurate. Results of the ground truthing exercise shown in table 4 indicate a reduction in slash volumes following burning, and good coherence between ground measurements and photo measurements of the same areas (a 4% difference on average). Inconsistencies between the ground truthing transects and the post-burn image analysis transects were likely caused by inaccurate walking along pre-determined transect lines.

TABLE 4: COARSE WOODY DEBRIS VOLUMES BASED ON PRE-BURN IMAGERY, POST-BURN IMAGERY, AND GROUND TRANSECTS.

Horetsky Ground Truthing Summary		
Transect	**Measurement Type**	**Volume (m^3/ha)**
A to B	**Pre-Burn Image Measurement**	161
	Post-Burn Image Measurement	122
	Post-Burn Ground Measurement	131

B to C	Pre-Burn Image Measurement	132
	Post-Burn Image Measurement	117
	Post-Burn Ground Measurement	113
C to A	Pre-Burn Image Measurement	466
	Post-Burn Image Measurement	180
	Post-Burn Ground Measurement	182

CONCLUSIONS AND RECOMMENDATIONS

In conclusion, the results of this analysis suggest that there are a number of accurate, viable information sources that can be used to evaluate and understand burn impacts. Using satellite imagery to derive burn severity, for instance, is useful for understanding where to allocate efforts in terms of restoration (after a wildfire for example), and provides a broad level visual representation (30 metre pixels) of how fire interacts on the landscape. Similarly, the CanFIRE model may be useful in providing users with a broad understanding of the potential effects of fire in terms of fuel consumption and fire behavior, and help them decide if fire management and forest management objectives can be met before any expenditures are incurred. Thermal imagery provides detailed quantitative data at a resolution of 8 to 10 cm pixels and is also a useful tool for understanding fire intensity if it can be acquired shortly after burning. RGB imagery has proven (in this and other projects) to be accurate in terms of estimating before and after fuel loading, and is potentially a more efficient method of volume estimation when compared to conventional ground based methods. Ground based measurements are also a reliable way of measuring burn impacts on various site features but sample plots and transects are also subject to sampling error and they do not provide a permanent photographic record that can be revisited, and reused in many different applications, the way that UAV imagery does.

With increasing interest in climate change adaptation, and an increase in the frequency and magnitude of wildfires in the central interior, land managers are increasingly interested in using prescribed fire as a tool to achieve fire, silviculture, and habitat objectives. Acquiring ecological data and fire weather data, and conducting before and after burn assessments is crucial to understanding the effects of fire on key site features such as coarse woody debris, forest floor condition, and vegetation cover. More research is needed to correlate fire weather and site conditions with burn impacts in the central interior of B.C. This study was a useful first step in illustrating the range of tools that can be employed to do this. It is recommended that licensees and government work together in implementing additional burns with the objective of better understanding burn outcomes, and that UAV imagery, in combination with limited ground sampling to validate image analysis, be acquired before, during, and after burning along with traditional fire weather data. In the long run, it will also be necessary for government to create a more supportive legislative and policy framework to facilitate better fuel and fire management.

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APPENDIX I – Additional Imagery

Slash levels in 2016 in CP633, Block 1.

Pre-Burn Fire Guarding

Test burning and black lining May 29th.

Infrared image (right) showing hot spots (not flame) in the same area as the photo on the left, taken at the same time.   Hottest spots are 205 degrees C with other spots showing up that are only 55 degrees C but still discernable as spots.

An area where fire guarding was not effective.

May 30th broadcast burn results – orthomosaic from imagery acquired June 8th.

One day after the burn.

Same spot as previous clip, 9 days after the burn.

Fringe kill one day after broadcast burning with a few hotspots persisting.

Two hotspots (one in a snag) one day after burning, east side of block.

