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FUEL TREATMENT INTENSITY AND FIRE BEHAVIOUR:

EXPERIMENTAL FIRES IN MULCHED FUELS AT PELICAN MOUNTAIN

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ABSTRACT

This study investigated the effects of applying three mulch treatment intensities on fuel bed characteristics and the resultant fire behaviour. This is a companion report to a previously published report titled *Mulching productivity in black spruce fuels: Productivity as a function of treatment intensity*. The findings of these fire behaviour trials, in conjunction with productivity results, can assist fuel management practitioners in developing appropriate cost-effective mulching prescriptions.

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TECHNICAL REPORT NO.18

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BACKGROUND

Mulching, a mechanized forest fuel treatment, is often prescribed in Alberta as a technique to reduce aerial fuels, increase stem spacing, and reduce the crown bulk density of a stand, thereby reducing the potential for active crown fire in forested stands within or adjacent to a community or other values at risk. During these operations, the reduction of aerial fuel is achieved by selective mulching of unwanted stems to attain the desired crown spacing or by complete mulching across an entire treatment area.

Mulching operations in boreal forest black spruce (*Picea mariana*) stands are typically conducted during the winter, when the ground is frozen, to permit access into areas with a high water table and to reduce ground disturbance. Mulching operations under winter conditions result in a layer of chips being deposited on top of the existing layers of moss and other surface fuels. Depending on the depth of snow, dead woody debris and other surface fuels can be mulched as part of the fuel treatment.

Experienced operators engaged in industry operations such as right-of-way clearing and maintenance are accustomed to creating a uniform fuel bed of fine and medium-sized chips, with little residual round wood or intact stems remaining in the surface fuel layer. To achieve a uniform bed of fine and medium-sized chips, multiple passes with a mulcher are often required, which can increase the cost of the operation. Fuel managers are interested in exploring the cost-effectiveness of these treatments and understanding how different treatment intensities affect machine productivity (cost) and fire behaviour potential (effectiveness).

In February 2018, comparative productivity trials were conducted at the Pelican Mountain FireSmart Fuel Management Research Site to evaluate the impact of different treatment intensities on mulcher productivity. The results from this productivity study, in conjunction with a clearer understanding of fire behaviour exhibited in these different mulch fuel beds, can assist fuel managers in prescribing a mulch intensity that reduces wildfire risk and is economically viable.

OBJECTIVES

Unit 2 at the Pelican Mountain FireSmart research area was subdivided into three subunits, which were mulched at three distinct treatment intensities. In August 2018, Alberta Agriculture and Forestry collaborated with FPInnovations and the Canadian Forest Service to conduct comparative fire behaviour trials in the three distinct fuel beds to evaluate the impact of the different fuel treatment intensities on fire behaviour. The first objective of this research project was to measure machine productivity when applying the three treatment intensities.

The second objective, addressed in this technical report, was to document and compare fire behaviour in the resultant fuel environments by measuring flame height, rate of spread, and heat flux.

STUDY SITE

The Pelican Mountain FireSmart Fuel Management Research Site[1] was developed by Alberta Agriculture and Forestry to conduct wildfire research that will contribute to the development of scientifically based community protection strategies and enhance knowledge about the effectiveness of forest fuel treatments in modifying fire behaviour. Unit 2 at this research area was dedicated to applying varying intensities of mulch fuel treatments and studying the ability of these treatments to modify fire behaviour.

Mulch fuel environments

Unit 2 was delineated into three subunits (Figure 1) that were mulched at different treatment intensities to produce three areas of distinct mulch fuel beds. A more detailed explanation of the treatment techniques that were applied in these areas can be found in the companion report (Hvenegaard 2019) published by FPInnovations.

