info@fpinnovations.ca
web.fpinnovations.ca

ORIENTED PILE FLAMMABILITY BURN TRIAL OCTOBER 2020

Collaborations with Mosaic Forest Management and British Columbia Wildfire Service

PROJECT NUMBER: 301014141 – New Fibre Sources

Stu Spencer, RPF
Steve Hvenegaard, WFBS
Brandon MacKinnon, M.Sc.

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FPInnovations

The clean air initiative led by the British Columbia Ministry of Environment seeks to develop innovative methods to improve community air quality by utilizing harvest residues and minimizing the volume of fibre burned at roadside. Retaining processed tops as roadside oriented piles is proposed as an alternative to burning debris.

These burn trials have demonstrated that in this unique arrangement of fuels and interaction of site-specific variables, particular areas of the piles will be more vulnerable to ignition sources which can lead to sustained burning and high intensity fire behaviour. In addition to the low fuel moisture conditions, other fuel properties, such as the close proximity of piles, high volume of fine fuels (branches and needles) and orientation of piles to road all contributed to enhanced burning at this site.

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APPROVER CONTACT INFORMATION
Ken Byrne
Manager, Forestry
ken.byrne@fpinnovations.ca

REVIEWER
Michael Benson
Manager, Wildfire Operations
michael.benson@fpinnovations.ca

AUTHOR(S) CONTACT INFORMATION
Steve Hvenegaard
Senior Researcher, Wildfire Operations
steven.hvenegaard@fpinnovations.ca
(780) 740-3310

Stu Spencer
Senior Researcher, Forestry
stuart.spencer@fpinnovations.ca
(604)222-5617

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1 BACKGROUND

The clean air initiative led by the British Columbia Ministry of Environment seeks to develop innovative methods to improve community air quality by utilizing harvest residues and minimizing the volume of fibre burned at roadside. Lower quality fibre is often left at roadside by the primary harvester in a form conducive to burning to facilitate fuel hazard abatement obligations. However, this also makes it unfeasible for a secondary user to economically recover the fibre in a useable form, free of contaminants. This hazard abatement technique simultaneously creates negative externalities through poor regional air quality, loss of potential economic opportunities, and release of GHGs without beneficial use or offsets. A substitute to burning is being investigated through alternative arrangement of residues to reduce fuel hazard.

2 ISSUE

The primary means of eliminating debris identified as a fuel hazard is the practice of pile burning. This hazard abatement practice is usually conducted in late fall or winter when the potential for fire spread to adjacent forests is low. Burning of debris piles creates a number of issues including:

- Generation of large volumes of smoke as atmospheric conditions are often not conducive to good ventilation, contributing to adverse health effects
- Generation of large volumes of greenhouses gases
- Elimination of fibre that potentially can be used in secondary products such as pulp log, pellet feedstock, hog fuel, etc.

3 PROJECT HISTORY

In October 2018, FPInnovations conducted a proof-of-concept study in the Coastal Western Hemlock biogeoclimatic zone near Port Alberni, British Columbia. In this area and other areas of B.C., harvest residues are often left in oriented piles (placed in parallel piles, perpendicular to the road) by the processor operator during harvesting activities. The overarching goal of this initial proof-of-concept study was to determine whether harvest residue piles that have been oriented for biomass extraction are a significant fuel hazard that require further abatement or whether they can be left until such time as they are extracted by secondary harvesters, or even simply left at roadside.

The 2018 proof-of-concept study was designed to explore and compare the ignition potential and potential fire behaviour in two different configurations of piled harvest residues. The first configuration was a product of the processing method which left harvest residues (tops) piled at roadside in a parallel orientation (oriented piles). The second configuration was a constructed *haystack* burn pile that is typically created for the purpose of disposing residues through burning (Figure 1).

Figure 1. Oriented pile (left) and a constructed haystack burn pile (right).

The ignition trials in twelve separate piles were conducted under low to moderate fire hazard conditions. Ignitions in an oriented pile and a burn pile were started simultaneously and fire behaviour characteristics were observed, including ease of ignition, sustained burning, resultant fire intensity, and extent of pile consumption. A key finding from these trials was that relative to the constructed burn piles, the oriented piles were much more difficult to ignite and burned with lower fire intensity and reduced pile consumption (Hvenegaard et al. 2019). A primary goal for continued research was to conduct burn trials in conditions of higher fire hazard in different fuel types found in other geographic areas.

4 OBJECTIVES

The extended research in 2019 and 2020 did not continue to study and compare the flammability of haystack burn piles but rather focused on the flammability of oriented piles. To study the flammability of oriented piles, it was proposed to ignite single oriented piles under higher fire hazard conditions and document fire behaviour.

The general goal of this research project was to simulate the most probable wildfire ignition mechanisms and evaluate the flammability of oriented piles.

Specifically, the objectives of this study were:

- To evaluate the fuel environment including a characterization of the oriented piles.
- To determine the ignition potential of oriented harvest debris piles from different ignition mechanisms under a wide range of Fire Weather Index and weather parameters.
- To document fire behaviour within the piles once sustained ignition has been achieved. These fire behaviour characteristics would include flame height, spread rate, and overall pile consumption.
- To evaluate the risk of fire spread from the oriented debris piles to fuels in adjacent debris fields. These spread mechanisms would include firebrand generation and transfer and direct flame spread from the burning piles.

5 STUDY SITE

The study site was approximately 30 km southwest of Nanaimo, British Columbia, in the Cowichan operating area managed by Mosaic Forest Management. Cutblock 101145 was harvested in the spring of 2019 and processed using a danglehead processor, leaving tops piled at roadside in an oriented fashion, although portions of the residual tops were left parallel to the road, instead of perpendicular (Figure 2). General site attributes are shown in Table 1.

Figure 2. Processed tops piled in oriented piles perpendicular and parallel to the road.

Table 1. Site and forest stand attributes of cutblock 101145.

Biogeoclimatic Zone	Coastal Western Hemlock Very Dry Maritime (CWHxm2)
Pre-harvest Species Composition	Douglas fir (70%); Western Hemlock (26%); Western red cedar (4%)
Pre-harvest Stand Age	60 years
Slope	20 to 25%
Aspect	North facing
Drainage	Well-drained

It was important to minimize disturbance to the piles or adjacent debris fields by maintaining the oriented piles and the surrounding fuels in a state that is typical of harvest/processing operations. However, British Columbia Wildfire Service (BCWS) project managers anticipated the need to create a fuel break that could be used for containment operations.

In the fall of 2019, BCWS personnel worked with an excavator operator to create a fuel break anchored to the access road on the north side and surrounding the trial site on the remaining three sides (Figure 3). Note that Figure 3 provides orientation of the site with a standard north looking reference. Due to smoke conditions, imagery during this burn trial was taken from a south looking viewpoint and subsequent images in this report are shown in this orientation. The fuel break was constructed by removing vegetation and debris to expose mineral soil in a four-metre-wide strip in order to create a barrier to fire spread and provide better access for the water delivery system and suppression crews (Figure 4).