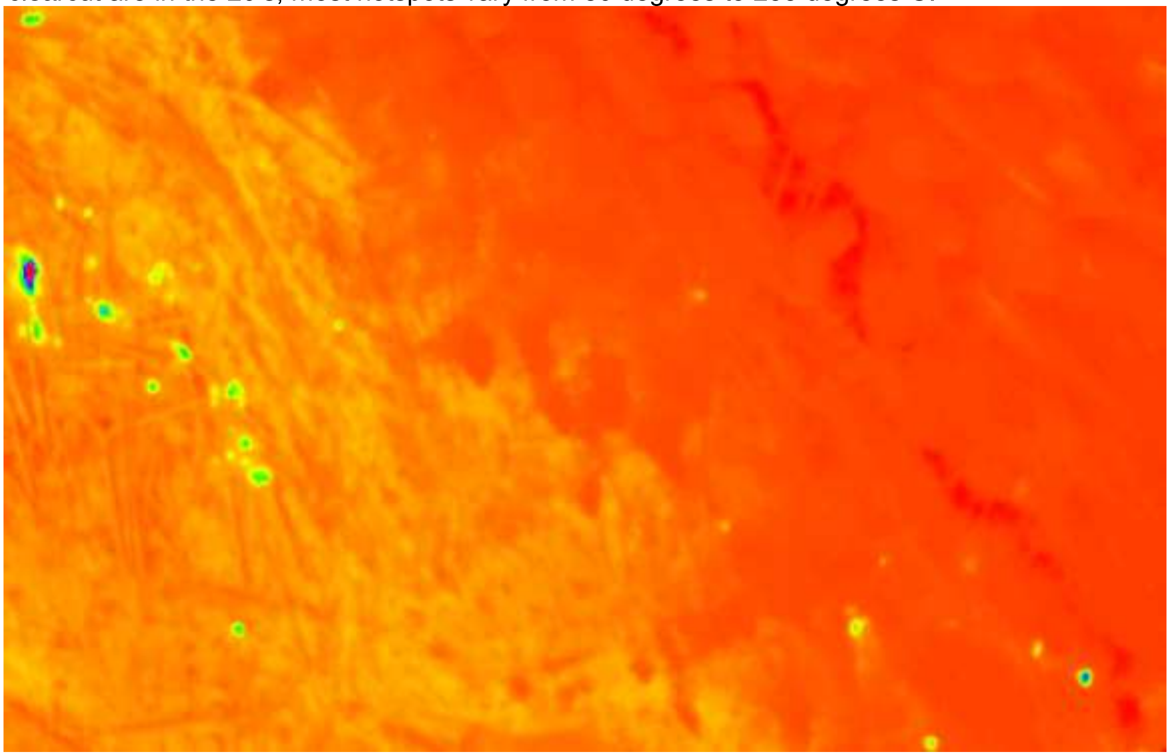
Several hotspots on the west edge of the plantation, east of the fire, one day after burning.

Burn area in the adjacent plantation one day post broadcast burning, with WMS staff on hand.

An effective fireguard in the adjacent plantation with extinguished escape spots in the mounded area.

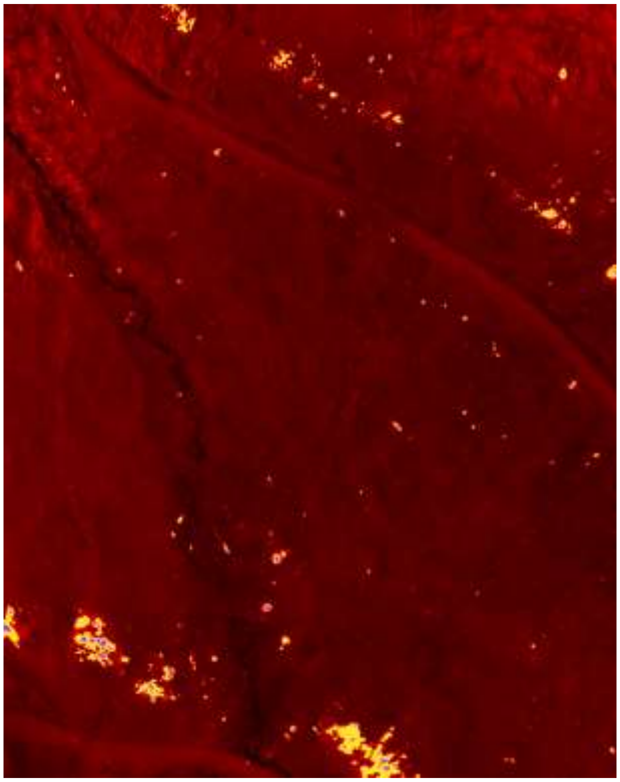
Clip of an RGB image in area in which thermal imagery was captured.

Thermal image in the same spot as previous image – ground temperatures (dark yellow and orange) in the clearcut are in the 20's, most hotspots vary from 80 degrees to 255 degrees C.



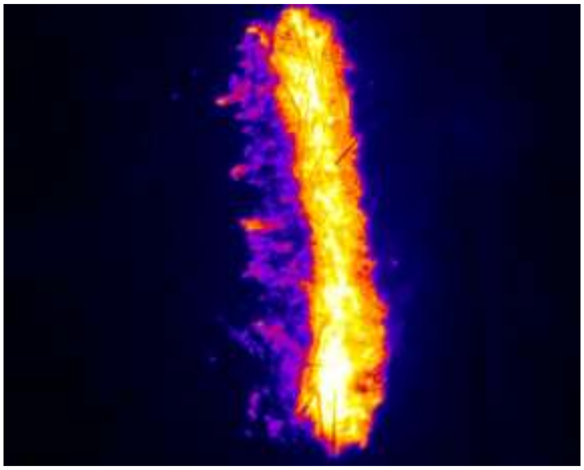
Hotspots > 100 degrees C (red) draped over the georeferenced orthomosaic.