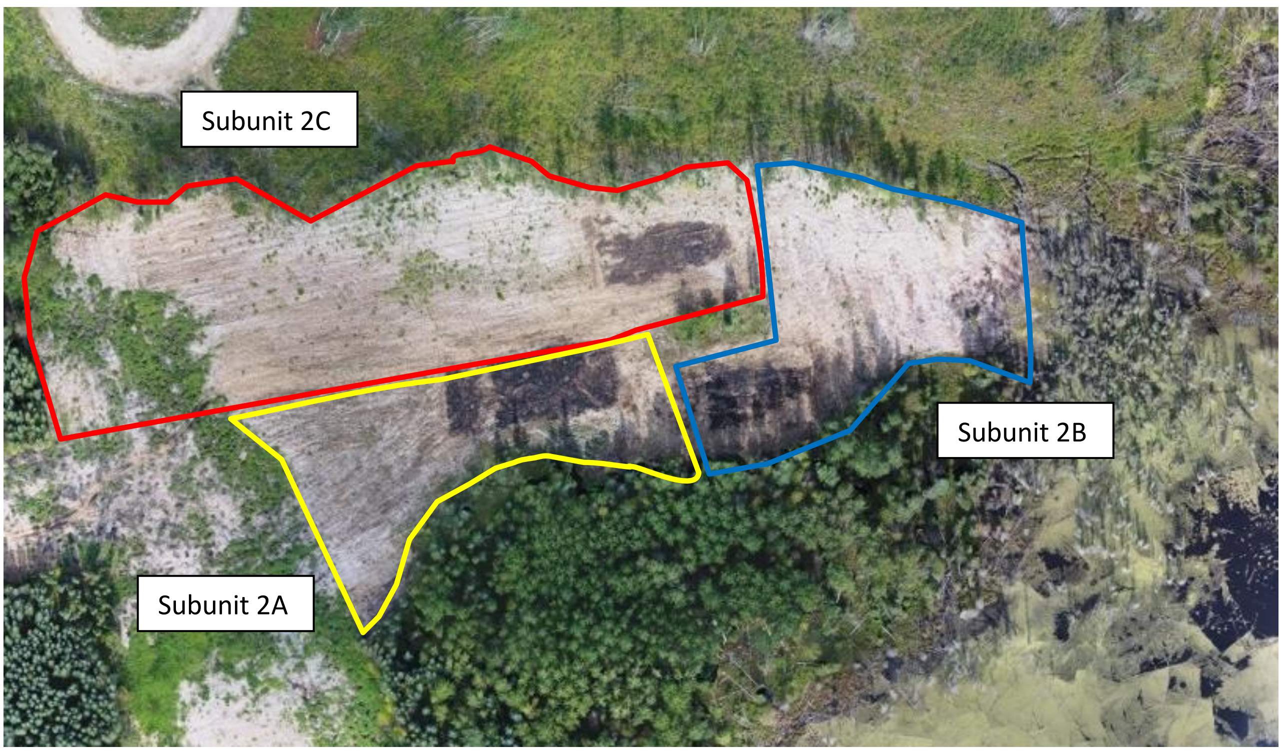

Figure 1. The subunits in Unit 2, with different mulch intensities applied. Image captured after experimental burns.

[1] For more information about the Pelican Mountain FireSmart research area, see the Canadian Wildland Fire and Smoke Newsletter

The differences between the mulch fuel beds in the three subunits are visually obvious. The primary differences in the low-intensity treatment subunit are the relatively minimal amount of mulch debris particles, greater volume of coarse woody debris, and undisturbed moss layer (Figure 2). This surface fuel layer is classified as coarse mulch.

Figure 2. Coarse mulch fuel bed resulting from a low-intensity mulch treatment.

A normal-intensity mulch treatment typically results in a fuel bed with most aerial and surface fuels processed into chipped debris. Some disturbance of the duff layer occurs. The fuel bed qualities of mulch treatments are often determined by the type of mulching head, amount of snow cover, and number of passes that a machine makes in the treatment area. The fuel layer created in this subunit (Figure 3) was typical of the fuel layer that is often created in utility corridors. The fuel layer created by the normal-intensity mulch treatment was classified as regular mulch.

Figure 3. Regular mulch fuel layer resulting from a normal-intensity mulch treatment.

The key characteristics of the high-intensity treatment were the high percentage of mulched debris in size classes 1 and 2, with the greatest extent of mixing of duff and mineral soil (Figure 4). By comparison, the normal-intensity treatment resulted in a fuel layer with little mixing of the duff layer.