Figure 3. Prepared fuel break anchored to the road and surrounding the burn trial area.

Figure 4. Hoselay with sprinklers along the eastern edge of site.

In October 2020, additional manual improvements were made to the fuel break to ensure a solid barrier to fire spread and to improve access. Branch lines from this fuel break were cleared to enable installation of hose lines and sprinklers and allow for easier access and quicker response to spot fires developing outside the fuel break.

The road and landing at the west end provided a good area for staging and setting up a water delivery system with two 1 500-gallon bladders. A water tender was contracted to supply water to these reservoirs during the burn trial (Figure 5).

Figure 5. Burn trial site with fuel break constructed and water delivery system installed.

6 RESULTS

6.1 Debris Pile Characterization

Terminology for harvest residue components (tops, butts, brush) has been applied from Spencer and Roser (2017). From the ground, each of the oriented piles was not clearly distinguished from adjacent piles. However, aerial imagery helps to define nine oriented piles (Figure 6), characterized individually, within the burn area. The numbering and bounding of individual piles have been modified from an earlier site description to reflect the parceling and ignitions applied during this burn trial.

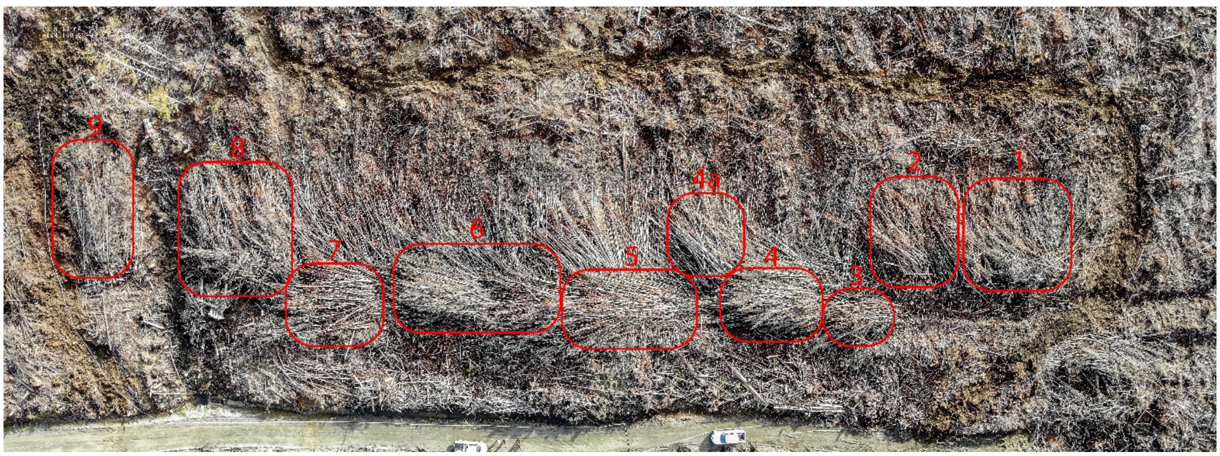

Figure 6. Individual piles identified for isolated ignitions.

The oriented piles consisted primarily of tops that were generally aligned in a parallel fashion, although a portion of piles 3 through 8 were parallel to the road instead of perpendicular. Pile characterization included measurements of butt diameter of pieces, classification by species relative evaluation of pile size, and density and composition of each pile component. The primary species was Douglas-fir with minor components of western red cedar and western hemlock (Appendix I).

6.2 Fuel Moisture Content

A Protimeter moisture meter and calipers were used to measure moisture content and butt diameter for 10 tops in each pile (Appendix II). The average moisture content and average diameter of the tops in the oriented piles were 18% and 11.8 cm, respectively. On average, moisture content in the tops on the uphill side of the piles were 2% lower than that on the downhill side (north facing).

6.3 Weather Conditions and FWI Values

The two BCWS weather stations most representative of the burn trial site—Summit (west) and Mesachie 2 (south)—were both 25 km from the study site. Reinhart weather station, operated by

Mosaic Forest Management, was 5 km southeast of the burn trial site. In the two weeks prior to the burn trial, a major rain event[1] (September 22 to 27) was followed by nine days of good drying with only 1 mm of precipitation recorded at Summit weather station.

The resulting Fire Weather Index (FWI) (Van Wagner 1987) values (Table 2) indicate the drying trend had boosted the Fine Fuel Moisture Code to near 90th percentile values[2] (Table 3) while Buildup Index values remained low.

Table 2. Weather and FWI values at representative BCWS weather stations.

Station	Weather Conditions at 12:00 on October 7				Forecast Fire Weather Index Values					
	Temperature	Relative Humidity	10 m Wind Speed	Wind Direction	FFMC	DMC	DC	ISI	BUI	FWI
Summit	19.8	68	2.2	319	83	13	53	2	16	2
Mesachie 2	20.2	74	3.7	302	85	15	96	2	21	4
Reinhart	21	61	4	90	86	17	58	3	20	5

The Canadian Forest Fire Weather Index (FWI) System[3] consists of six components that account for the effects of fuel moisture and weather conditions on fire behaviour:

FFMC – Fine Fuel Moisture Code
DMC – Duff Moisture Code
DC – Drought Code
ISI – Initial Spread Index
BUI – Buildup Index
FWI – Fire Weather Index

Table 3. 90th percentile values for representative BCWS weather stations.

Station	90th Percentile Values		
	FFMC	ISI	BUI
Summit	89.8	5.8	75.6
Mesachie 2	92.4	8.4	159.3

Onsite weather conditions were recorded using a Kestrel 5500 weather meter. At noon on October 7, the onsite weather conditions were as follows:

- temperature – 20.4°C
- relative humidity – 65.9 %
- wind – calm

In the timeframe of 12:00 to 17:00, wind direction was predominately from the north (Figure 7) with an average speed of 8.5 km/h (converted to 10 m wind speed) and maximum speed of 20 km/h. Typical increases in wind speed were observed and documented in the timeframe between 14:00 and 16:00. A quarter hourly analysis of wind speed and direction is presented in

1 BCWS weather records for this time frame show Summit and Mesachie 2 weather stations received 249 mm and 165.8 mm, respectively. The Reinhart weather station recorded 173 mm of rain.

2 https://www2.gov.bc.ca/gov/content/safety/wildfire-status/prevention/vegetation-and-fuel-management/fire-fuel-management/fuel-management

3 https://cwfis.cfs.nrcan.gc.ca/background/summary/fwi

Appendix III. Average temperature during the burn trial was 22°C, while minimum relative humidity was 46%.

