info@fpinnovations.ca
www.fpinnovations.ca

FOREST FUEL TREATMENT PRODUCTIVITY RESEARCH IN ALBERTA:

A SYNTHESIS OF RESULTS AND FINDINGS

PROJECT NUMBER: 301012718

Steven Hvenegaard

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Forest fuel treatments are applied across a broad range of ecosites in Alberta and Canada, with an overarching goal of managing hazardous fuel buildup to mitigate wildfire. These treatments use various manual and mechanical processes to achieve fuel treatment objectives. Planning and application of a specific forest fuel treatment technique is often shaped by several factors, including objectives of the fuel treatment, availability of resources (personnel and equipment), and commitment to using local resources (socio-economics). In addition, site conditions in certain ecosites will favour the application of some treatment techniques over others.

With the broad nature of numerous fuel treatment techniques applied over a wide range of environmental conditions, it is difficult to document all treatments and develop comparative productivity and cost evaluations. This summary of fuel treatment studies accesses current research to present relevant findings and identify knowledge gaps in research on stand-level fuel treatment productivity.

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APPROVER CONTACT INFORMATION
Michael Benson
Manager, Wildfire Operations
michael.benson@fpinnovations.ca

REVIEWERS
Peter Dyson
Researcher, Forestry Group
peter.dyson@fpinnovations.ca

AUTHOR CONTACT INFORMATION
Steven Hvenegaard
Researcher, Wildfire Operations

steven.hvenegaard@fpinnovations.ca
(780) 740-3310

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INTRODUCTION

Forest fuel treatments are conducted at a stand level in the wildland-urban interface to reduce the potential for catastrophic loss caused by wildfire. Given the considerable expense of conducting these fuel treatments, fuels managers want to better understand the productivity and cost of commonly applied fuel treatments to prescribe cost-effective treatment techniques. With limited data available and the myriad combinations of fuel treatment options and equipment types in a diverse range of ecosystems, cost projections for fuel treatments are difficult to forecast reliably.

Similar questions and concerns regarding cost and efficiency have been addressed in harvest operations in the forest sector. Forest harvest and silviculture operational staff have collaborated with forestry researchers to address these concerns by developing data collection programs, monitoring operations, and conducting productivity studies. FPInnovations' Wildfire Operations group has applied these data collection methods and technologies in vegetation management to measure productivity of equipment (primarily mulchers) conducting commonly applied treatment techniques in boreal and montane ecosites. To a lesser extent, productivity trials of motor-manual fuel treatments have been conducted to assess the performance of workers using hand tools (mechanical and manual).

Background

Productivity studies in timber harvest operations have been conducted for over 50 years. At the inception of equipment productivity evaluations, there was a "growing need to be able to predict the expected productivity of logging machines when working under different environmental and operating conditions" (Aird et al., 1970). The Pulp and Paper Research Institute of Canada and the Forest Engineering Research Institute of Canada developed productivity evaluation methods and conducted extensive testing on harvesting machines performing different harvest operations.

Productivity studies are conducted to evaluate the cost and efficiency of equipment performing selected forest harvest operations. Productivity studies are also conducted to evaluate how a modification to an operation can impact productivity and reduce operational costs.

Initially, short-term studies (one to two weeks) were conducted on new harvesting equipment to describe the technical and operating characteristics of new machines and to estimate their potential productivity under measured operating and environmental conditions. Recognizing the limitations of the short-term studies, the Forest Engineering Research Institute of Canada developed long-term data collection methods that would evaluate machinery performance capabilities under a wider range of environmental conditions (Folkema, Giguere, & Heidersdorf, 1981).

The terminology and methods developed for these equipment evaluation programs form the basis of current productivity studies conducted by FPInnovations' Wildfire Operations group.

OBJECTIVES

Since the commencement of productivity trials by the Wildfire Operations group in January 2014, the results of these studies have been shared through several knowledge transfer mechanisms, including technical reports, conference presentations, and webinars. Most of these reports and presentations were focused on a specific equipment type, treatment technique, or summary of productivity studies at a specific research area.

The objectives of this report are to:

- Summarize fuel treatment productivity trials conducted by FPInnovations.
- Identify knowledge gaps in fuel treatment productivity studies.

This synthesis of knowledge and practice can assist fuel practitioners in applying cost-effective fuel treatments.

METHODS

Measuring productivity

"The direct relationship between product output and time input is called productivity" (Magagnotti & Spinelli, 2012) and can be expressed using different metrics depending on the outcome or product of an operation. Commonly applied product outputs in harvest operations are volume and weight. Productivity metrics are, therefore, expressed as volume/time or weight/time.

The most commonly applied product output for fuel treatments is area. Hence, area/time is the most prevalent productivity metric, since fuels practitioners are primarily interested in treating defined areas of forest, grassland, or other wildland fuels.

Common productivity measurements are:

Productive machine hours (PMH) = the time a machine is actively working at its primary function (i.e., mulching, felling trees). PMH excludes any time delay greater than 15 minutes.

Scheduled machine hours (SMH) = the scheduled shift length. This is usually reported as monthly or yearly and is often used in machine costing formulas (Ryans, 2014). Most fuel treatment productivity studies have been conducted in winter when the duration of the shift is variable and often dictated by weather. During winter productivity studies, the shift length was taken as on-site arrival time to departure time.

Machine utilization (%) = a measure of longer-term machine efficiency, calculated as PMH/SMH.

Area/PMH is the most common productivity metric the Wildfire Operations group uses in assessing fuel treatments. Area is the size of the treatment area in hectares. Given the small scale of fuel treatment operations relative to harvest operations, all fuel treatment productivity data was collected from short-term studies.

A MultiDAT unit[1] with a GPS antenna was installed in each machine before each study. The MultiDAT recorded machine working (productive) and non-working time, and the GPS showed the area treated. This data was used to determine PMH and area treated to calculate the area/PMH metric.

Volume/time was calculated in a productivity study of a broadcast mulching operation in a black spruce forest stand with large variations in stem size and biomass loading within a single treatment unit. Using stand data provided by the Alberta Wildland Fuel Inventory Program (AWFIP) as inputs, biomass equations (Lambert, Ung, & Raulier, 2005) were used to calculate biomass volume processed in each subunit. Biomass volume was used to determine volume/time as one of the productivity metrics (Hvenegaard, 2019). Volume/time was also determined by measuring post-harvest debris piles and machine productivity in hazard abatement trials (Schroeder & Mooney, 2008).

An evaluation of recovering biomass using innovative technology included productivity trials of a bioenergy baling system (Gardeski & Keddy, 2017). In this study, production constituted bales produced, and the productivity metric was bales/PMH. In addition, baling system productivity was calculated as oven dry kg/PMH.

Machine costs are the largest expense in fully and semi-mechanized fuel treatments. Hence, FPInnovations' studies focus on mechanized productivity studies. However, in some fuel treatments, additional thinning work requires manually cutting and piling branches. In a semi-mechanized fuel treatment productivity study (Hvenegaard & Hsieh, 2017a), time spent on manual treatment was incorporated in the production summary.

Detailed timing data collection is often conducted to capture time spent on specific work time elements. During a motor-manual productivity study, detailed timing provided a breakdown of timed elements associated with chainsaw and debris piling operations (Hvenegaard & Hsieh, 2017b). Detailed timing analysis can be used to identify inefficiencies in mechanized and manual operations.

Identifying variables and assessing outcomes in the design of fuel treatment studies

Slave Lake Mulch Research Area

In the early stages of designing mulching productivity research studies, major environmental and operational influences on productivity were identified. Four of these were selected for isolated trials at the Slave Lake Mulch Research Area. These influences were stand type, treatment type, treatment intensity, and equipment type.

