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ABSTRACT

Timber harvest companies are looking for cost-effective methods for harvesting low value fibre. FPInnovations conducted a multi-faceted research project in the Nazko region to compare several operational aspects of two harvest methods: cut-to-length and conventional.

As part of this research project, FPInnovations’ wildfire group measured and assessed the harvest residue resulting from both harvest methods. With this information, we were able to evaluate potential fire behaviour in each of the harvest areas.

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EXECUTIVE SUMMARY

This study is part of a larger project initiated by FPInnovations’ Forest Operations group to compare two harvesting methods: conventional and cut-to-length. Several operational aspects of these two methods were evaluated and will be presented in a forthcoming FPInnovations report.

This study was designed to provide a comparative analysis of potential fire behaviour in logging residue produced in areas harvested using these two methods. Our study methods consisted of collecting pre-harvest and post-harvest debris load inventory and compiling a photo inventory to establish debris loading for the two harvested areas. This debris loading combined with other fuel characteristics was used to evaluate potential fire behaviour and identify fire suppression challenges in each of these fuel environments.

The pre-harvest forest fuel environment in the Nazko logging area primarily consisted of a mature lodgepole pine overstorey with a heavy loading of fallen large-diameter stems in a criss-cross pattern in the surface fuel layer. Mountain pine beetle infestation has progressed to this grey-stage fuel environment typified by fallen stems in early stages of decay with few branches or little bark intact. The pre-harvest debris loading for the overall harvest area was estimated to be 72 t/ha with 87% of this loading made up of coarse woody debris (CWD) greater than 7.0 cm in diameter.

Post-harvest debris loadings in the areas harvested using the cut-to-length and the conventional methods were 39 t/ha and 47 t/ha, respectively. Post-harvest inventories indicate a shift in debris composition by size class with an increased loading of debris less than 7.0 cm and a decrease in CWD loading in both harvest areas. The conventional harvest area had a greater post-harvest composition of CWD at 45% while the cut-to-length harvest area had a CWD composition of 33%.

Of the woody debris fuel component, debris less than 7.0 cm in diameter has the greatest influence on potential fire behaviour in the active flaming stage while CWD makes a larger contribution to the smouldering combustion stage. With similar post-harvest loadings of debris less than 7.0 cm, fire behaviour modelling yielded little difference in head fire intensity values between the two fuel environments. At high fire danger ratings, the fuel environments resulting from both harvest methods have the potential to produce high intensity fire behaviour that will present fire suppression challenges.

While debris loading values input to fire behaviour models yields quantifiable potential fire behaviour, qualitative observations are equally important in assessing the overall fuel environment to identify potential fire suppression challenges. There were notable differences in arrangement and loading of debris between the two harvest areas. Debris loading in the cut-to-length harvest area was relatively uniform with a pattern of compacted broken debris in the corridors travelled by the harvester. These corridors were interspersed by strips of branches and CWD. Broken woody debris compacted in the duff layers will likely decompose at a faster rate and result in reduced long-term fire behaviour potential.

Continuous debris fields along the perimeter of the harvested areas will create fire suppression challenges, and fire spread to the crown fuels of the adjacent forest stands will be a control issue. One specific area of concern is the southeast perimeter of the conventional harvest area, where heavy accumulations of elevated fuels have the potential for higher intensity fire and increased sustained burning relative to areas in the interior of the harvest area where debris has been pushed into piles.
INTRODUCTION

Extensive tracts of forested land in the Caribou region of central British Columbia have been impacted by mountain pine beetle attack over the last 15 to 20 years. The remaining fibre (standing and downed) is difficult to salvage and harvest companies need innovative and cost-effective ways to harvest this low value fibre. FPInnovations conducted a multi-faceted research project in the Nazko region to address this issue by monitoring and comparing several operational aspects of two harvesting methods: conventional and cut-to-length.

Debris loading and the associated potential fire behaviour is a concern for harvest managers and wildfire managers. As part of the overall research project, FPInnovations’ Wildfire Operations group conducted field studies to achieve the following objectives:

- Assess the loading and arrangement of debris produced by the two harvesting methods.
- Evaluate and compare potential fire behaviour in the two harvest areas.

STUDY SITE

This study site is located 40 km west of Quesnel, British Columbia and is accessed by Nazko and Doig roads. The mature lodgepole pine in this area was infested by mountain pine beetle approximately 15 to 20 years ago and is in the late (grey) stage of attack with a large portion of stems down and dead with few branches and little bark intact.