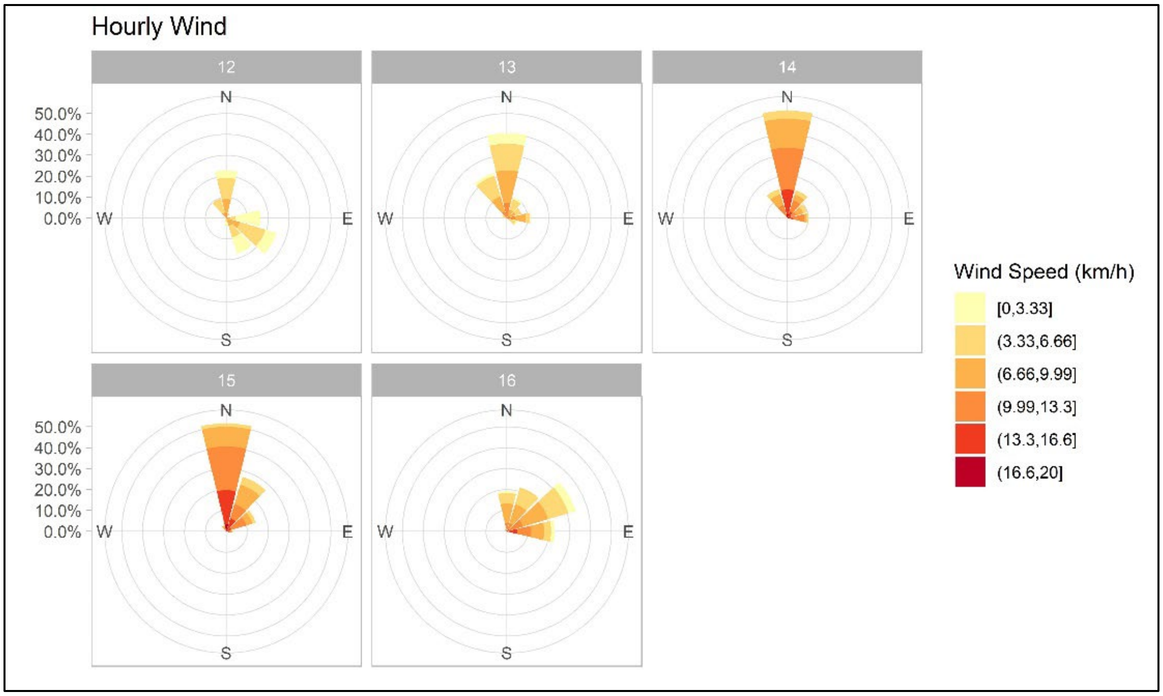

Figure 7. Hourly wind roses indicating frequency of wind speed and direction between 12:00 and 17:00.

6.4 Fire Behaviour

Video analysis combined with onsite notes from observations provided data to analyze ignitions, sustained burning, and fire growth in the oriented piles. This description of fire behaviour includes a condensed account of events during the ignition phase and fire development phase of select piles where significant fire behaviour principles were illustrated or important findings were realized.

The significance of these observations will be addressed in the discussion section.

6.4.1 Ignition and Fire Growth in Individual Piles

6.4.1.1 Pile 7

At 12:37, ignition operations commenced using three drip torches. The portion of the pile closest to the road where ignition occurred was oriented parallel to the road so that ignition occurred in the fine branches of the tops. Drip torch fuel was applied continuously for three minutes to the fuels near the ground, but these fuels in pile 7 would not sustain ignition beyond the influence of the drip torch fuel.

The ignition team shifted the ignitions to the west end of pile and sustained ignition was achieved after two minutes of continuous ignition (Figure 8) in the elevated branches of the side of the pile. Twenty-five minutes after ignition, pile 7 was burning vigorously, and 59 minutes after sustained ignition was achieved the pile was fully engaged with three to four metre flames above the pile (Figure 9).

Figure 8. Sustained ignition in pockets of fine fuel in pile 7 at 12:57.

Figure 9. Full engagement of pile 7 at 13:41 with sustained burning in the fine fuels (branches) of pile 8.

6.4.1.2 Pile 8

At 13:02, ignition was initiated along the base of the east side of pile 8 in the fine fuels of the tops. One single bead of drip torch fuel self-extinguished within two minutes.

A line ignition with three beads of fuel was commenced and self-extinguished in two minutes. More aggressive ignitions in pockets of fine fuel higher on the bank succeeded in sustaining ignition and accelerating fire growth in pile 8. With greater vertical continuity in these pockets of fine fuel (branches and needles), sustained burning was achieved (Figure 10).

Figure 10. Sustained burning in elevated fuels of pile 8 at 13:14. Pile 7 engaged on east end of pile.

6.4.1.3 Pile 6

A five-metre-wide swath of residue on a bench of ground north of pile 6 was identified as a source of fuel that could be ignited to simulate a wildfire encroaching the pile. At 13:29 several ignitions of varying duration were attempted (single bead, three bead) along the edge of the pile, but these would not sustain burning (Figure 11).

Figure 11. Attempts to directly ignite fuels adjacent to pile 6 were not successful and ignition was diverted to the swath of debris north of the pile.

After 15 minutes of continuous ignition along the entire swath in front of pile 6, sustained burning was achieved in some pockets of fine fuel. This area was damp with moist fine fuels on the ground and coarse debris that was difficult to ignite. After 18 minutes of aggressive efforts to ignite the residue in the front of the pile, burning was sustained in the coarse residue (Figure 12). Rank[4] 2

[4] BCWS uses a ranking scale from 1 to 6 to quickly describe fire behaviour based on a set of visual indicators.

and 3 fire behaviour persisted in the heavy fuels of this debris for over 30 minutes (Figure 13) without having yet engaged pile 6.

The simulation of wildfire, attempted in the swath of residue downhill of pile 6, resulted in slow fire spread due to minimal fine fuels, low wind speed, and gentle slope. Eventually, sufficient fire intensity developed, and fire spread in the coarse fuels in the swath to engage pile 6; however, ignition of fuels in pile 6 was still slow due to the lack of fine fuels within the pile. Pile 6 was also ignited by high intensity fire spreading from adjacent piles and was fully engaged at 15:13.

Figure 12. Sustained burning in swath of debris downhill of pile 6 at 14:07.

Figure 13. 33 minutes after ignition - Rank 2 and 3 fire behaviour in swath of residue downhill of pile 6.

6.4.1.4 Pile 5

Ignition along the base of pile 5 was initiated at 13:58 using three drip torches to conduct spot ignitions in concentrations of fine fuels. After five minutes, well developed fire in fine fuels was achieved (Figure 14). At 14:10, vigorous fire had developed in pile 5, while fire in the swath of debris below pile 6 lingered as Rank 2 or 3 surface fire (Figure 15).

Figure 14. Five minutes after ignition of Pile 5.

Figure 15. Varying stages of fire development. Full engagement in piles 7 and 8 with lingering surface fire below pile 6 and developing fire in pile 5.