The two predominant stand types in this area are mixed wood and black spruce dominated. The black spruce-dominated forest stands comprised two distinct environments (lowland and upland) with stand characteristics that influenced mulcher selection and productivity.

[1] MulitDAT is a device built by Castonguay Electronique that records machine working and non-working time. It has the capability to provide working time elements and details of forestry machines.

At the time of this study, two basic fuel treatments (inter-tree spacing and strip mulching) were commonly applied with mulchers in the Slave Lake area. As a subset of each of these fuel treatment types, two intensity levels were prescribed for evaluation.

Equipment for these mulching trials was selected based on the most commonly used types and sizes available locally. A medium-sized mulcher (CMI Hurricane C250) was evaluated in the mixedwood stands and the upland black spruce-dominated stands (Figure 1). A smaller mulcher (Lamtrac 6125T) was evaluated in the less-mature (shorter and smaller-diameter stems) lowland black spruce-dominated stands. Physical dimensions and power ratings of these mulchers can be found in the section titled capabilities and limitations associated with mulcher size.

Figure 1. Mulchers used at Slave Lake Mulch Research Area: CMI Hurricane C250 (*left*) and Lamtrac 6125T (*right*).

A supplemental cleaning operation was applied in selected plots using a Volvo MCT 135C skid steer loader with a log grapple and a Caterpillar 305.5D mini-excavator to remove debris that had been lodged in the standing stems (Figure 2).

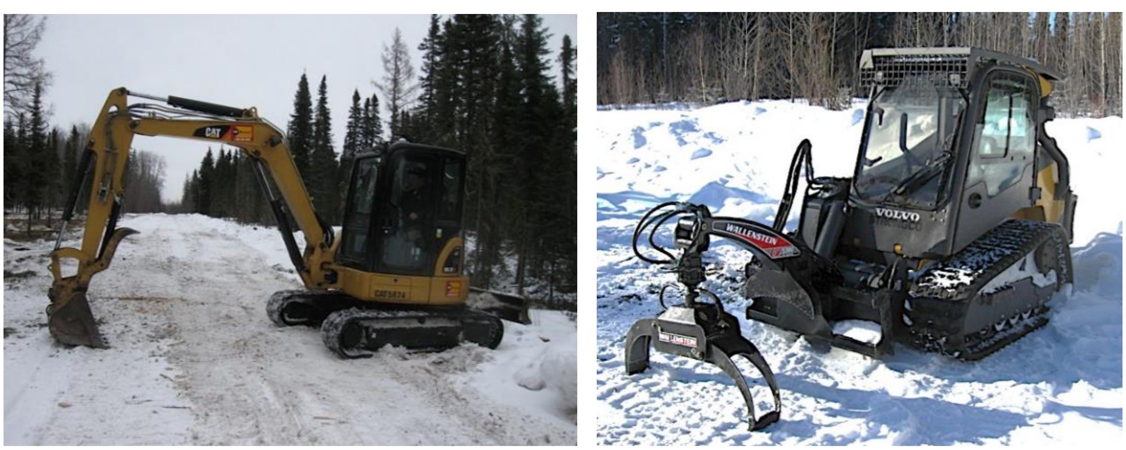

Figure 2. Machines used in cleaning operations to move debris to an area where it can be mulched.

The research area was subdivided into plots (Figure 3) to facilitate data collection for assessing the research variables. A summary of site characteristics, machines, and treatment assignments with productivity evaluations can be found in the summary of mulch treatments and equipment productivity at the Slave Lake Mulch Research Area (Hvenegaard & Hsieh, 2014a).

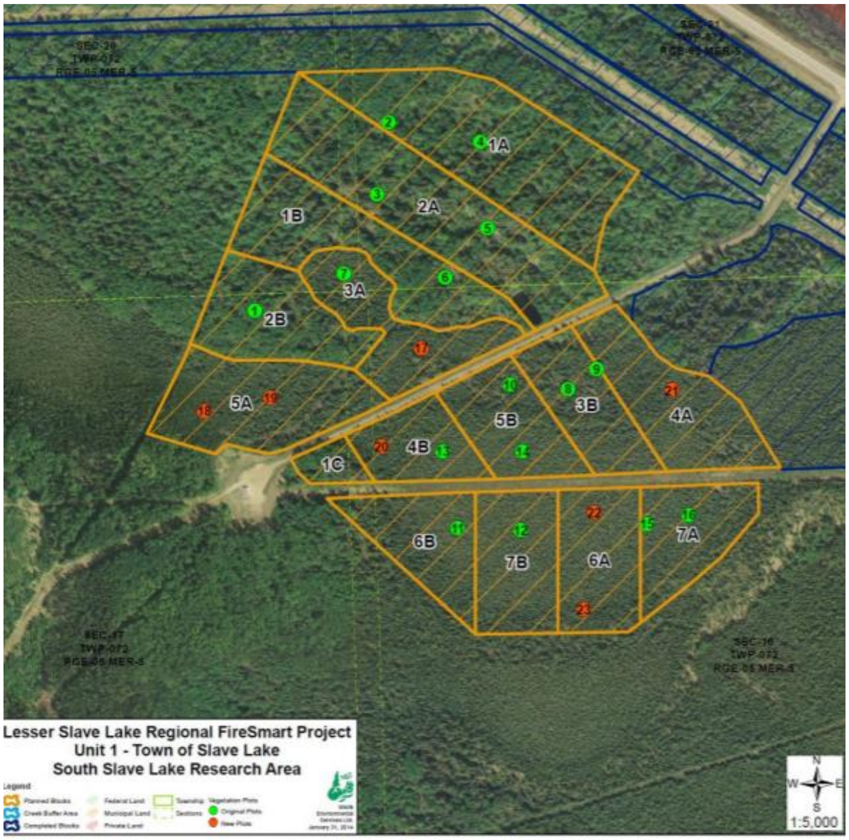

Figure 3. Slave Lake Mulch Research Area, subdivided into treatment plots. (Plot map created by Mistik Environmental Services.)

Pelican Mountain FireSmart Fuel Management Research Site

The initial mulching work at the Pelican Mountain FireSmart Fuel Management Research Site[2] focused on constructing a fuel break around Unit 1 and other research plots. While productivity trials were not conducted during this mulching work, the work made Unit 1 more accessible for productivity trials conducted as part of the two treatments in this unit.

[2] For more information about the Pelican Mountain FireSmart Fuel Management Research Site, see the Canadian Wildland Fire & Smoke Newsletter.

Unit 1 was designed to compare the cost-effectiveness of two commonly applied fuel treatment techniques: motor-manual and semi-mechanized (Figure 4). A motor-manual fuel treatment can achieve several key fuel treatment principles for creating wildfire-resilient forests (Agee & Skinner, 2005). Hand crews thin forest stands to decrease crown density, remove lower limbs to increase live crown base height, pile and burn vegetative residue and surface fuels to reduce surface fuel load, and retain large stems of more resistant species.