The project site was designed to study two harvesting methods (conventional and cut-to-length) within a 20 ha parcel of forested land. Conventional harvesting was conducted in a 12 ha parcel in the southern portion of the area, while cut-to-length harvesting was conducted in a 4 ha parcel (Figure 1).

![Figure 1. Harvesting trial sites with inventory plots marked.](image-url)
METHODS

Pre-harvest inventory
On June 13 and 14, 2017 we established 20 inventory plots within the proposed boundaries of the harvesting area (Figure 1). A photo inventory for each site included the plot identifier (given by GPS location and waypoint number) associated with one photo from the plot centre in each of the cardinal directions.

For two of the plots (155 and 157), we used line intersect fuel sampling methods (McRae, Alexander, & Stocks, 1979) to inventory woody debris along a 25 m transect in each of the four cardinal directions. This inventory yielded eight sets of data that were input into a line intersect calculator\(^1\) to create a fuel load inventory photo guide. The photo guide associates calculated debris load (in tonnes per hectare) in assigned size classes with a photo of the measured transect. This photo guide was then used to compare photos from all other transects in order to estimate the fuel load for each transect and establish an average fuel load for the overall area.

Post-harvest inventory
We conducted post-harvest inventories on August 16 and 17, 2017. Only four of the established pre-harvest inventory plots overlaid the harvest area processed using the cut-to-length method. During the road building process, one of these plots was removed and, therefore, unusable for post-harvest inventory. To provide a more complete spatial representation of the post-harvest inventory in the northern section, an additional five inventory plots were established. Woody debris was inventoried along each of the four transects in four of the eight post-harvest plots in the northern section. These inventory data were input into the line intersect calculator to yield woody debris load for each transect. The debris load data from these sixteen transects with post-harvest photos of each transect provided a photo guide that was used to estimate debris loading in the remaining four plots.

Nine of the pre-harvest inventory plots in the southern section (conventional harvest area) were usable and two plots were added to provide a more complete spatial representation. Four of the 11 post-harvest plots were measured for woody debris along each of the four transects. The photos and debris loading data for these 16 transects was used to create a post-harvest photo guide that was used to estimate woody debris loading in the remaining seven plots.

Fire behaviour predictions
We input post-harvest debris loadings by size class in the Canadian Fire Effects (CanFIRE) model (de Groot 2012) to evaluate the potential fire behaviour in the two harvest debris fuel environments. Additionally, two extremes of debris loading were considered and calculated. Each of these fire behaviour predictions was generated using the same weather values and Fire Weather Index (Van Wagner, 1987) moisture codes which would be representative of a high fire danger rating: Wind Speed – 10 km/h, Fine Fuel Moisture Code – 90, Buildup Index – 70, Drought Code – 400.

\(^1\) Created by Natalie Lavoie, former leader, Fire Sciences, British Columbia Wildfire Service.
RESULTS

Overall debris loading and distribution by size class
Prior to harvesting, the forest stand was in the late (grey) stage of mountain pine beetle attack and most of the needles and branches had fallen and decomposed, leaving a 1-m-high layer of down and debarked stems interwoven in the plots (Figure 2). These fallen stems were the most predominant woody debris component. Detailed pre-harvest inventories from eight transect show that woody debris greater than 7 cm in diameter (coarse woody debris) made up about 87% of the total debris loading (Table 1).

![Figure 2. Pre-harvest accumulations of woody debris – 58.5 t/ha (left) and 99.8 t/ha (right).](image)

<table>
<thead>
<tr>
<th>Size class (cm)</th>
<th>0.00 to 0.49</th>
<th>0.50 to 0.99</th>
<th>1.00 to 2.99</th>
<th>3.00 to 4.99</th>
<th>5.00 to 6.99</th>
<th>≥7.0</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (t/ha)</td>
<td>0.0</td>
<td>0.2</td>
<td>1.2</td>
<td>2.7</td>
<td>5.9</td>
<td>62.1</td>
<td>72.1</td>
</tr>
<tr>
<td>Composition (%)</td>
<td>0.0</td>
<td>0.3</td>
<td>1.5</td>
<td>3.5</td>
<td>7.9</td>
<td>86.8</td>
<td>100</td>
</tr>
</tbody>
</table>