6.4.1.5 Piles 4 and 4a

Pile 4a is an extension of the tops from pile 4. At 14:20, a line ignition (single bead) using three drip torches, was set one metre back from the uphill edge of piles 4 and 4a. The higher volume of elevated and drier fine fuels on the uphill side contributed to rapid ignition and sustained burning along the edge of the piles. Fire behaviour in pile 4a grew rapidly through the influence of the convective indraft produced by the fully engaged pile 5 (Figure 16). At 14:44, ignition was initiated in a debris field on the downhill side of pile 4 with ignition of the elevated fine fuels (branches). Within 5 minutes, pile 4 was fully engaged with six to eight metre flame length (Figure 17).

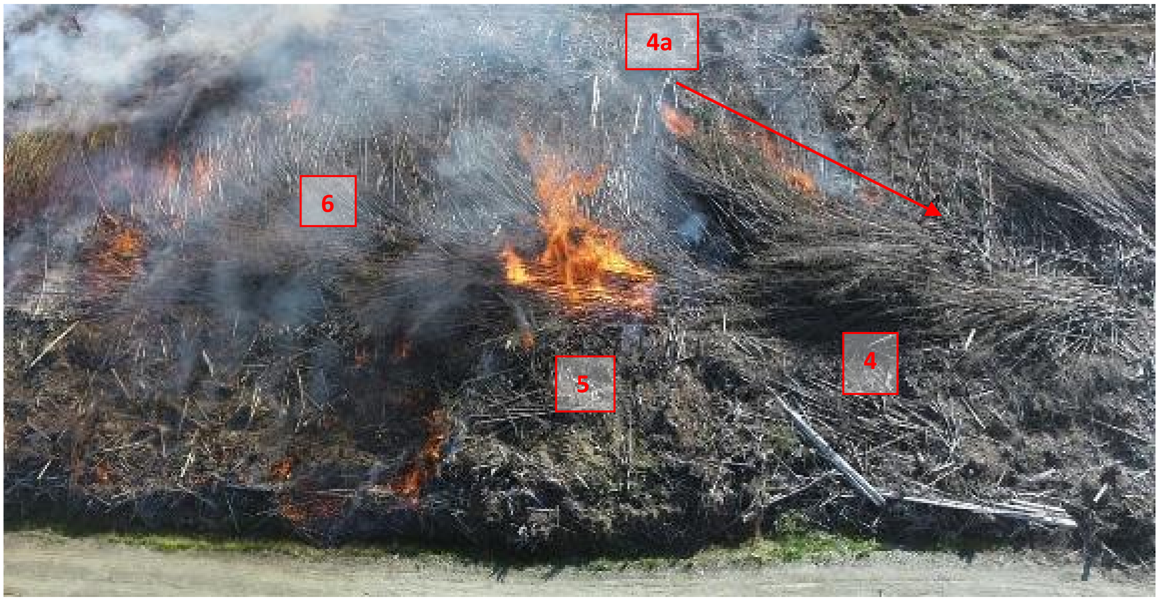

Figure 16. Established fire along the south edge of 4 and 4a three minutes after ignition (14:23).

Figure 17. Pile 4 fully engaged 5 minutes after ignition (14:49).

6.4.1.6 Pile 3, 2, and 1

At 14:45, two members of the ignition team started spot ignitions on the uphill edges of piles 1 and 2 (Figure 18). Ignitions in the debris field north of pile 3 and 4 continued to build in intensity and by 15:05 pile 3 was fully engaged. Ignitions in pile 1 and 2 burned downhill to engage the larger stems in the downhill half of these piles.

Figure 18. Ignition of pile 2.

6.4.1.7 Pile 9

Pile 9 was not ignited because, prior to the start of the trial, it was assessed to be outside the containment area and the onsite crews felt it was safer to not ignite the pile.

6.4.2 Spread Rate and Direction

Aerial imagery at different stages of fire growth overlaid on a GIS grid (Figure 19) was used to interpret fire growth and calculate spread rate. During a 35-minute time frame (13:16 to 13:51) of fire growth in piles 7 and 8, the average rate of spread was calculated to be 0.6 m/min. The average wind speed during this stage of fire growth was 7.2 km/h. With the predominant north wind during this time, fire spread quickly from pile 7 and merged with fire spreading from pile 8.

As the fire spread beyond the defined boundaries of these piles and entered the containment zone where there were fewer branches and fine fuels, there was little difference in spread rates between these zones, but there was a reduction in flame height and fire intensity.

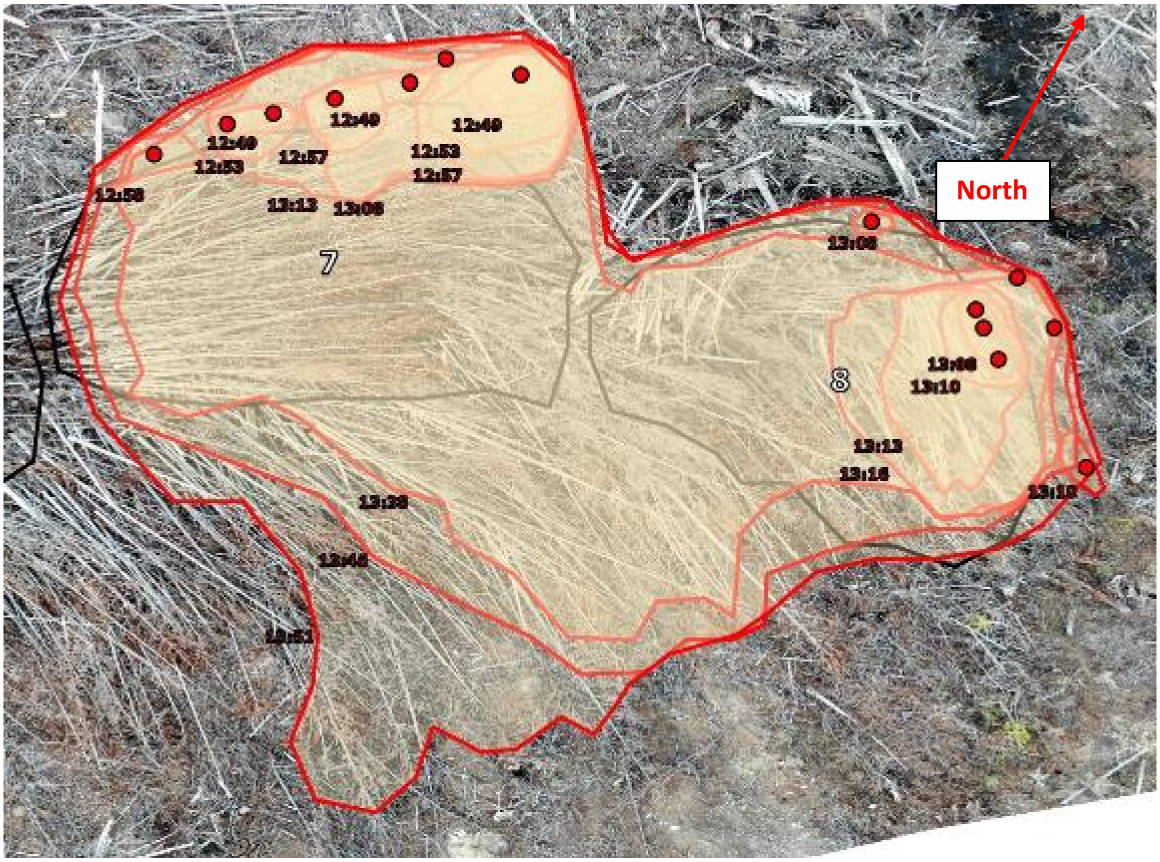

Figure 19. Fire progression map indicating iterations of fire growth in piles 7 and 8.