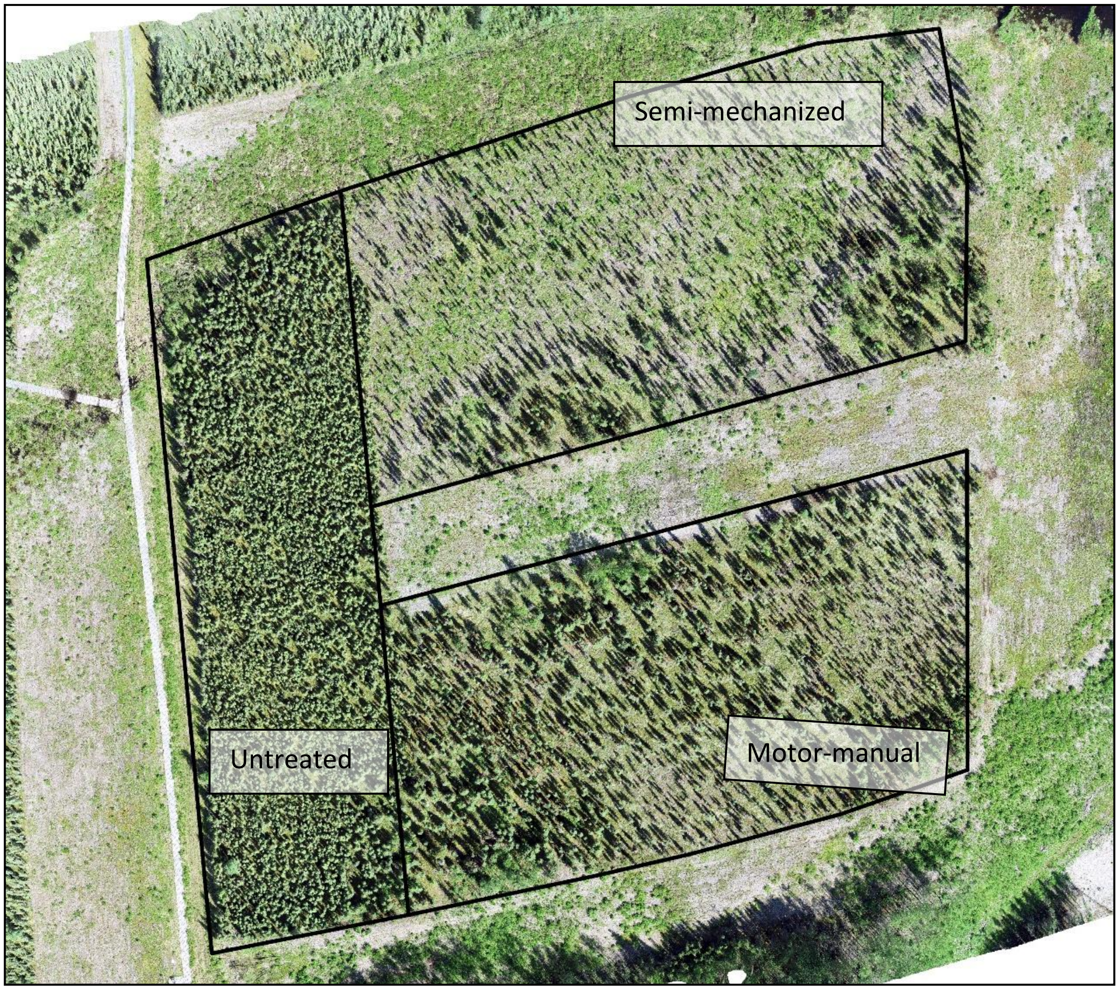

Figure 4. Two fuel treatments in Unit 1 at the Pelican Mountain FireSmart Fuel Management Research Site.

A semi-mechanized fuel treatment was designed to apply these fuel treatment processes by using a small mulcher to remove stems and open up the stand for hand crews to limb residual stems. Limbs and other debris were manually moved to an open space in the treatment area to allow the mulcher to process the debris. The key difference between the motor-manual treatment and the semi-mechanized treatment is that in the motor-manual treatment, fuel is removed by piling and burning. In semi-mechanized treatment, debris (stems and branches) is not removed, but rather is mulched to form a component of the surface fuel layer.

Productivity of a motor-manual thinning treatment was also evaluated in Unit 5.

In contrast to the inter-tree spacing treatments applied in Units 1 and 5 that create a shaded fuel break (Agee et al., 2000), a broadcast mulching treatment was applied in Unit 2, with all of the standing stems in the treatment area processed and displaced to the surface fuel layer. Productivity as a function of fuel treatment intensity was a research question that was addressed by applying three distinct treatment prescriptions of different intensity. Productivity in each subunit was measured using area/PMH and biomass/PMH as the productivity metrics (Hvenegaard, 2019).

Similarly, Unit 10 was treated by applying the same mulch intensities, and productivity was documented as area/PMH. Unit 10 was designed to evaluate *Larix* seedling survival in varied states of stand and ground preparation, and variation in mulch intensity was one of the ground condition variables.

Gregg Lake fuel treatment

Thinning by mulching was the primary fuel treatment technique prescribed in a montane ecosite north of Gregg Lake, Alta. In one treatment plot, high-density mature black spruce stems made the thinning treatment unfeasible, and a clumping technique was developed. This type of treatment in dense forest stands has also been applied as a mulch grid technique to prepare a research plot for an experimental burn trial in a jack pine/black spruce fuel environment at the Canadian Boreal Community FireSmart Project (Hvenegaard, 2017). The productivity of a Lamtrac 8300T mulcher was measured in this study.

Stand characterization and data collection

Forest fuel inventory for the treatment areas in these trials was conducted by the Alberta Wildland Fuels Inventory Program crews using AWFIP data collection methods.

Terminology

During each productivity trial, FPInnovations applied the terminology for the equipment and treatment technique that was used by the practitioners in that area at that time. Over time, it became apparent that several terms were being used synonymously for the same process. For example, inter-tree spacing and thinning by mulching have both been used to describe a mechanical thinning treatment using a mulcher. The glossary of terms at the end this document provides further clarification of terminology and some of the overlap in terms.

RESULTS

Stand type is one of the initial variables to consider in determining an appropriate fuel treatment prescription. The two predominant stand types that were studied in these productivity trials are mature mixedwood and black spruce-dominated forest stands.

Key questions when considering stand type and stand characteristics are:

- What are the appropriate fuel treatment techniques and treatment intensities for a given forest stand?
- Is there an optimum machine size or machine type for a given forest stand?

Mechanized productivity trials conducted at several research areas and fuel treatment project sites across Alberta provided data that aided researchers in evaluating the suitability of different treatment types and machine sizes in these study areas.

Mature mixedwood stands

Mature mixedwood forest stands with dominant deciduous and conifer stems in the overstory provide an ideal environment for applying an inter-tree spacing treatment. This treatment technique reduces stand density by retaining larger, healthier stems and removing smaller, less healthy stems in the midstory and understory (Figure 5). These forest stands with widely spaced overstory stems allow a mulcher to manoeuvre between stems and process surface vegetation and downed woody debris. Two research areas in mixedwood forests provided an opportunity to assess the productivity of two different mulchers conducting the inter-tree spacing treatment.

Figure 5. Inter-tree spacing in a mature white spruce forest stand (*left*) and a mixedwood stand (*right*).

Inter-tree spacing

In three treatment plots at the Slave Lake Mulch Research Area, a CMI Hurricane C250 was used to conduct an inter-tree spacing treatment (Hvenegaard & Hsieh, 2014b). A similar fuel treatment was conducted using a Lamtrac 8300T in a mature mixedwood stand in the fuel treatment area at Gregg Lake, Alta. (Hvenegaard & Hsieh, 2014c).

The two mulchers have similar power ratings and both use the FAE 200/U-225 mulcher head (2300 mm working width). The limited data set from the two different trial sites (Table 1) provides a rough productivity guide for this machine size. The higher productivity of the Lamtrac 8300T compared to that of the CMI Hurricane C250 may seem counterintuitive considering the higher stand density in that treatment area. However, other factors such as machine condition, operator skill, and volume of downed woody debris may have impacted productivity in the other trials. Clearly, a larger data set is required in forest stands of similar composition to provide reliable comparative results.