Figure 4. Fine mulch layer resulting from a high-intensity mulch treatment.

Fuel inventories conducted by the Alberta Wildland Fuels Inventory Program crews yielded fuel loading and size class distribution of these mulch fuel layers (Table 1). Mulch fuel loading and size class distribution were quantified using destructive sampling of mulch fuel beds, with sorting and measuring of individual mulch particles (Schicks & Wotton, 2015). Measurements of mulch particles were taken across the minimum thickness of the particle, with size classes corresponding to those established by McRae, Alexander, and Stocks (1979).

Table 1. Post-treatment debris loading

Subunit (mulching intensity)	Mulched debris loading (t/ha) and percentage of total					
	Diameter SC (cm)					Overall loading
	Litter and SC1 (0.00–0.49)	SC2 (0.50–0.99)	SC3 (1.00–2.99)	SC4 (3.00–4.99)	SC5 (5.00–6.99)	
2A (low)	32.9 (54.8)	7.8 (13.0)	8.2 (13.6)	9.3 (15.4)	1.9 (3.2)	60.1 (100)
2B (normal)	96.9 (58.3)	28.2 (17.0)	32.8 (19.8)	8.2 (4.9)	0.0	166.1 (100)
2C (high)	64.7 (69.1)	13.1 (14.0)	14.6 (15.5)	1.3 (1.4)	0.0	93.7 (100)

SC, Size class

METHODS

Plot design

The burn plots in each subunit were oriented in line with the predominant west winds in this area. In each plot, an array of flags was established to allow the researchers to record the time of flame passage at each flag to calculate an ongoing rate of spread across each plot (Figure 5). Each plot was instrumented with three heat flux sensors (Figure 6) to record the quantity of energy generated by the flame front in each plot. A range pole was positioned in front of an in-fire camera to document the flame length at that point. Depth of burn pins were positioned at each flag in the array.

Figure 5. Coarse mulch subunit instrumented with array of flags to document rate of spread.

Figure 6. Installing heat flux sensors in the fine mulch fuel bed.

Fire behaviour trials

Comparative fire behaviour trials were conducted in Unit 2 on August 21 and 22, 2018. Simultaneous line ignition was initiated in each subunit on the upwind side of a predetermined burn area (Figure 7). As the fire spread through the subunits, researchers recorded the time that the base of the flame front passed each flag (Figure 8).

Figure 7. Line ignition in the coarse mulch fuel bed.

Figure 8. Collecting the rate of spread data in the array of flags in the regular mulch fuel bed.

RESULTS

Weather conditions and Fire Weather Index (FWI) values indicated a high to very high fire hazard rating[2] (Table 2). Fuel moisture codes provide a numerical rating of the relative fuel moisture of different fuel components, while fire behaviour codes provide a relative indicator of potential fire behaviour in a standard fuel type (mature jack pine) (Hirsch, 1996).

Table 2. Weather and FWI values

	Weather values				FWI values					
					Fuel moisture codes			Fire behaviour codes		
Date (dd/mm/yyyy)	Time (hh mm)	Temp. (° C)	Relative humidity (%)	Average wind (km/h)	FFMC	DMC	DC	ISI	BUI	FWI
21/08/2018	1557	29	25	5 G8	90	42	284	5	61	16
22/08/2018	1324	29	29	10 G17	90	45	292	7	65	20

BUI, Buildup Index
DC, Drought Code
DMC, Duff Moisture Code

[2] Alberta Wildfire. Understanding Fire Weather. https://wildfire.alberta.ca/wildfire-status/fire-weather/understanding-fire-weather.aspx

FFMC, Fine Fuel Moisture Code
ISI, Initial Spread Index

Fire behaviour

August 21 trials

Line ignition in the three subunits was commenced at 1557. Low wind conditions limited fire behaviour in all of the subunits. In the high-intensity mulch subunit, burning was not sustained beyond the influence of the drip torch fuels. The overall rate of spread in the normal-intensity subunit and low-intensity subunit was calculated to be 0.16 m/min and 0.27 m/min, respectively (Table 2).

