Discussion Paper

Assessing Feasibility of Wildfire Fuel Reduction Targets in North-Central British Columbia

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Abstract

Wildland fire has long been recognized as an important disturbance to consider in natural resource management in British Columbia (BC), Canada. Fuel reduction treatments are conducted to achieve designated fuel load targets, measured as the weight of the remaining fuel per unit area (tonnes/hectare [t/ha]). Multiple methods are available to professionals for measuring hazard abatement, but this prevents standardization of data for comparison across the province. To promote a study based in science but through an operational lens, the authors used freely available BC Government documents and guidebooks to perform fuel measures and fuel load tallies. Thirty-two fuel plots were established in the summer of 2021 within the Burns Lake Community Forest. Field measurements were carried out following mechanical raking treatments to determine if units within the 'severe' fuel hazard threshold (FHT) met the target fuel load of 1–5 t/ha. Less than one third of the plots had a fuel load within the target range. Implications of results are discussed, and several recommendations are proposed to improve the feasibility of post-harvest fuel mitigation practices, including a streamlined fuel measurement methodology and more flexible fuel load targets that would enable better comparisons of treatment feasibility across different fuel types and ecosystems within the province.

Keywords: fuel treatment, wildfire risk reduction, Canada, fuel hazard threshold, mechanical raking

Introduction

Wildfire is a common occurrence across most of the forested lands within British Columbia (BC), Canada, and in many northern and central parts of the province it is the predominant disturbance type (Swift & Ran 2012). There is an intricate balance between climate change, natural disturbance, and forest ecosystems in Canada, and both DeLong (2007) and Wiensczyk et al. (2012) highlighted the need for forest management that promotes resiliency and adaptation to shifting disturbance regimes, particularly those where fire is the main disturbance agent. Under changing climate conditions, this balance becomes more delicate, as the frequency and size of wildfires have increased in Canada over the last several decades, with increasing area burned in western parts of the country (Hanes et al. 2019). Forest fuels impact the fire environment alongside weather and climate (Alexander 2000).

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Given that they are easier to manipulate, suppression efforts oftentimes prioritize reducing spread potential (Wotton et al. 2017) through surface and ladder fuel reduction. This form of hazard abatement becomes complicated in Mountain Pine Beetle (MPB) (*Dendroctonus ponderosae*) affected stands, where the likelihood of surface fires increases immediately after outbreak due to needle shed and twig breakage (Page et al. 2014), and again 5–60 years later resulting from increased solar radiation and wind drying in more open stands (Kremsater et al. 2009). In north-central parts of BC, the MPB epidemic started in the early 2000s, meaning affected stands are now within the 5–60-year range where surface fire intensity is projected to increase as dry surface fuels accumulate (Kremsater et al. 2009).

Further contributing to surface fuel load are salvage operations in stand openings that prioritize stem removal using stumpside processing (Forest Practices Board 2006). This harvesting method cuts logs to certain lengths in the block, leaving residual debris on-site rather than piling and burning it (Forest Practices Board 2006). As a result, forest types classified using the Canadian Fire Behaviour Prediction (FBP) System (Forestry Canada Fire Danger Group 1992) may be different from current landscape conditions and require constant updating, as was done by Wotton et al. (2009) and Perrakis et al. (2018). The most common forest cover type in BC is consistent with the C-3 fuel type, but following the MPB epidemic, fuel structures became more complex given time since incident and intensity of disturbance, resulting in modelled fire behaviour more similar to C-2 fuel types in grey-attacked stands (Perrakis et al. 2018). Fire behaviour in this fuel type can produce embers that promote spotting several kilometers ahead of the flame front (Perrakis et al. 2018). In critical fire weather conditions, landscapes where grey-attacked stands persist, such as designated forest reserves like old growth management areas (OGMAs), landscape connectivity matrices (LCMs), riparian zones, or areas with visual quality objectives (VQOs), may be more at risk of ignition and act as channels for fire spread. Forest reserves have conflicting ecosystem obligations and management restrictions that are not often considered in fuel mitigation work (Forest Practices Board 2006), and areas with unmanaged fuel load and fuel arrangement may jeopardize long-term ecosystem sustainability in fire-prone landscapes (Abbott & Chapman 2018; Daniels et al. 2020) and can hinder efforts to improve community wildfire resilience.