Table 1. Inter-tree spacing productivity results in mixedwood forest stands

Mulcher type	Power	Study plot	Treatment intensity	Pre-treatment stand density (stems/ha)			Productivity (ha/PMH)
				> 9 cm DBH	< 9cm DBH	Total	
CMI Hurricane C250	202 kW (275 hp)	1A	High	450	600	1050	0.35
		1B	High	525	1500	2025	0.15
		2A	Low	325	600	925	0.27
Lamtrac 8300T	216 kW (290 hp)	1	Normal	1400	1575	2975	0.46
		2	Normal	1125	1700	2825	0.48

DBH - diameter at breast height

Black spruce-dominated stands

Inter-tree spacing and clump spacing

The inter-tree spacing treatment was also applied in black spruce-dominated treatment plots at the Slave Lake Mulch Research Area. The treatment was modified to retain clumps of stems rather than individual stems (Figure 6). A higher density of larger stems in plot 4 (Figure 7) at the Gregg Lake site proved difficult for the Lamtrac 8300T operator, and the clump spacing technique was deemed to be an acceptable alternative to achieve thinning treatment objectives.

Figure 6. Inter-tree spacing (*left*) and clump spacing (*right*) in black spruce-dominated forest stands at the Slave Lake Mulch Research Area.

Figure 7. Inter-tree spacing in a white spruce stand (*left*) and clump spacing in an upland black spruce stand (*right*) at the Gregg Lake fuel treatment site.

Trial results suggest that in high-density black spruce stands, the clump spacing technique results in improved machine productivity compared to inter-tree spacing (Table 2).

Table 2. Inter-tree spacing productivity results in black spruce-dominated stands

Mulcher type	Power	Study plot	Treatment type	Pre-treatment stand density (stems/ha)			Productivity (ha/PMH)
				> 9 cm DBH	< 9cm DBH	Total	
CMI Hurricane C250	202 kW (275 hp)	3A	Inter-tree spacing	1425	3750	5175	0.09
		3B	Clump spacing	1950	4875	6825	0.18
Lamtrac 8300T	216 kW (290 hp)	3	Inter-tree spacing	1250	933	2183	0.37
		4	Clump spacing	3383	1900	5283	0.37

Strip mulching

Strip mulching has been applied extensively as a wildfire mitigation technique in high-density black spruce forest stands surrounding the Mitsue Lake Industrial Park in central Alberta. This treatment was accomplished by mulching the uniformly sized black spruce stems in straight lines and leaving a strip of residual forest standing. The straight-line processing requires minimal manoeuvring by the mulcher, relative to an inter-tree spacing treatment. Strip mulching is effective in low-value forests, whereas inter-tree spacing is better where retaining mature and healthy stems is important. This treatment technique was evaluated at the Slave Lake Mulch Research Area in two black spruce ecosites (upland and lowland) using two different sized mulchers and two mulching intensities.

A CMI Hurricane C250 machine was used in the upland plots, where the stems were larger. The low-intensity treatments in 4A and 4B were achieved by mulching in a single pass, one mulcher head wide (3 m), with no additional cleaning. A residual strip of standing stems was left unmulched between the mulched strips (Figure 8). The high-intensity strip mulch treatment in 5A and 5B incorporated a cleaning phase using a Caterpillar mini-excavator (mini-hoe). The Caterpillar removed fallen stems and other debris from the adjacent standing timber and piled it in the mulched strip (Hvenegaard & Hsieh, 2014d). A final pass with the mulcher processed this piled debris.

Figure 8. Strip mulching treatments of low intensity (*left*) and high intensity (*right*).

Similarly, strip mulch treatments were achieved using similar tactics and the Lamtrac LTR6125T (Hvenegaard & Hsieh, 2014e) (Figure 9). The key differences were 1) the mulch strip was two passes wide (3.5 m), and 2) a skid-steer loader with a log grapple (Hvenegaard & Hsieh, 2014f) cleaned the strip.

Figure 9. Low-intensity (*left*) and high-intensity (*right*) mulch treatments created with the Lamtrac 6125T.

Results from evaluating two mulchers of different size and power in strip mulching productivity trials (Table 3) indicate that these mulchers were appropriately sized for the stand conditions in these plots. Neither mulcher encountered any difficulties processing stems or debris in the respective treatment areas. As can be expected for both machines, productivity was lower in the high-intensity treatments.

Table 3. Productivity in strip mulch treatments by mulcher type and treatment intensity

Mulcher type	Power	Study plot	Treatment intensity	Pre-treatment stand density (stems/ha)			Average tree height (m)	Productivity (ha/PMH)
				> 9 cm DBH	< 9cm DBH	Total		
CMI Hurricane C250	202 kW (275 hp)	4A	Low	2100	5000	7100	7	0.35
		4B	Low	1075	6625	7800	6	0.35
		5A	High	1400	3887	5287	8	0.15
		5B	High	1087	6500	7587	7	0.20
Lamtrac LTR6125T	93 kW (125 hp)	6A	Low	1375	5000	6375	7.8	0.26
		6B	Low	400	4750	5150	6.0	0.20
		7A	High	663	7000	7663	5.9	0.12
		7B	High	550	6000	6550	6.0	0.18

Mulching intensity and productivity

The previous section introduced productivity as a function of treatment intensity using a strip mulching technique in black spruce stands. In February 2017, Unit 2 at the Pelican Mountain FireSmart Fuel Management Research Site was mulched by applying three treatment intensities. The mulching treatment was a clearing treatment that processed all stems within each subunit in preparation for experimental fires in the resultant mulch fuel beds (Figure 10).

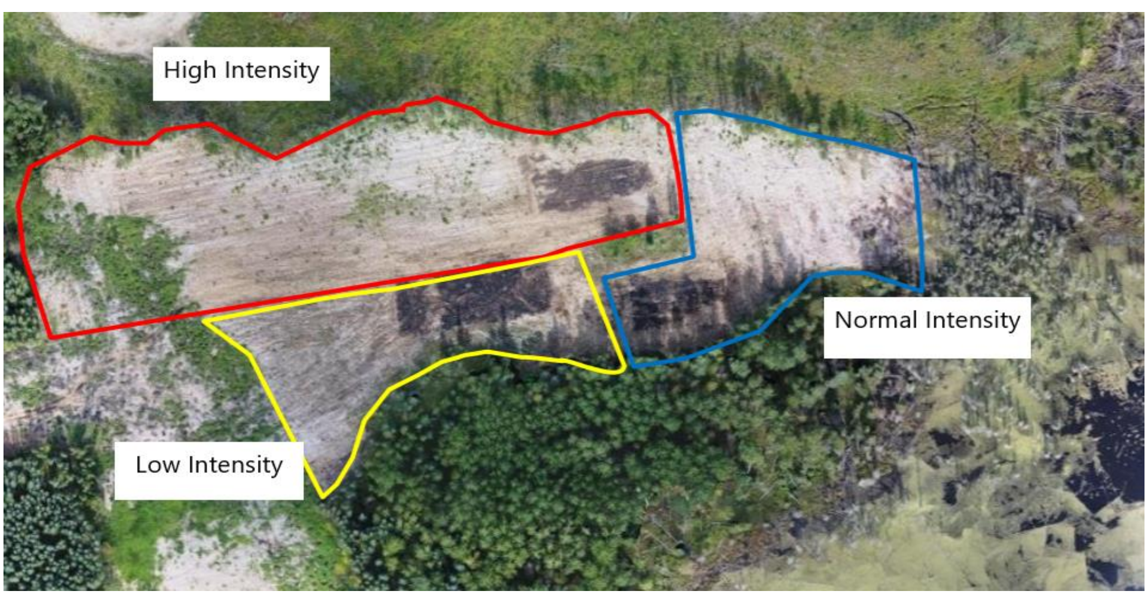

Figure 10. Three distinct mulch treatment intensities applied in Unit 2. Image captured after experimental burns.

These productivity trials validated an intuitive notion regarding fuel treatment intensity. That is, a higher-intensity treatment requires more machine processing time and, hence, results in a lower productivity rate (Table 4). Another key observation is that in areas with a higher density of larger-diameter stems, mulcher productivity (ha/PMH) is reduced.