August 22 trials

With stronger winds the next day, fire behaviour was more aggressive, and the highest rate of spread and fire intensity was observed in the coarse mulch fuels of the low-intensity subunit. Fire behaviour in the compacted fine fuels of the high-intensity treatment was relatively subdued, with a rate of spread less than 20% of that in the coarse fuels (Figure 9). The images in Figure 9 show the average flame length observed during these trials. Fireline intensity in the coarse mulch was estimated to be 400 kW/m, with peaks of 800 kW/m during wind gusts.

Figure 9. Fire behaviour in three distinct mulch fuel beds: fine *(left)*, regular *(centre)*, and coarse *(right)*. August 22 trials.

Fire behaviour characteristics measured in the three mulch fuel environments are presented in Table 3. The greatest depth of burn was measured in the low-intensity treatment subunit on August 22, when the fire intensity was the highest. The results in Table 3 suggest a direct relationship between fire intensity and depth of burn.

Table 3. Fire behaviour and post-fire data collection

Fire behaviour characteristics and depth of burn							
Date (dd/mm/yyyy)	Subunit (mulching intensity)	Fire behaviour		Depth of burn (cm)			
		Rate of spread (m/min)	Flame height (m)	Average	Maximum	Minimum	Standard deviation
21/08/2018	2A (low)	0.3	1.0	1.3	10.5	0	1.7
	2B (normal)	0.2	0.2	0.8	5.00	0	1.2
	2C (high)	0.0	0.0	n/a	n/a	n/a	n/a
	2A (low)	1.2	1.0	3.7	13.0	0	3.0

22/08/2018	2B (normal)	0.3	0.4	1.6	8.5	0	2.4
	2C (high)	0.2	0.2	1.4	4.0	0	1.0

Data collected from the heat flux sensors indicated a trend of higher fire intensity, with greater energy output, in the coarse mulch treatment, and the lowest fire intensity in the high-intensity mulch treatment (Table 4).

Table 4. Heat flux data recorded on August 22

Maximum heat flux (kW/m^2)			
Subunit (mulching intensity)	Sensor		
	1	2	3
2A (low)	24.5	29.0	21.5
2B (normal)	12.0	29.0	15.0
2C (high)	35.0[a]	9.0	9.0

[a] This higher reading is an outlier in the data set that occurred briefly due to the close proximity of the sensor to the oncoming flame front.

DISCUSSION

Comparative fire behaviour in mulched fuel beds

The Initial Spread Index (ISI) for the two trials on August 21 and 22 was 5 and 7, respectively. Other experimental fires (Hvenegaard & Price, 2018; Hvenegaard, Schroeder, & Thompson, 2016) in mulch fuel were conducted at a higher ISI (12.3 and 15.7, respectively) and exhibited more vigorous surface fire (Table 5).

Table 5. Extremes in fire behavior in experimental fires

Experimental fire	FWI values		Fire behaviour	
	ISI	BUI	Overall rate of spread (m/min)	Maximum fire intensity (kW/m)
Pelican Mountain (August 22, 2018)	7.0	65	1.2	800
Pelican Mountain (May 30, 2017)	12.3	64	3.1	1200
Red Earth Creek[a] (May 14, 2015)	15.7	51	22.0	27 840

[a] Fire behaviour in the treatment area at the Red Earth Creek experimental fire was initiated by an active crown fire in a mature black spruce stand, while the other two fires were initiated by line ignition in mulch fuel with a drip torch.

The extremes in fire behaviour observed in these experimental fires over a wide range of ISI values illustrate the volatile fire behaviour potential of this fuel environment and confirm that fine fuel moisture and wind are critical influences on fire behaviour in the fuel environment.