6.4.3 Firebrand Generation and Spot Fire Development

The holding crew reported numerous spot fires ignited from firebrands in the debris field uphill from the oriented piles. One spot fire was detected approximately 20 metres outside the fuel break, approximately 30 metres from piles 7 and 8 which were the likely source of the firebrands.

Prior to ignition, the holding crew had set up branch lines from the main hose line with sprinklers and extensively wet the fuels outside the fuel break on the uphill side of the trial site. This preventative measure had been established to prevent spot fire ignition.

6.4.4 Pile Engagement and Consumption

At 15:13, all the piles were in different stages of engagement, with considerable fuel consumption in piles 7 and 8 and the surrounding debris fields (Figure 20).

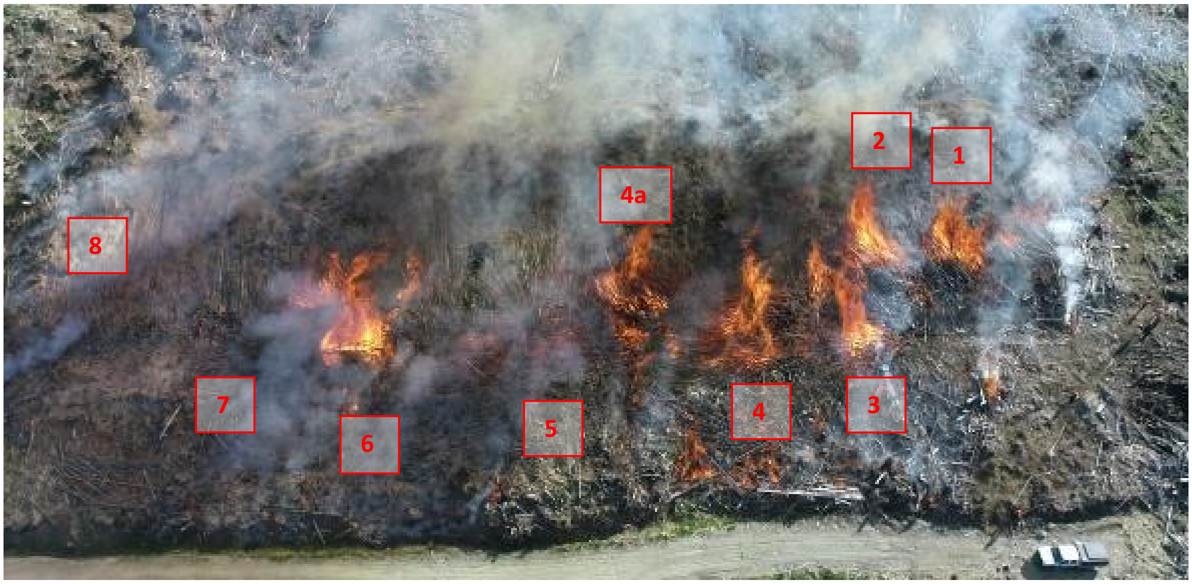

Figure 20. Varying stages of engagement and consumption across piles at 15:13.

At 15:52, pile 6 burned with high intensity flames, while the remaining piles smouldered or burned with reduced intensity (Figure 21). The holding crews created a wet line inside the fuel break to reinforce the barrier impeding fire spread beyond the fuel break. The piles continued to smoulder overnight and by 09:00 the next morning, the majority of the stems in the piles and the adjacent debris had been consumed (Figure 22).

Figure 21. Reduced fire activity in most piles with high intensity fire behaviour in pile 6.

Figure 22. Complete consumption of stems and debris in the burn trial on October 8, 2020.

7 DISCUSSION

7.1 Applied Ignition as Simulations of Wildfire Ignition

A key objective of this study was to evaluate the ignition potential of oriented harvest debris piles using different ignition mechanisms, under a higher range of FWI and weather parameters. This trial evaluated two ignition mechanisms: firebrands and an encroaching wildfire.

Previous studies (Schroeder et al. 2006, Schiks and Hvenegaard 2013) to assess ignition probability have applied standard data collection methods including fuel moisture sampling, hourly weather readings, and ignition attempts with simulated firebrand sources (typically wooden matches) in the fuel beds under study and in a natural forest stand. Due to the time constraints, ignition probability tests could not be conducted using this same methodology or rigor.

However, these trials provided insights into the ease of ignition in the varying fuel environments across the site. An extreme contrast in ease of ignition was evident in the ignitions of pile 7 and pile 4/4a, where time of day and aspect influenced moisture content and the availability of fuels. North facing fuels of pile 7 at 12:37 proved difficult to ignite and a continuous application of drip torch fuel was required to sustain ignition. In contrast, ignition of pile 4/4a at 14:21 was almost instantaneous due to a greater volume of elevated dry branches along on the south facing (uphill) edge of the piles.

In both ignitions (piles 7, 4/4a), the primary receptor for ignition and the carrier for sustained burning were the branches and needles. Typically, fine fuels in the surface layer, such as litter, lichens, and grass are considered likely firebrand receptors.

It was unclear from these trials to what extent these fuel components influenced ignition and sustained burning. In the ignitions on the north side (downhill) of the burn trial site, these fuels were wet to the touch and did not ignite initially. However, in areas on the south edge of the trial area, ignitions from firebrands in the drier fuels were numerous.

It was a challenge to create ignition patterns that simulated an encroaching wildfire and the burn team adjusted conventional ignition tactics to accommodate this research objective. In the sparse and moist debris fields along the north side with a lack of fine fuels, ignition of these fuels was difficult and, in most cases, line ignitions in the debris adjacent to the piles self-extinguished. The one exception was the ignition of the swath of debris north of pile 6 where a prolonged ignition attempt achieved sustained burning in the debris field.