Table 4 shows similar productivity (ha/PMH and tonnes/PMH) for subunits 2B and 2C. The greater proportion of large trees in 2B compared to units 2A and 2C, and the greater amount of time required to process these stems may explain this similarity; however, the impact of large stems on productivity is not well documented and further studies would help to better understand this effect.

Table 4. Productivity as a function of mulching intensity in Unit 2

	Biomass (oven dry weight) (tonnes/ha)				Productivity	
Subunit (mulching intensity)	Large stems >= 9 cm DBH	Small stems < 9 cm DBH	Seedlings[a] < 1.3 m	Total	Tonnes/PMH	(ha/PMH)
2A (low)	11.7	54.9	0.1	66.7	12.4	0.19
2B (normal)	77.2	25.5	0.1	102.8	5.85	0.06
2C (high)	17.1	71.3	0.1	88.5	5.24	0.06

[a] Seedling mass applied at 0.008 kg per seedling (Miao & Li, 2007).

Trials evaluating the effect of mulching intensity on mulcher productivity were continued in February 2018 at Pelican Mountain in Unit 10. The two separate sites in Unit 10 were more consistent in density and stem size than those compared in Unit 2. The potential difference in productivity due to variation in operator skill and experience was eliminated by using the same operator in the same machine in Units 2 and 10. The treatment intensity prescriptions were the same in both units.

Subunits 10b and 10c shared a narrow strip of larger stems. To measure productivity differences due to stem size, these two subunits were divided into east and west. The difference in stem size in the east and west subunits was not as extreme as that in Unit 2. Table 5 indicates a similar trend of reduced productivity with increased treatment intensity and shows a minimal impact of stem size on productivity.

Table 5. Productivity as a function of mulching intensity in Unit 10

Subunit (mulching intensity)		Productivity (ha/PMH)
10g (low)		0.24
10h (normal)		0.19
10i (high)		0.17
10a (low)		0.35
10b east (normal)	Smaller stems	0.21
10b west (normal)	Larger stems	0.15
10c east (high)	Larger stems	0.10
10c west (high)	Smaller stems	0.11

Capabilities and limitations associated with mulcher size

Mulchers are a specific type of machine used to masticate forest fuels (stems and branches, woody debris, surface vegetation, and ground fuels). Mulchers are used extensively in industrial vegetation management operations to clear vegetation for industrial facilities and maintain hydro rights-of-way. Given the large pool of available mulchers in various sizes and an abundance of experience in the industrial arena, the transition of mulchers to operations in the wildland-urban interface was straightforward, and they have been adopted as a primary piece of machinery for fuel treatments.

Mulchers have several advantages in smaller, stand-level fuel treatment operations. They are easily transported, exert lower ground pressure relative to wheeled vehicles, and can operate in inclement winter conditions.

In Alberta, the most common mulcher configuration used in vegetation management is the tracked vehicle equipped with a horizontal drum mulcher head. This mulcher type was the primary machine evaluated in the productivity trials summarized in this report. An excavator with a boom-mounted mulcher is another popular machine for managing vegetation.

The physical size of a mulcher (overall dimensions and mulcher head width) is generally related to its power rating (Table 6). Currently, the most common machine for fuel treatments has a power rating of 250 to 300 hp, which is considered mid-size.

Table 6. Specifications of mulchers used in these Research studies

Mulcher type	Power	Ground pressure	Mulcher head working width (m)
CMI Hurricane C250	202 kW (275 hp)	22.7 kPa (3.3 psi)	2.25
Lamtrac LTR8300T	216 kW (290 hp)	23.4 kPa (3.4 psi)	2.25
Lamtrac 8290Q	216 kW (290 hp)	27.37 kPa (3.97 psi)	2.25
Lamtrac LTR6125T	93 kW (125 hp)	25.86 kPa (3.75 psi)	1.75
Rayco C130	97 kW (130 hp)	Not available	1.25

Smaller mulchers were required in two productivity trials to achieve specific equipment testing objectives. The two trials were a comparative strip mulch trial at Slave Lake Mulch Research Area and a semi-mechanized fuel treatment at Pelican Mountain FireSmart Fuel Management Research Site. Smaller mulchers in the 125 to 140 hp range were evaluated. One advantage of smaller mulchers is that they have greater manoeuvrability and can more easily achieve a 3-m crown spacing prescription without impacting or scarring stems in the treatment plot. Low machine ground pressure is another advantage, as this is often required in sensitive areas, where ground disturbance is a concern. In areas of a high-water table, mulching operations must be performed in winter when the ground is frozen.

Other equipment productivity trials

Ongoing fuel treatment monitoring with appropriate re-treatment is critical to maintaining the capacity of a treatment area to modify fire behaviour. As an exploration into re-treatment operations, mulcher productivity in two re-treatment areas was measured in a montane ecosite that had been treated by mulching five years earlier (Hvenegaard & Hsieh, 2015). The treated fuel consisted primarily of willow regrowth in open meadows and woody debris in forested areas (Figure 11). In most areas, a Lamtrac 8290Q quad track mulcher easily processed this vegetation and debris.

Figure 11. Vegetative regrowth to be processed as prescribed in a re-treatment operation.

Harvest debris is typically disposed of by pile burning. In many areas, the window for burning piles is limited due to the high risk of fire escape in spring and summer and smoke management regulations in winter. A further risk of burning piles is the potential for fire escape in the spring due to over-winter burning in piles. Schroeder & Mooney (2008) investigated the potential for harvest debris disposal using mulchers in a comparative productivity trial conducted in southern Alberta. Four mulchers were evaluated.

Productivity trials have also been conducted to assess the feasibility of using mulchers to construct fuel breaks (Clark, 2008) as a wildland fire suppression tactic (Halbrook, Han, Graham, Jain, & Denner, 2006). Dodson & Mitchell (2016) found that mulchers could have potential as a cost-effective method for constructing a fireline, with some modifications to the mulcher head to provide more thorough scraping to mineral soil. These productivity results may be useful when considering options for constructing other forest-related features, such as lease sites, seismic lines, or other linear corridors.

A blade-and-pile operation in a dense black spruce forest stand was evaluated to assess the productivity of a Caterpillar D6 dozer conducting the blading operations (Hvenegaard & Hsieh, 2014g) and the productivity of a Caterpillar D7 dozer with a brush rake conducting the piling activities (Hvenegaard & Hsieh, 2014h). The productivity rates for these D6 and D7 dozers was 0.69 ha/PMH and 0.48 ha/PMH, respectively. The piled debris was eventually burned, but this treatment phase was not documented.

Motor-manual and semi-mechanized fuel treatments

A motor-manual fuel treatment is conducted by personnel equipped with various motorized hand tools, such as chainsaws, pole saws, or clearing saws. Key advantages of motor-manual treatments over mechanized treatments are that manual workers can be more selective removing stems and there is no chance of machine-caused stem damage. Another major advantage of these treatments is that workers using motorized tools can remove lower branches (ladder fuels) and put them in a burn pile. Motor-manual fuel treatment techniques enable workers to achieve fuel treatment principles of reducing surface fuel, increasing height to live crowns, decreasing crown density, and retaining larger and healthier stems.

However, these treatments are some of the most expensive fuel treatment techniques, and fuels managers would like to have a better understanding of these treatment costs.

Two motor-manual productivity trials in two different treatment units at Pelican Mountain FireSmart Fuel Management Research Site were conducted in the winters of 2016/17 and 2017/18.

The prescription for these treatments was based on FireSmart guidelines (Partners in Protection, 2003) for thinning stems to 3-m crown spacing and removing lower branches to a height of 2 m. However, to maintain average stem spacing throughout the plot, the textbook prescription was modified slightly because some areas of the stand were patchy, with dense clumps of stems in larger open areas. In these cases, some clusters of stems were thinned to a tighter spacing.