Where applicable, fire hazard assessment and abatement following industrial activities is required by law in BC under the Wildfire Act and Wildfire Regulation (Wildfire Management Branch 2012). This includes an assessment of the fuel hazard and fire spread potential on a site; however, the approach used to quantify fuel load is at the discretion of the forest professional conducting the assessment. Resources like "A Guide to Fuel Hazard Assessment and Abatement in British Columbia" (hereafter "the Guide"; Wildfire Management Branch 2012) are available for licensees to follow but do not enforce a standardized fuel measurement methodology (Forest Practices Board 2008). Without a standardized method, assessing and comparing the success of fuel mitigation projects across the province becomes difficult due to a lack of scientific rigour. This limits inferences that can be made between projects and makes comparing fuel treatments in different fuel types difficult, limiting BC's fuel mitigation database. Although this disconnect exists, the authors elected to adhere to the recommendations in the Guide to assess if target fuel loads had been met following hazard abatement fuel treatments. Using this method enabled the employment of a scientifically rigorous protocol and discouraged possible bias resulting from professional reliance in choosing an alternate fuel measurement methodology.

Study area

The Burns Lake Community Forest (BLCF) is an area-based tenure within the traditional territory of the Wet'suwet'en Peoples, and spans 92,062 hectares (ha) of the Sub-Boreal Spruce (SBS) zone (Meidinger & Pojar 1991; Swift & Ran 2012) in the northern interior of BC, Canada. Centered around the village of Burns Lake, it is the oldest community forest in the province and works closely with local First Nations, Indigenous communities, the public, and stakeholders who all maintain an interest in the health and prosperity of the land (Figure 1).

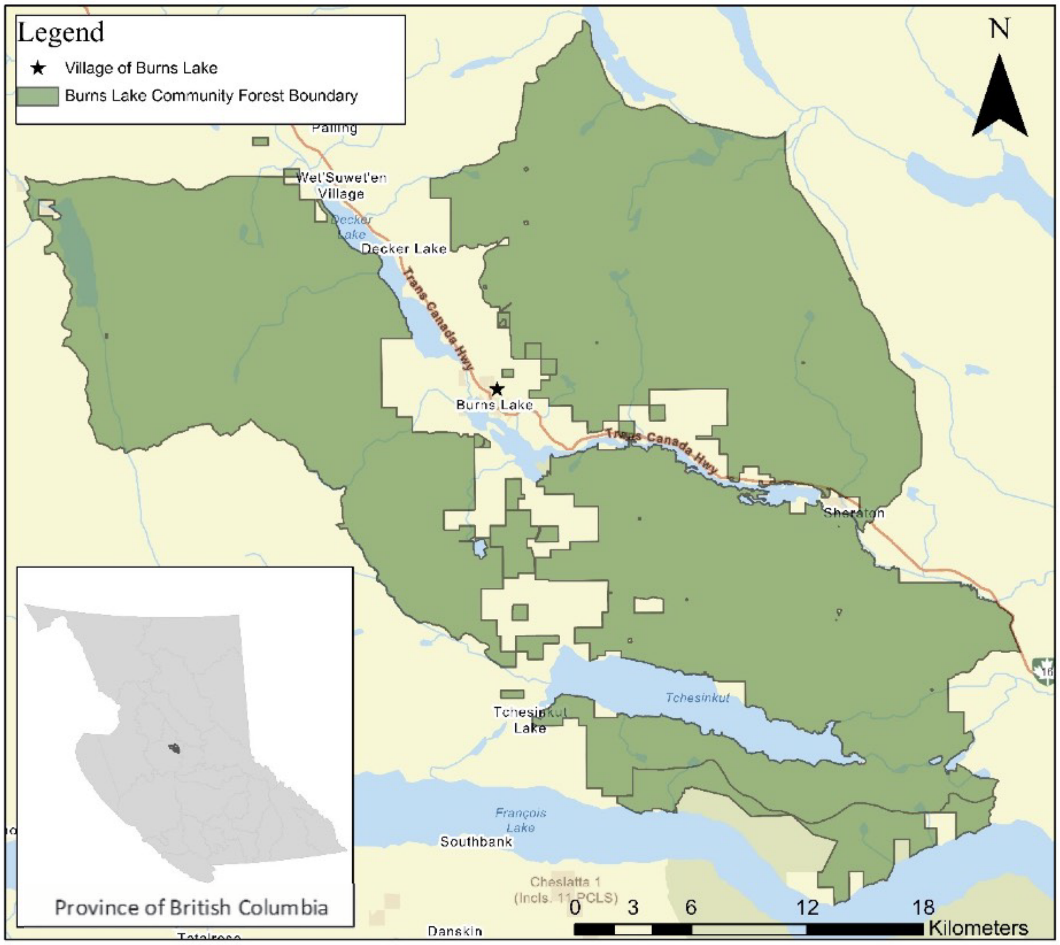

Figure 1. Map of the Burns Lake Community Forest boundary in relation to the village of Burns Lake.