The intensity of wildfires approaching a cutblock will be dependent on several factors. In these trials, wind and slope were not significant influences on fire behaviour in fuels adjacent to the burn piles; hence, it was difficult to simulate a well-developed wildfire encroaching on an oriented pile. However, the slope in the gully on the east side of the site, created vertical continuity of fuels in pile 8 and provided an indicator of the influence of slope. Even though this was one of the earliest ignitions, and on an east facing slope, this ignition in the elevated fine fuels spread quickly to the fine fuels above with building intensity.

In the early stages of fire growth in piles 4 and 4a, the convective indraft from pile 5 created a wind source that accelerated fire spread in pile 4a in a downhill direction towards pile 5. At this stage, it was estimated that the flame length and rate of spread in pile 4a was three times that of pile 4. As fire became well established in these ignition lines, a more typical fire growth pattern developed under the combined influence of alignment of ambient wind and slope.

Site design in future burn trials should incorporate slope or amendment of adjacent fuels to achieve a more realistic simulation of an encroaching wildfire. With a continuous fuel bed of slash or branches on the upwind or downslope side of an oriented pile it would be easier to develop fire spread and fire intensity more representative of an encroaching fire.

The ignition sources in this burn trial (drip torch) provided a generous heat source (volume and intensity) to the fine fuels in the piles and this may not be indicative of firebrands as an ignition mechanism. Firebrand generators (Manzello 2014) have been used to study the ignition potential of building materials and construction methods. These devices and methods could also be used to more realistically replicate firebrands landing on oriented piles to study ignition probability of oriented piles and other forest fuel environments.

7.2 Compounding Environmental and Operational Factors

7.2.1 Pile Layout

7.2.1.1 Orientation of Pile Pieces

Typical oriented pile layout requires pieces to be placed in a parallel fashion, perpendicular to the road. During the site selection process, it was noted that the piles on the proposed site deviated from the recommended oriented pile layout method because approximately half the pile (the half closest to the road) was laid out parallel to the road, rather than perpendicular.

Although not ideal, it was decided that any opportunity to document the fire behavior in different orientations would be beneficial due to lack of existing data on the topic.

In most of the piles ignited during the trial, ignition occurred along the bottom side of the pile, in the branches and needles of the tops. The fines then ignited the medium and then larger fuels until the pile was fully engaged. In a traditional oriented pile, ignition would have occurred along the butt ends of the tops, on the downhill side of the pile, closest to the road, limiting or preventing full engagement of the pile.

If oriented piles are to become an accepted practice of pile and fuel management, care needs to be taken to understand the most likely direction fire may approach from and orient piles with the largest pieces forward.

7.2.1.2 Distance between Piles

The close proximity of piles and the multiple ignitions across the site influenced fire growth and intensity. One of the most obvious effects was convective indrafts produced by well-developed fires accelerating fire growth in adjacent piles. This was specifically obvious in the interaction between piles 7 and 8 and piles 5 and 4a. In these situations, pre-heating of fuels from one pile to another may have been another contributing factor in the rapid-fire growth. As more piles became fully engaged (5, 4, 4a, and 3) the convective column compounded the effects of indrafts on fire intensity and fire spread.

As mentioned in the section titled ‘Orientation of pile pieces’, if oriented piles are to become an accepted fuel hazard reduction practice, care needs to be taken to make sure that the piles are placed with enough space between them to minimize the proximity effects if adjacent piles are ignited. Long ‘windrow’ like piles should not be left without attempting to place adequate breaks along the windrow.

7.2.1.3 Ignition Methods and Fire Spread in the Oriented Piles

During this burn trial there were seven separate ignition operations in the piles and two ignitions to burn out fuels from the fuel break. The ignitions in the piles were intended as independent events to simulate wildfire ignition mechanisms of firebrand transfer (point ignition) and encroaching wildfire (line ignition). Due to the close proximity of the piles, with multiple ignitions, there were few opportunities to determine spread rate within a pile from a single independent ignition that wasn’t influenced by fire behavior in adjacent piles.

One exception to this was the line ignitions in pile 7 and 8. The slow engagement of pile 6 provided a window of time to observe fire growth in these piles where there was little influence from high intensity fire behavior in adjacent piles.

During a 35-minute time frame (13:16 to 13:51) of fire growth in piles 7 and 8, rate of spread was calculated to be 0.6 m/min. This was considered a steady state spread rate because the line ignition had sufficient time from ignition to achieve equilibrium rate of spread. The average wind speed (7.2 km/h) during this stage of fire growth was below the average wind speed (8.5 km/h) for the day but provides a good indication of fire growth potential in the oriented piles.

Using the REDapp[5] fire behaviour calculator, rate of spread in the coastal cedar/hemlock/ Douglas-fire (S-3) slash fuel type[6] at the peak of the burning day (17:00) was predicted to be 0.2 m/min. Fire behaviour observed in the swath of debris north of pile 6 was a good indicator of the slow spread rate predicted for this fuel environment. The elevated and drier branches, combined with the low moisture content of the stems in the oriented piles, produced a much drier moisture regime, which resulted in higher fire intensity with more rapid rate of spread.

Regardless of the number of ignitions in the burn trial site, with the low moisture content in the oriented piles, the heavy fuels in the piles were available for consumption. In this arrangement of continuous fuels from pile to pile, sustained ignition from any source would have resulted in continued fire spread with eventual consumption of all fuels.

With greater pile separation, direct fire spread from pile to pile would have likely been much slower and influence between the piles would have been eliminated or reduced. More study is needed to test this theory.

7.3 Stand Age and Crown Ratio

The piles were mostly composed of tops left after the sawlog was removed from the stem. In many harvest operations, branches are broken off during the felling, bunching, and skidding or harvester forwarding (hoe-chucking) stages. However, in younger stands, the springy nature of the branches prevent breakage, and most branches arrive at roadside attached to the stem. Also, the species composition and density of a stand can lead to differences in crown to stem ratio, meaning that residual tops can be left with variable amounts of fine branches, depending upon these differences.

The trial stand was approximately 60 years in age and had a relatively large crown to stem ratio compared to the 100-year-old stand in the 2018 pilot trial, meaning that the tops within the 2020 trial's piles had many fine branches that were not broken off in the primary harvest. These fine branches burned easily when dried, providing good ignition material when the drip torch was applied and creating firebrands after pile engagement.

It is unclear to what extent the age of the stand and the crown ratio affect the volume of branches arriving at roadside. It is recommended that further research is needed to determine the thresholds for these variables to further the understanding of when and where oriented piling may be an approved strategy for fuel hazard reduction.

7.3.1 Environmental Factors and Fire Hazard

This trial was conducted with fine fuel moisture conditions (FFMC) and wind conditions that were close to 90th percentile. Compounding this high fire hazard was the low fuel moisture content measured in the stems. The fuel moisture content of the stems measured in this trial was near

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[5] REDapp version 6.2.4 – The Universal Fire Behaviour Calculator. https://www.redapp.org/
[6] Canadian Forest Fire Behaviour Prediction System fuel types are described in Hirsch (1996).

the seasonal low fuel moisture content (15% as measured with the Protimeter) as documented by Baxter (2009) in Douglas-fir stems of similar size in October 2009.