In the southern subunit of Unit 1, the motor-manual treatment achieved complete removal of the understory component, while the overstory density was reduced from 2334 to 1228 stems per hectare. Live crown base height increased to 3.5 m. This motor-manual treatment was conducted in three phases, employing a varying number of personnel. Taking this variation in personnel numbers into account, the overall productivity rate for this treatment in Unit 1 was calculated at 0.0051 hectares per worker-hour (Hvenegaard & Hsieh, 2016).

Unit 1 was designed to compare the cost-effectiveness of a fuel removal treatment (motor-manual) to that of a fuel displacement treatment (semi-mechanized) by evaluating the productivity of each treatment technique and the capacity of each treatment to modify an encroaching crown fire. A key difference between these two treatments is that a motor-manual treatment removes residue (stems and branches) by piling and burning, while a semi-mechanized treatment displaces debris to the surface layer, where it is mulched and incorporated into the surface fuel layer.

Semi-mechanized silviculture operations (St-Amour, 2007) use machines to remove most unwanted stems and create pathways for workers. This makes it more efficient for workers equipped with motorized tools to remove additional stems and perform other work required to meet the prescription.

Productivity of a semi-mechanized treatment was assessed in the northern subunit of Unit 1. A relatively small mulcher removed most of the stems and created better access for crews to selectively remove unwanted stems and remove lower branches on stems. The treatment removed all the understory and reduced the overstory density from 1278 to 568 stems per hectare. Post-treatment live crown base height was 3.5 m. Machine productivity was calculated at 0.08 ha/PMH, and overall personnel commitment was 72 worker-hours over the 4 days of treatment work.

Cost analysis

The motor-manual fuel treatment in Unit 1 was administered through Alberta Agriculture and Forestry and was conducted by seasonal staff retained to work on winter fuel treatment projects. The overall cost for the motor-manual fuel treatment, including all three treatment segments, was $18 976.

For the 1.5-ha treated area, the cost was $12 650/ha. This cost is mid-range on the spectrum of costs reported for manual treatment costs by other Canadian wildfire management agencies (Hvenegaard, 2012).

The semi-mechanized fuel treatment project was administered through a contractor who hired local workers and subcontracted the mulchers with operators. The total cost for the treatment, including equipment, fuel, personnel, management, and administration, was $27 962. For the treated area of 1.8 ha, the cost was $15 534/ha.

Mitchell (2007) documents the productivities and costs of manual and mechanized operations in a thinning-from-below forest fuel treatment at a site in a B.C. interior Douglas-fir biogeoclimatic zone. Detailed timing summaries provided separate time elements of manual felling and brush piling. Detailed timing also supplied productivity data on the three machine types used for skidding. From detailed timing data and monitoring of operations, researchers created implementation guidelines for improving efficiency. The total cost of manual and mechanized fuel treatment was $3000/ha.

The overall cost of fuel treatments can be offset when there is an opportunity to use fibre in the form of sawlogs, pellet logs, or hog fuel. A thinning-from-below fuel treatment using a selective harvest technique in a mature Douglas-fir forest stand (Dyson, 2021) used innovative machinery and techniques to harvest and process merchantable trees. Non-merchantable trees and dead and down stems were extracted and piled separately in biomass piles, with branches and tops generated from processing the merchantable stems. Manual operations limbed branches to a height of 3 m and removed small-diameter trees (less than 10 cm in diameter). This residue was added to biomass piles. A forwarder later removed all of the biomass piles to the roadside, where a grinder processed the biomass to hog fuel, which was transported to a local mill.

The harvest machinery and techniques facilitated efficient removal and transport of logs and residual biomass. Revenues generated through harvested logs and biomass offset the costs of harvesting, stumpage fees, and manual cleaning operations. The very thorough removal of debris through mechanical and manual processes resulted in a light loading of woody debris and surface fuel. While this fuel treatment was very successful in mitigating hazardous fuels and using residual fibre to offset costs, challenges persist in all treatment operations in minimizing fuel removal and cleaning expenses to optimize cost-effectiveness of the treatment.

Productivity of larger crews

Crew size varies in motor-manual fuel treatments. In Alberta, eight-person contract firefighting crews are common. Planning and budgeting of motor-manual fuel treatments could be improved with good data for eight-person crew productivity. The most reliable productivity data would be from case studies; however, there is a lack of case study data. Unit 1 results were extrapolated to provide a coarse estimate of potential productivity for an 8-person crew. Based on the overall productivity of 0.0051 hectares per worker-hour in Unit 1 (Pelican Mountain), an 8-person crew working 8 hours per day could treat 0.33 ha/d. In a 5-day work week (40 h), the crew could treat 1.63 ha.

Another motor-manual treatment with the same treatment prescription was conducted in Unit 5 at Pelican Mountain in December 2017. Productivity (unpublished) of a 6-person crew was evaluated, and trial results found productivity averaged 0.0087 hectares per worker-hour. This is similar to the productivity of the 4-person crew in Unit 1 (0.008 hectares per worker-hour) in their first 4 workdays under similar conditions (mild weather and minimal snow cover). This would translate to a daily rate of 0.55 ha/d for an 8-person crew for 8 hours of on-site treatment work. It should be noted that actual on-site treatment work hours were approximately 5.5 h/d. Extrapolation to eight hours of treatment work per day assumes crews could maintain the same working pace.

Both documented motor-manual productivity trials were conducted in winter with limited daylight hours. This shorter workday was also a consequence of longer travel distance. With longer days and shorter travel distance, the utilization rate (efficiency) of a crew will be increased.

DISCUSSION

The productivity trials summarized in this report yield a limited data set, but nonetheless provide a general representation of productivity rates for a given set of variables that are commonly encountered in fuel treatments in Alberta. This data should not be considered representative of productivity rates for other treatment techniques conducted with other equipment in other fuel environments.

Contractors and agency personnel have captured productivity rates for mechanical and manual fuel treatments. Some data was provided to FPInnovations. It should be noted that the data sets collected by others have value as a stand-alone evaluation, but it is difficult to incorporate data sets without a consistent approach to productivity measurement and forest stand data collection.

Many environmental and operational variables affect productivity, and these could not all be included in the studies discussed in this summary report. For example, environmental variables such as weather, snow depth, and stand age could not be accounted for. Operational variables such as machine condition or operator experience are difficult to assess. However, in most of the trials, operators had experience in other industrial mulching operations and adapted quickly with appropriate briefings and feedback. It should be noted that research areas were selected to achieve wildfire mitigation objectives around communities and forest stands. Sites were not selected to provide consistent research variables. However, fuels inventory data collected by the AWFIP crews was invaluable and enabled parcelling fuel treatment plots with relatively uniform characteristics and provided data for forest stand characterization of individual treatment plots.

Comparing the productivity rates of different models of mulchers was not an objective of these trials. The differences in forest stand characteristics between research sites does not promote reliable “apples to apples” comparisons of mulcher capabilities, and data should not be used for assessing or selecting one mulcher over another. The data sets collected in these trials are not adequate to allow extrapolation of productivity rates to other forest stands with varying stand density or stem size.

KNOWLEDGE GAPS

Exploring fuel treatment alternatives

Relative to the overall extent of fuel treatments conducted in the wildland-urban interface across Canada, the productivity trials summarized in this report represent a small fraction of all Canadian vegetation management activities. Similarly, the techniques and machinery applied in these fuel treatments do not capture all practices carried out in other areas where other types of equipment are used. Enhanced knowledge transfer between wildfire management agencies can increase awareness of alternative fuel treatment techniques and, hopefully, develop innovative and cost-effective strategies.

At the landscape level, numerous industrial-scale projects use a wide variety of equipment and techniques to achieve different goals and objectives. For example, the primary goal of vegetation management operations in hydro rights-of-way is to mitigate line contact to "maximize public and worker safety and service reliability" (BC Hydro, 2016). Despite the differences in objectives, there may be equipment and techniques used in these activities that could improve the cost-effectiveness of fuel treatments in the wildland-urban interface.