Wildfire hazard abatement began in the BLCF in 2016 due to concerns around wildfire risk to the community following the Horse River wildfire in Fort McMurray, Alberta, earlier that year (MNP LLP 2017). Similar wildfire potential was noted in the forests around Burns Lake, and areas of concern included those with high densities of grey-attacked MPB stands where blowdown was extensive. With guidance from the BC Wildfire Service (BCWS), areas of highest treatment priority in the BLCF were identified using the Guide. Treatment priority was designated to areas within the "severe" fuel hazard threshold (FHT) which covers approximately 10% of the BLCF (Figure 2).

FHTs are determined based on distance to interface values (values at risk), such as infrastructure, community watersheds, timber supply, parks or protected areas, or wildlife habitat (Wildfire Management Branch 2012), and areas marked as "severe" tend to centre around communities and the wildland–urban interface (WUI). A foundational component of fuel management is to disrupt the potential spread of fire and decrease the fire intensity (Omi 2015; Beverly et al. 2020) and improve public and firefighter safety (Forest Practices

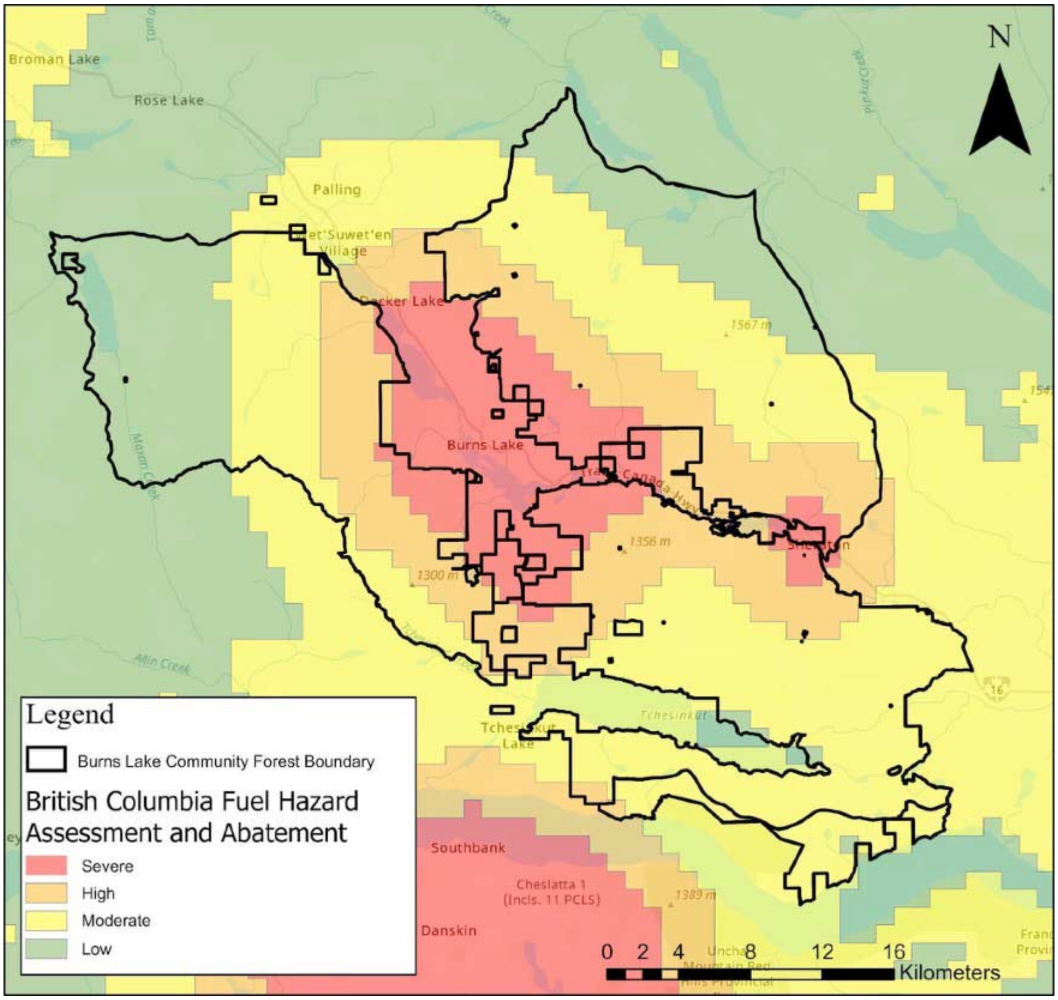

Figure 2. The Burns Lake Community Forest area-based tenure (black perimeter) in relation to the British Columbia Fuel Hazard Assessment and Abatement Risk Classification Map.