With this combination of low fuel moisture content (fine fuels and large stems) in cutblock 101145, the resultant fire behavior is not unexpected and there is no question that this type of fire behavior will occur with weather conditions beyond the 90th percentile. Under these fire hazard conditions, we would assert that any configuration of debris (oriented, haystack, or scattered) would be equally combustible. However, the comparative risk of these configurations in fire hazard conditions below the 90th percentile has not been well documented.

In the Ash valley burn trials (Hvenegaard et al. 2019) with FFMC below 70 and moisture content of stems at 20%, it was very difficult to ignite fine fuels and create enough heat intensity to engage larger fuels in the oriented piles. One of the recommendations from the Ash burn trials was to further study fire behavior at lower fuel moisture conditions in order to zero in on possible thresholds where oriented piling could contribute to fuel hazard reduction after harvesting. This trial has produced results of potential fire behavior at the higher extreme of fuel moisture conditions that suggest that in extreme conditions there is no reduction in the fuel hazard produced by alternative piling methods.

With a better understanding of fire behavior in oriented piles at opposite extremes of fuel moisture conditions, the remaining question is what type of fire behavior will result with environmental factors (fuel moisture and wind) between these two extremes.

8 CONCLUSION

The clean air initiative led by the British Columbia Ministry of Environment seeks to develop innovative methods to improve community air quality by utilizing harvest residues and minimizing the volume of fibre burned at roadside. A substitute to burning is being investigated through alternative arrangement of residues to reduce fire fuel hazard. To evaluate the flammability of oriented piles, FPInnovations collaborated with British Columbia Wildfire Service on a Mosaic Forest Management site to ignite single oriented piles and observe and document fire behaviour.

Multiple ignitions were conducted in the oriented piles and debris fields under a range of fuel moisture conditions with varying fuel arrangements. In this short timeframe (12:37 to 15:15), there was wide variation in ignition success and sustained burning. Optimum conditions for ignition and sustained burning included elevated fine fuels (branches and needles) with a south aspect at mid-day. Low fuel moisture content contributed to hazardous fuel conditions with a Fine Fuel Moisture Code near 90th percentile and moisture content in the piled tops at their seasonal low. With low fuel moisture conditions and moderate winds, once sustained burning was achieved and larger stems were engaged, high intensity fire developed and spread easily between the closely spaced piles.

These burn trials have demonstrated that in this unique fuel arrangement and interaction of site-specific variables, particular areas of the piles will be more vulnerable to ignition sources which can lead to sustained burning and high intensity fire behaviour. In addition to the low fuel moisture conditions, other fuel properties, such as the close proximity of piles, high volume of fine fuels and orientation of piles to the road all contributed to enhanced burning at this site.

Unlike fuel moisture content, these fuel properties and site conditions can be managed to reduce fire spread potential and fire intensity in these piles.

Two oriented pile burn trials (2018 and 2020) conducted at opposite extremes of fuel moisture condition, fuel composition, fuel arrangement, and pile separation have resulted in two extremes of fire behaviour. With a better understanding of fire behavior in oriented piles at these extremes, the remaining question is what type of fire behavior will result with fuel conditions (moisture, size, and arrangement), weather conditions, and site conditions in the middle ground between these two extremes.

It is unclear to what extent the age of the harvested stand and the crown ratio affect the volume of branches arriving at roadside. It is recommended that further research is needed to evaluate oriented piles of different age classes to determine fine fuel content. Ultimately, additional burn trials in oriented piles of different age class and fuel sizes will clarify probability of ignition and potential fire behaviour.

Future burn trials should explore how different piling techniques and site preparation practices can limit fire intensity in the oriented piles and minimize the potential for fire spread between piles and to adjacent forest stands. A valuable outcome of continued trials would be guidelines for processing and piling stems that would contribute to a fuel hazard abatement plan and provide for enhanced secondary fibre utilization.

9 ACKNOWLEDGEMENTS

Support from BCWS and Mosaic Forest Management were critical in the planning and execution stages of this burn trial. Access to recently cut harvest areas is important to conducting burn trials and Mosaic Forest Management was very supportive in providing opportunities to explore innovative strategies for harvest debris management.

BCWS personnel at the Coastal Fire Centre have extensive experience in planning and executing prescribed burns, and their direction and collaboration was invaluable in setting up the burn trial in a short timeframe. Furthermore, site preparation, equipment installation, and suppression capacity that BCWS provided are all essential elements of a burn trial at a higher fire hazard.

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APPENDIX I: PILE CHARACTERIZATION

Pile number	Size	Height (m)	Tops	Long Butts	Brush	Needle Retention (%)	Alignment	Length	Density	Species
1	L	2	100	0	0	100	4	25	4	60Fd40Cw
2	M	2	95	5	0	80	4	16	4	50Fd50Cw
3	S	1.5	100	0	0	75	4	10	4	60Fd40Cw
4	M	3.5	100	0	0	10	4	12	4	80Fd20Cw
5	M	4	100	0	0	30	4	12	4	80Fd20Eb
6	S	2.5	100	0	0	50	4	10	4	70Fd30Cw
7	M	5	95	5	0	0	4	10	4	60Fd40Hw
8	L	1.5	100	0	0	10	4	12	2	70Fd30Cw
9	M	2.5	100	0	0	10	4	15	4	70Fd30Cw

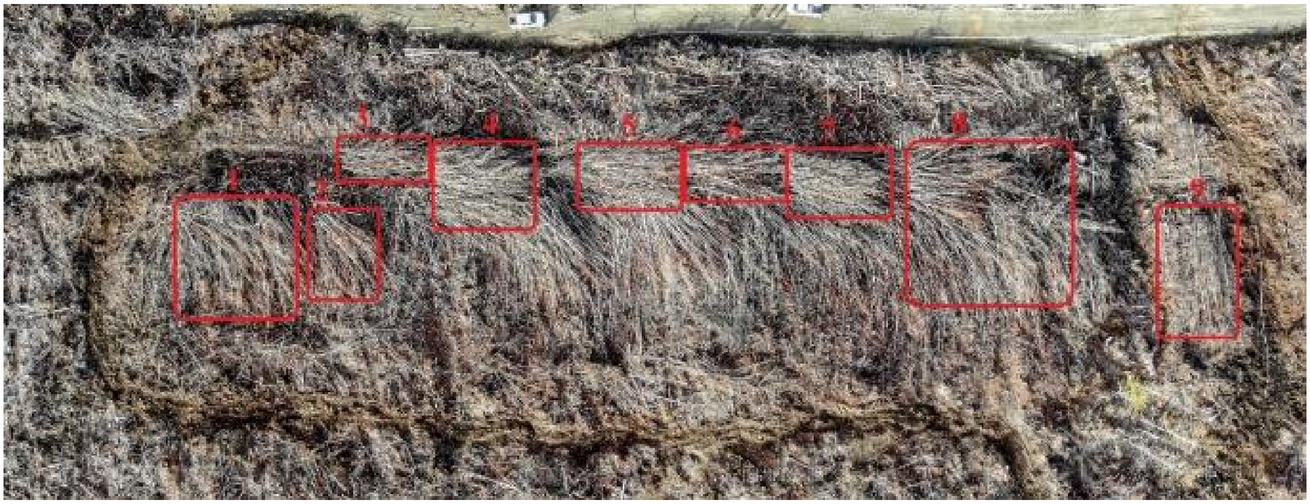
Relative scales:

Size: S = small, M = medium, L = large
Pile components: (tops, long butts, and brush) are identified by a ratio of weights within the pile, rounded to the nearest 10%
Alignment: scale of 1 to 5 where 1 = poor alignment (typically seen in haystack burn piles) and 5 = pieces are parallel with minimal airspace between pieces
Length: average length of the tops' component of the pile in metres
Density: scale of 1 to 5 where 1 = loose material with lots of airspace between pieces; typically, pieces are not parallel and 5 = neatly stacked pieces with minimal airspace between pieces, or compacted brush with minimal airspace between pieces
Species: ratio based on weight, rounded to the nearest 10%

Fd = Douglas-fir
Cw = Western cedar
Hw = Western hemlock
Eb = Paper birch

Note: *Soil content in all piles was minimal and, hence, not evaluated as part of the pile characterization.*

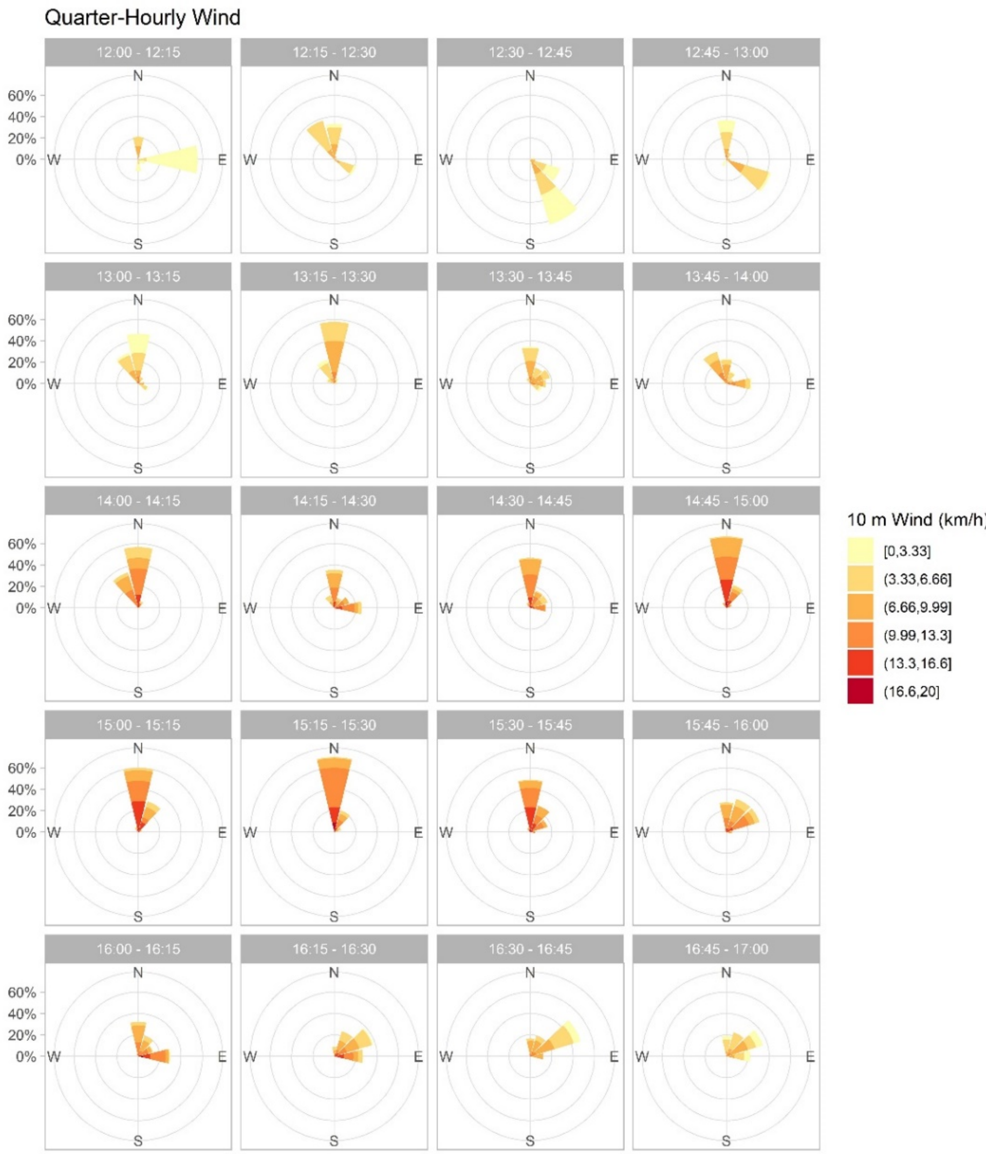
APPENDIX II: FUEL MOISTURE BY PILE



Pile Number	Average Moisture Content (%)	Maximum	Minimum	Standard Deviation	Average Butt Diameter (cm)	Maximum	Minimum	Standard Deviation
1	19.7	26.8	15.5	3.22	13.2	19.5	7.5	4.61
2	21.9	36.1	14.6	5.52	12.5	20.5	7.5	3.65
3	18.0	24.5	14.0	3.29	11.8	14.5	8.5	1.94
4	17.4	23.6	12.8	3.47	10.1	12.5	7.5	1.76
5	15.4	18.3	13.6	1.51	11.0	12.5	7.5	1.56
6	19.3	25	14.5	2.96	11.6	25	5	6.43
7	16.6	21.6	13.0	2.51	11.7	15.5	8.0	2.75
8	15.5	20.2	12.9	2.09	12.7	15.5	9.5	1.96
9	N/A				N/A			

Note: Pile 9 was not included in this burn trial and moisture content in this pile was not measured.

APPENDIX III: QUARTER HOURLY WIND ROSES



FPInnovations

info@fpinnovations.ca
web.fpinnovations.ca

OUR OFFICES

Pointe-Claire	Vancouver	Québec
570 Saint-Jean Blvd.	2665 East Mall	1055 rue du P.E.P.S.
Pointe-Claire, QC	Vancouver, BC	Québec, QC
Canada H9R 3J9	Canada V6T 1Z4	Canada G1V 4C7
(514) 630-4100	(604) 224-3221	(418) 659-2647