Re-treatment operations

Vegetative regrowth and accumulation of woody debris in fuel treatment areas create a dynamic fuel environment, with changing fire behaviour potential over time. Re-treatment may be necessary to maintain the capacity of a fuel treatment to modify wildfire. A re-treatment prescription does not need to be the same as the original prescription, and alternative treatment techniques and machinery should be considered to reduce the cost of the re-treatment operation.

A holistic approach to developing long-term forest fuel hazard mitigation strategies includes considering vegetation response within a treated stand and how an initial treatment will impact subsequent re-treatments. Developing fuel management cycles (Hsieh & Hvenegaard, 2021) that include initial treatment tactics with re-treatment tactics and required frequency can aid practitioners in developing long-term cost projections for fuel treatment areas.

Ongoing data collection and analysis

The productivity trials and data analysis synthesized in this summary report were conducted over six years and required a large commitment of resources to establish research areas, collect forest stand data, monitor fuel treatment operations, and collect productivity data. Extensive data collection and analysis, with detailed documentation of these trials, has provided a source of literature available to fuels managers. Comprehensive fuel treatment evaluation is only feasible with a coordinated research approach and access to a large resource pool.

However, less detailed approaches to fuel treatment monitoring and data collection can be equally valuable to fuels managers. While detailed stand characterization provides comparative data for assessing productivity in forest stands of varying density and volume, a visual estimation that gives less detail of stand attributes can also provide a valuable record of stand conditions.

Similarly, productive machine hours and processed area as measured by a MultiDAT instrument provide a solid data set of machine operations. A less detailed approach to capturing machine operation data can include measuring the treatment plot area with a GPS and recording machine start and stop times to determine productivity rates.

If monitoring fuel treatments and evaluating productivity continue as operational priorities, there may be value in establishing guidelines for forest stand characterization and productivity data collection that can be implemented by a larger population of managers and technicians with a reduced resource requirement.

CONCLUSION

In an environment of continued development in the wildland-urban interface and increasing wildfire risk, wildfire management agencies recognize the need for applying fuel treatments on a larger areal extent. Given the high costs of fuel mitigation, agencies want to better understand the cost-effectiveness of fuel treatments. A dedicated approach to studying fuel treatment productivity with committed research funding has provided several opportunities to assess the productivity of techniques and equipment typically applied in fuel treatment operations.

Data collected from six years of productivity trials has provided benchmark productivity rates that can be used to estimate cost projections for fuel treatments in a limited set of ecosites. Additional productivity trials applying the same research variables in other fuel environments and ecosites can further refine this data set. Also, evaluating the productivity of novel equipment applying innovative fuel treatment techniques can identify opportunities for cost savings.

An expanding fuel treatment productivity data set grown through continued trials would lend to better understanding of fuel treatment costs and provide for a more efficient application of fuel treatments. Ultimately, developing decision-support tools would aid fuels managers in projecting treatment costs and enable recommended treatment techniques based on ecosite and forest stand attributes.

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REFERENCES

Agee, J. K., Bahro, B., Finney, M. A., Omi, P. N., Sapsis, D. B., Skinner, C. N., van Wagtendonk, J. W., Weatherspoon, C. P. (2000). The use of shaded fuelbreaks in landscape fire management. *Forest Ecology and Management, 127*, 55–66.

Agee, J. K., & Skinner, C. N. (2005). Basic principles of fuel reduction treatments. *Forest Ecology and Management, 211*, 83–96.

Aird, P. L., Winer, H. I., Cottell, P. L., Bredberg, C. J., & Berlyn, R. W. (1970). *Techniques for evaluating the productivity of logging machines: Results of a study of Beloit harvesters* (Woodlands Report No. 27). Pointe-Claire, Quebec: Pulp and Paper Research Institute of Canada.

BC Hydro. (2016). *Integrated vegetation management plan for BC Hydro transmission and distribution power line corridors* (Confirmation Number 105-0982-16/21). Retrieved from https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/corporate/safety/Corridor-PMP-May-2016.pdf

Clark, M. (2008). *Preliminary evaluation of mulcher-built firelines*. Retrieved from https://wildfire.fpinnovations.ca/65/PreliminaryEvaluationofMulcher-BuiltFirelines.pdf

Dodson, E., & Mitchell, D. (2016). Cost, production and effectiveness of masticated fireline. In *Proceedings of the 2016 COFE and Demo International 2016 Technical Conference, Canada's Forest Sector, Adapting to a New Reality*. Vancouver, B.C.

Dyson, P. (2021). *Stand treatment to reduce wildfire fuels: Forest machine productivity*. Retrieved from https://wildfire.fpinnovations.ca/206/FESBCQuesnelFireFinal.pdf

Folkema, M. P., Giguere, P., & Heidersdorf, E. (1981). *Shift level availability and productivity: Revised manual for collecting and reporting field data*. Pointe-Claire, Quebec: Forest Engineering Research Institute of Canada.

Gardeski, C., & Keddy, T. (2017). *Innovative biomass recovery – Evaluating the productivity of the Gyro-Trac bio-energy baling system* (Info Note No. 1). Hinton, Alberta: FPInnovations.

Halbrook, J., Han, H.-S., Graham, R. T., Jain, T. B., Denner, R. (2006). Mastication: A fuel reduction and site preparation alternative. In W. Chung & H.-S. (Eds.), *Proceedings of the 29th Council on Forest Engineering Conference* (137–146). Coeur d'Alene, Idaho.

Heinsch, F. A., Sikkink, P. G., Smith, H. Y., & Retzlaff, M. L. (2018). *Characterizing fire behavior from laboratory burns of multi-aged, mixed-conifer masticated fuels in the western United States* (RMRS-RP-107). Fort Collins, Colorado: U.S. Department of Agriculture.

Hsieh, R., & Hvenegaard, S. (2021). *Development of the Canadian wildfire fuel management knowledge base*. Retrieved from https://wildfire.fpinnovations.ca/Research/ProjectPage.aspx?ProjectNo=204

Hvenegaard, S. (2012). *National wildland fuels management survey (revised)* (Contract Report CR-729(R)). Hinton, Alberta: FPInnovations.

Hvenegaard, S., & Hsieh, R. (2014a). *Summary of mulch treatments and equipment productivity at the Slave Lake Mulch Research Area*. FPInnovations. Retrieved from https://wildfire.fpinnovations.ca/119/Slave Lake Summary_v5.pdf

Hvenegaard, S., & Hsieh, R. (2014b). *Productivity assessment for a CMI Hurricane C250 mulcher: A case study at the Slave Lake Mulch Research Area*. FPInnovations. Retrieved from https://wildfire.fpinnovations.ca/155/Report_HurricaneC250_v4 (FINAL).pdf

Hvenegaard, S., & Hsieh, R. (2014c). *Productivity assessment for a Lamtrac LTR8300T mulcher: A case study at a fuel treatment near Gregg Lake, Alberta*. FPInnovations. Retrieved from https://wildfire.fpinnovations.ca/155/Report_Lamtrac 8300_v7 (FINAL).pdf

Hvenegaard, S., & Hsieh, R. (2014d). *Productivity assessment for a Caterpillar 305.5D CR hydraulic mini-excavator (mini-hoe): A case study at the Slave Lake Mulch Research Area*. FPInnovations. Retrieved from https://wildfire.fpinnovations.ca/155/Report_CAT305_minihoe_v2 (FINAL).pdf

Hvenegaard, S., & Hsieh, R. (2014e). *Productivity assessment for a Lamtrac LTR6125T: A case study at the Slave Lake Mulch Research Area*. FPInnovations. Retrieved from https://wildfire.fpinnovations.ca/155/Report_Lamtrac 6125_v4 (FINAL).pdf