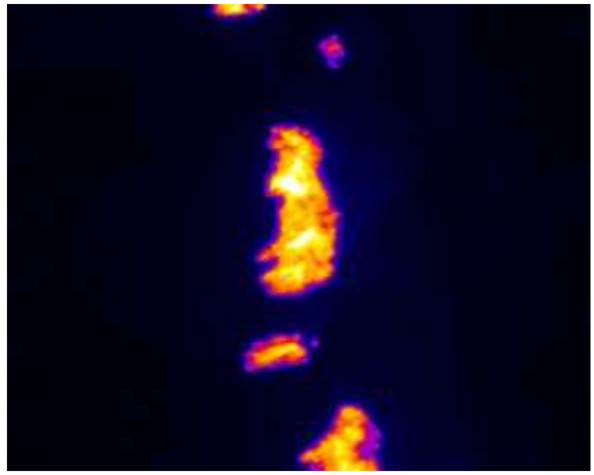
Portion of a thermal image orthomosaic showing hotspots (yellow and purple) on May 31st (left) the day after broadcast burning and an rgb orthomosaic of the same area the same day (right).



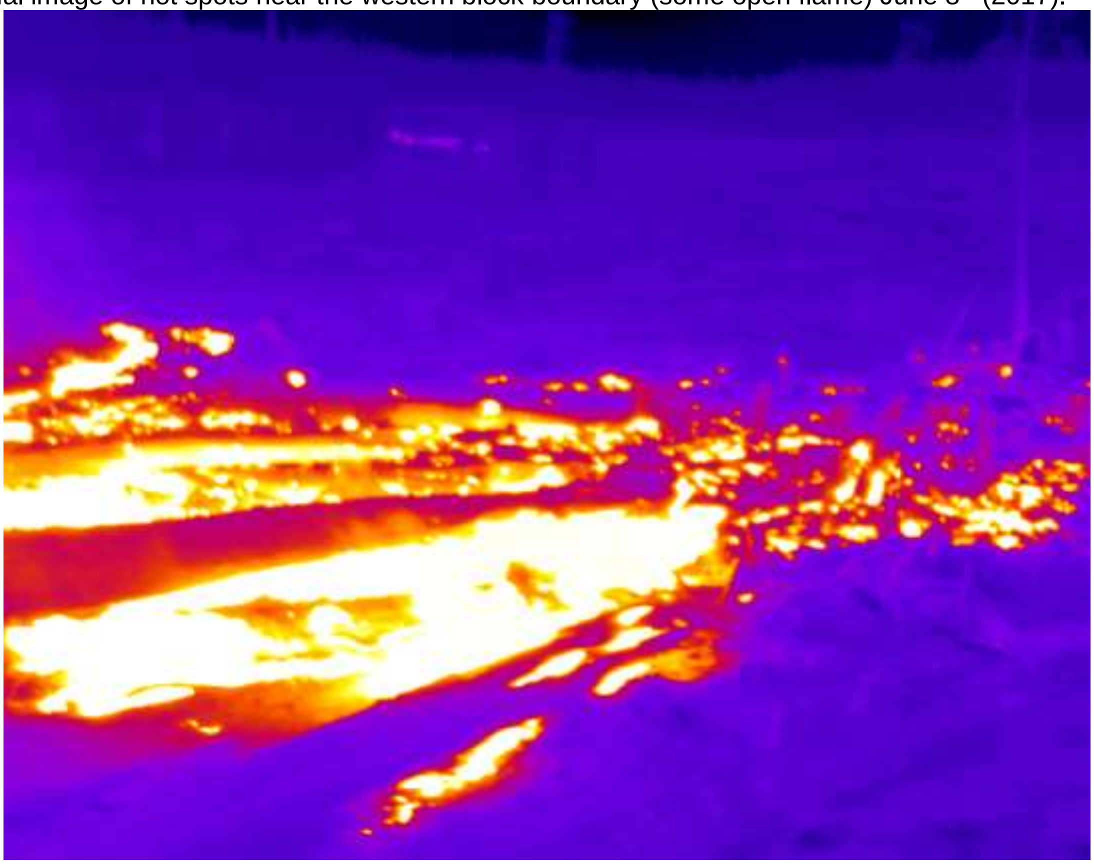
Burn piles RGB (2016).

Thermal images of the burn piles (2016).





Thermal image of hot spots near the western block boundary (some open flame) June 8th (2017).



Thermal images, June 8th, 2017.