Detailed sampling inventories from 16 transects in each of the harvest areas yielded post-harvest debris loadings for all size classes (Table 2). Compared with Table 1, these data indicate a general post-harvest trend of an increase in woody debris less than 7 cm and a decrease in woody debris greater than 7 cm.
Table 2. Average post-harvest debris distribution by size class

<table>
<thead>
<tr>
<th>Size class (cm)</th>
<th>0.00 to 0.49</th>
<th>0.50 to 0.99</th>
<th>1.00 to 2.99</th>
<th>3.00 to 4.99</th>
<th>5.00 to 6.99</th>
<th>Total &lt;7.0</th>
<th>≥7.0</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut-to-length</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight (t/ha)</td>
<td>1.1</td>
<td>0.9</td>
<td>5.7</td>
<td>5.5</td>
<td>12.9</td>
<td>26.1</td>
<td>12.8</td>
<td>38.9</td>
</tr>
<tr>
<td>Composition (%)</td>
<td>2.8</td>
<td>2.3</td>
<td>14.7</td>
<td>14.1</td>
<td>33.2</td>
<td>67.1</td>
<td>32.9</td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight (t/ha)</td>
<td>1.0</td>
<td>1.2</td>
<td>5.9</td>
<td>4.7</td>
<td>12.8</td>
<td>25.6</td>
<td>21.1</td>
<td>46.7</td>
</tr>
<tr>
<td>Composition (%)</td>
<td>2.3</td>
<td>2.9</td>
<td>13.0</td>
<td>10.5</td>
<td>27.3</td>
<td>55.0</td>
<td>45.0</td>
<td></td>
</tr>
</tbody>
</table>

Arrangement of harvest debris

The debris field in the area harvested using the cut-to-length method appeared to be more consistent with a well-defined pattern of debris produced through the harvesting, forwarding, and debris disposal processes (Figure 3). Larger woody debris had been compacted in “corduroy roads” (7 to 10 m wide) interspersed by strips (10 to 12 m wide) made up of branches and other debris.

The measured and estimated loading of debris produced by the cut-to-length harvesting method ranged from 25.8 to 55.5 t/ha.

![Figure 3. Well-defined patterns of debris produced in cut-to-length harvest area.](image-url)
In contrast, the conventional harvest area showed extremes in debris loading (Figure 4) and arrangement with large accumulations of elevated and loosely compacted stems and branches on the southeast side of the plot. Much of the harvest debris had been pushed into piles close to the haul road, resulting in relatively lower debris loading in this area. Debris loading in the conventional harvest area ranged from 25 t/ha (estimated) to 82.1 t/ha (measured).

![Variations in debris loading in conventional harvest area.](image)

**Figure 4. Variations in debris loading in conventional harvest area.**

**Potential fire behaviour**

Fire suppression in logging debris is typically problematic, and fire managers are challenged with highly variable slash fuel environments. Variables such as loading, size distribution, needle retention, compaction, age, and decomposition influence fire behaviour.

Rate of spread and head fire intensity are key fire behaviour characteristics that are used as metrics for probability of containment in wildland fires. Rate of spread in open fuel types, including harvest slash, is primarily dependent on wind speed, while an increase in fuel loading has a greater influence on fire intensity and fire residence time.

Head fire intensity is a numerical value (expressed in kW/m) that represents the amount of energy generated per metre of fire front. Several fuel components contribute to fire intensity and these vary by fuel type (slash, grass, or standing timber). In slash or logging debris, dead woody debris less than 7 cm in diameter is considered to be the fuel component that contributes to head fire intensity to the greatest extent (Brown, Reinhardt, & Kramer, 2003). The average debris loading in this size class is similar between the two separate harvest areas under study. Fire behaviour predictions generated by the CanFIRE model indicate little difference in head fire intensity and fuel consumption for the average loading in the two debris fuel environments produced by the two different harvesting methods (Table 3).
Table 3. Predicted fire effects in two post-harvest debris fuel environments.