Hvenegaard, S., & Hsieh, R. (2014f). *Productivity assessment for a Volvo MCT135C rubber-tracked skid-steer loader: A case study at the Slave Lake Mulch Research Area*. FPInnovations. Retrieved from https://wildfire.fpinnovations.ca/155/Report_Volvo_MCT135C_skidsteer_v3 (FINAL).pdf

Hvenegaard, S., & Hsieh, R. (2014g). *Productivity assessment for a Caterpillar D6 dozer: A case study at a fuel treatment near the Mitsue Industrial Park*. FPInnovations. Retrieved from https://wildfire.fpinnovations.ca/155/Report_D6 Dozer_v3 (FINAL).pdf

Hvenegaard, S., & Hsieh, R. (2014h). *Productivity assessment for a Caterpillar D7 dozer: A case study at a fuel treatment near the Mitsue Industrial Park*. FPInnovations. Retrieved from https://wildfire.fpinnovations.ca/155/Report_D7 Dozer_v3 (FINAL).pdf

Hvenegaard, S., & Hsieh, R. (2015). *Productivity assessment of a Lamtrac LTR8290Q mulcher: A case study at two forest fuel re-treatments near Hinton, Alberta*. FPInnovations. Retrieved from https://wildfire.fpinnovations.ca/155/Lamtrac 8290_v4.pdf

Hvenegaard, S., & Hsieh, R. (2017a). *Productivity of a semi-mechanized forest-fuel reduction treatment: A case study in central Alberta*. FPInnovations. Retrieved from https://wildfire.fpinnovations.ca/191/TR2017N50.pdf

Hvenegaard, S., & Hsieh, R. (2017b). *Productivity of a motor-manual forest-fuel reduction treatment: A case study in Central Alberta* (Technical Report No. 51). FPInnovations. Retrieved from https://wildfire.fpinnovations.ca/191/TR2017N51.pdf

Hvenegaard, S. (2017). *Fire behaviour in jack pine/black spruce forest fuels following mulch fuel treatment: A case study at the Canadian Boreal Community FireSmart Project* (Technical Report No. 24). FPInnovations. Retrieved from https://wildfire.fpinnovations.ca/119/TR2017N24.pdf

Hvenegaard, S. (2019). *Mulching productivity in black spruce fuels: Productivity as a function of treatment intensity*. FPInnovations. Retrieved from https://wildfire.fpinnovations.ca/119/TR2019N4.pdf

Lambert, M.-C., Ung, C.-H., & Raulier, F. (2005). Canadian national tree aboveground biomass equations. *Canadian Journal of Forest Research, 35*(8), 1996–2018. https://doi.org/10.1139/x05-112

Magagnotti, N., & Spinelli, R. (2012). *Good practice guidelines for biomass production studies* (COST Action FP-0902). Florence, Italy: CNR-IVALSA.

Mitchell, J. (2007). *Managing forest fuels for community protection in the interior of British Columbia: Productivities and costs of thinning from below* (Advantage Report, Vol. 9., No. 4). FPInnovations. Retrieved from https://wildfire.fpinnovations.ca/Research/ProjectPage.aspx?ProjectNo=80

Partners in Protection. (2003). *FireSmart: Protecting your community from wildfire*. 2nd ed. Edmonton, Alberta: Partners in Protection. Retrieved from https://firesmartcanada.ca/wp-content/uploads/2018/10/FireSmart-Protecting-Your-Community.pdf

Ryans, M., & Cormier, D. (1994). *A review of mechanized brush-cutting equipment for forestry* (Special Report No. SR-101). Pointe-Claire, Quebec: Forest Engineering Research Institute of Canada.

Ryans, M. (2014). *Operational methods for monitoring productivity and costs*. National forest fuels management workshop. January 14–16, 2014. Hinton, Alberta: FPInnovations. Retrieved from https://wildfire.fpinnovations.ca/151/Presentations/01150800-MarkRyans-ProductivityMonitoringofFireSmartTreatments.pdf

Schroeder, D., & Mooney, C. (2008). *Mulching trials on harvest debris piles at Dutch Creek, Alberta*. FPInnovations. Retrieved from https://wildfire.fpinnovations.ca/Research/ProjectPage.aspx?ProjectNo=68

St-Amour, M. (2007). *Semi-mechanized precommercial strip thinning: A practical operations guide* (Advantage Report, Vol. 8, No. 1). Pointe-Claire, Quebec: Forest Engineering Institute of Canada.

USDA Forest Service. (2004*). Fuels planning: Science synthesis and integration; economic uses fact sheet 01: Mastication treatments and costs* (Res. Note RMRS-RN-20-1). Fort Collins, Colorado: U.S. Department of Agriculture. https://doi.org/10.2737/RMRS-RN-20-V1

APPENDIX A: GLOSSARY OF TERMS

Through the design phase of these fuel treatment project sites, current (or most widely accepted) terminology was used to describe operations and label research plots. As fuel treatment research continued, with the application of novel treatment techniques in different areas, we learned that terminology is not a universal language applied consistently within an agency. In some cases, different terms were used synonymously to describe the same process. This glossary provides some clarity.

Clump spacing: A fuel removal treatment used to create crown-to-crown spacing between clumps of residual stems. Clump spacing is typically achieved through mechanical treatments, but motor-manual operations can also be used effectively in areas where natural clumps of stems occur.

Inter-tree spacing: A fuel removal treatment that typically retains dominant, healthy stems to achieve a defined crown spacing as specified in a fuel treatment prescription.

Mastication: The process of chipping or shredding components of the tree canopy or above-ground vegetation to reduce the canopy, alter fire spread rates, and reduce crown fire potential (Heinsch, Sikkink, Smith, & Retzlaff, 2018). Mastication can be achieved through the use of several different equipment types, including mowers, grinders, chippers, or mulchers.

Mulcher: The mulchers evaluated in these studies were primarily tracked carriers equipped with a horizontal drum cutting head with fixed cutting teeth. Boom-mounted mulchers on excavators are another option for fuel treatment operations on steeper slopes.

Mulching: A mechanical fuel treatment that changes the structure and size of fuels in the stand. Trees and understory vegetation are chopped, ground, or chipped, and the resulting material is left on the soil surface (USDA, 2004).

Mulch thinning: A mechanical fuel treatment conducted using a mulcher to achieve a prescribed crown spacing or stem spacing. Also known as thinning by mulching.

Semi-mechanized forest fuel-reduction treatment: Applying the same principles as in a semi-mechanized pre-commercial strip thinning operation, mechanical and motor-manual resources are combined to achieve a thinning treatment as part of a wildfire mitigation goal.

Semi-mechanized pre-commercial strip thinning: A mechanical treatment that typically uses a brush cutter to create corridors that improve access for manual thinning operations. Motor-manual operations complete the treatment by thinning the stand to promote growth of select crop trees (Ryans & Cormier, 1994).

Strip mulching: A mechanical fuel treatment typically conducted using a mulcher to mulch strips of forest stand and displace the mulched fuel to the surface layer. A strip of residual stems (typically the same width as the mulched strip) is retained. The width of the mulched strips can be altered to increase the crown-to-crown separation between strips. Pre-commercial strip thinning has been used as means to accelerate the growth of crop trees. Also known as strip thinning.

FPInnovations

info@fpinnovations.ca
www.fpinnovations.ca

OUR OFFICES

Pointe-Claire
570 Saint-Jean Blvd.
Pointe-Claire, QC
Canada H9R 3J9
(514) 630-4100

Vancouver
2665 East Mall
Vancouver, BC
Canada V6T 1Z4
(604) 224-3221

Québec
1055 rue du P.E.P.S.
Québec, QC
Canada G1V 4C7
(418) 659-2647