The three mulch treatment intensities applied in the black spruce fuels of Unit 2 resulted in different size class distributions of mulch in the individual subunits. Size class distribution is only one factor to consider in assessing potential fire behaviour in these distinct fuel environments. Another important finding of these comparative trials is the extent of surface fuel disturbance. In the low-intensity treatment, most of the natural surface fuel layer (duff, mosses and lichens, and shrubs) was undisturbed and maintained a natural vertical structure. In contrast, the highly processed surface layer, with mixing of duff, in the high-intensity treatment resulted in a more compacted fuel layer. With reduced vertical structure in this fuel layer, there was limited availability of surface fuels to accelerate fire spread. The compacted nature of the fine fuel layer also inhibited air movement through the mulch layer, which reduced the potential drying effect and oxygen supply to ignitions.

Predicted fire behaviour in untreated black spruce fuel

The fire behaviour observed in the mulch fuel environments studied was well below that predicted by the Canadian Forest Fire Behavior Prediction System (Taylor, Pike, & Alexander, 1997) for the pre-treatment black spruce forest stands in Unit 2. Fire behaviour predicted for the C-2 fuel type (boreal spruce) under the weather and fuel moisture conditions on August 22 is intermittent crown fire, with a rate of spread of 9 m/min. This reduction in fire behaviour to a low to moderate intensity surface fire suggests that mulching as a forest fuel treatment can, under these conditions, reduce fire behaviour to a level that would permit safe and effective fire suppression.

Implications for fuels and fire managers

Any modification to the surface fuel layer that can reduce surface fire intensity is considered a benefit. Manual fuel treatments achieve this reduction through the removal of surface fuels (burning of debris on site or physically transferring it). With little opportunity for removal of surface fuels through mechanical mulching, applying a higher intensity mulch treatment may be a viable option for converting the surface fuel layer into a less combustible state, limiting surface fire intensity and, thus, reducing the potential for crown fire initiation.

Burning of mulch debris following a mulch treatment has been considered as a technique for reducing surface fuels. If this technique is applied, a low-intensity mulch treatment would be the optimum treatment intensity for achieving the highest fire intensity in the coarse mulch with maximum fuel consumption. Under the high fire hazard conditions during the burn trials in Unit 2, control and suppression of the surface fire in the coarse mulch were easily achieved with one fire crew and a MARK-3 water delivery system pre-positioned at the burn site.

In their natural state, black spruce forest stands have an inherent potential for high-intensity fire. Each mulch fuel treatment in this study produced fuel beds that generated fire intensity lower than what would occur in natural stands under the same fire hazard conditions.

Each mulch treatment intensity studied would be easy to apply in the deep duff layers of black spruce forest stands. However, a high-intensity mulch treatment would not be successful in areas with a thin duff layer and rocky soils, where mulching to a deep depth would result in equipment damage and, potentially, ecological impact such as root damage.

Because most mulch fuel treatments are conducted in winter, snow cover will have an influence on the extent of surface fuel processing. When a higher intensity treatment is desired, this should be communicated as part of a treatment prescription, with monitoring at the site to ensure this objective is achieved.

CONCLUSION

Fire behaviour trials were conducted in three mulch fuel beds created by different treatment intensities of mulching. Under high to very high fire hazard ratings, we observed large differences in fire behaviour across the three fuel environments, with the highest fire intensity and rate of spread produced in the coarse mulch fuel of the low-intensity treatment subunit.

Mulch particle size is only one factor to consider in evaluating an overall fuel bed and assessing potential fire behaviour. Evaluating other fuel components, including mosses and lichens, branches, and needles, as well as the arrangement or compaction of these components, is critical to assessing potential fire behaviour in mulch fuel beds.

This two-part study of productivity and fire behaviour potential as a function of the intensity of mulch fuel treatment has delivered relevant preliminary findings regarding the cost-effectiveness of these treatments. While the productivity of a low-intensity mulch fuel treatment may be high, the resulting coarse mulch fuel bed generates more volatile fire behaviour relative to regular and fine mulch fuel beds. In boreal forests with a deep duff layer, a high-intensity mulch treatment with mixing of the duff layer can reduce surface fire intensity to a point that crown fire initiation is less probable.

The fire behaviour trials in this study were conducted at a moderate to high ISI. Fire behaviour predictions at a higher ISI cannot be reliably extrapolated from this limited data set, but they can be expected to increase under lower fuel moisture conditions with stronger winds.

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