<table>
<thead>
<tr>
<th>Harvesting method</th>
<th>Debris loading (t/ha)</th>
<th>Fire behaviour</th>
<th>Fuel consumption (kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Size class</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;7.0 cm</td>
<td>≥7.0 cm</td>
<td>Total</td>
</tr>
<tr>
<td>Cut-to-length (average)</td>
<td>26.1</td>
<td>12.8</td>
<td>38.9</td>
</tr>
<tr>
<td>Conventional (average)</td>
<td>25.7</td>
<td>21.0</td>
<td>46.7</td>
</tr>
<tr>
<td>Plot and transect</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light loading (Plot 148 T1)</td>
<td>14.6</td>
<td>14.1</td>
<td>28.7</td>
</tr>
<tr>
<td>Heavy loading (Plot 153 T3 )</td>
<td>44.1</td>
<td>38.0</td>
<td>82.1</td>
</tr>
</tbody>
</table>

However, given the extremes in debris loading across the conventional harvest area, fire behaviour predictions indicate a greater difference in head fire intensity in areas along the southeast edge of this area. The average post-harvest debris loading in the plots along the southeast edge of the conventional harvest area was 54 t/ha, while the average loading along the road was 37 t/ha. Fire behaviour projections (Table 3) indicate that areas of heavier debris accumulation (e.g., Plot 153, Transect 3) will generate head fire intensity higher than that encountered in areas of lighter debris loading (Plot 148, Transect 1).

In addition to the higher debris loading along the southeast edge, the less compacted and elevated fuels in the jackpots of debris can generate more volatile fire behaviour with greater intensity. While head fire intensity is proportional to the “quantity of fuel consumed in active flaming zone” (Alexander 1982), in heavy fuel loads such as harvest debris a greater quantity of fuel can be consumed during the smouldering stage (Table 3). Sustained burning in heavy accumulations of debris with the additional energy output during the smouldering phase can increase the degree of fire severity with negative impacts such as soil heating and loss of organic matter (Brown, Reinhardt, & Kramer, 2003).

**Fire suppression challenges**

Under conditions of low fuel moisture with moderate winds, the debris fields in both harvest areas have the potential to produce high-intensity fire behaviour that will challenge suppression resources. In this open fuel type, wind has an immediate impact on new ignitions and fire will spread quickly. Direct attack by ground crews may not be feasible or safe on fast-spreadign fires beyond the first few minutes of fire growth. Air attack with helicopters and airtankers will be challenging under extreme burning conditions.
Fire spread to the adjacent forest stands will be a concern. Fire persistence with higher resistance to control can be expected in the heavier accumulations of debris along the southeast edge of the conventional harvest area. Under drought conditions, larger volumes of debris will be available for combustion with sustained flaming residence time. Dozer guard construction in these areas may be slower due to larger volumes of debris that need to be moved. In these areas with higher volumes of fuel, more time for mop-up and extinguishment will be required.

DISCUSSION

For the purposes of this analysis, it was assumed that the debris piles would be removed by prescribed burning and, hence, were not considered as fuel load in the fire behaviour evaluation. roadside debris piles were present in both harvest areas but to a greater extent in the conventional harvest area. Roadside processing of logs and piling debris is a typical practice within conventional harvest methods. Conversely, the cut-to-to length harvest method leaves tree tops and branches on the harvest area. With a greater reduction in fuel loading through the roadside piling and burning of tree tops and branches, it would seem counter-intuitive that there is a similar volume of fine and medium woody debris in the two harvest areas. This discrepancy could be explained by the absence of branches on the downed stems that were processed and harvested. Other factors that may explain the greater volume of CWD in the conventional harvest area are differences in operators and/or economics of large stem recovery.

Fire behaviour modelling used in this analysis should not be considered an exact representation of fire effects, but does reflect a relative measure of change in fire behaviour characteristics that occurs as a result of changing environmental inputs (weather or fuel loading). Evaluation of fuel bed characteristics in these trial sites was also essential to developing an overall assessment of potential fire behaviour.

CONCLUSION

Under high fire hazard conditions, fire behaviour in each of the harvest debris environments will produce challenges in fire suppression operations. The average loading of harvest debris less than 7 cm in diameter was similar across both harvest areas. With a similar fuel loading in this size class, fire behaviour modelling indicates that there would be little difference in potential rate of spread and head fire intensity generated through the two fuel environments. However, the greater loading of coarse woody debris measured in the conventional harvest area will result in sustained fire intensity during the smouldering combustion stage with greater resistance to control and increased mop-up time. Heavy accumulations of elevated and less compacted debris along the southeast edge of this area have the potential to escalate fire behaviour.

This comparative analysis presents results unique to the harvest debris fuel environments produced through two different harvesting methods conducted in a lodgepole pine forest stand impacted by a mountain pine beetle infestation. The results in this study should not be considered representative of fuel environments produced through other cut-to-length and conventional harvesting operations in other forest stands.
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