Note: Map shows regions of low, moderate, high, and severe fuel hazard thresholds (FHT), as found in "A Guide to Fuel Hazard Assessment and Abatement in British Columbia" (Wildfire Management Branch 2012).

Board 2015). Direct fire suppression in C-3 fuel types that burn like C-2 fuel types (Perrakis et al. 2018) becomes challenging when fire intensities >2000 kW/m (Alexander & Cole 1995). Within the "severe" FHT, fuel mitigation that reduces the amount, distribution, and arrangement of combustible material must occur such that fire intensity will not exceed 2000 kW/m (Wildfire Management Branch 2012), supporting direct suppression in wildfire events. Using Chart 1 of the Guide for lodgepole pine *(Pinus contorta* var *latifolia)* slash, it was determined that a fuel load between 1 and 5 tonnes per hectare (t/ha) would be required to reduce future fire intensity below this level.

To attempt to meet this target fuel load, the BLCF used mechanical treatments, which, in some landscapes, have been modelled as effectively influencing wildfire behaviour (Huggett et al. 2008; Marshall et al. 2020) by reducing fuel load and altering fuel structure and density. Unlike with prescribed fire, mechanical treatments are unhindered by weather, airshed quality, or risks of fire escape that can threaten nearby values (Vaillant et al. 2009), thus increasing the flexibility of where and when abatement occurs, especially in areas close to the WUI (Kalabokidis & Omi 1998; Forest Practices Board 2015). Given these considerations, it was in the best interest of the BLCF to use mechanical fuel treatments instead of prescribed fire. Rather than thinning and pruning, however, the BLCF elected to attempt mechanical raking to reduce fuel load. In this way, it could optimize timber recovery from harvested units and try an innovative approach to hazard abatement, which included outfitting excavators with modified brush-rake attachments to collect fine fuels into piles (Figure 3).

Figure 3. Image of excavator with modified brush-rake attachment used to collect fine fuels in the Burns Lake Community Forest in mechanically raked fuel treated units.

Note: This equipment allowed operators to make repeated passes to reduce fuel load to the required threshold. *Photo credit:* Burns Lake Community Forest 2016.

Three units within the BLCF underwent mechanical raking fuel treatments, including one area that follows a major hydroelectric power line east of Burns Lake (treatment unit Forest Enhancement Society [FES]) and two areas located around the Boer Mountain Bike Park (treatment units Boer Mountain 1 [BM1] and Boer Mountain 2 [BM2]; Figure 4).

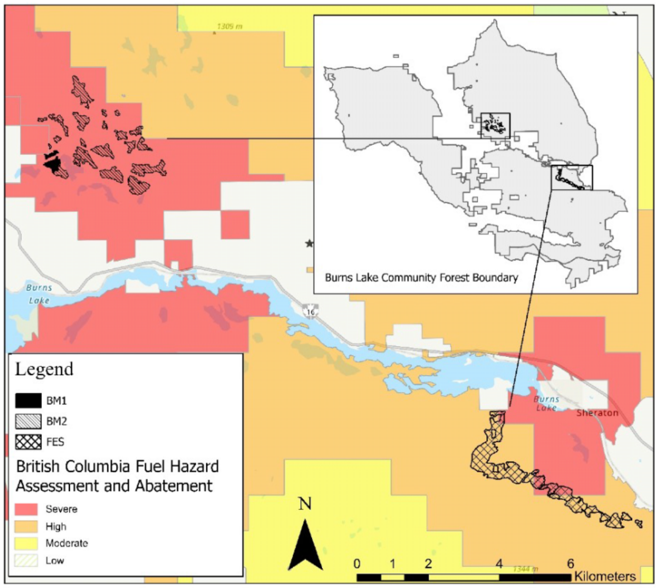

Figure 4. High-priority mechanically raked fuel treatment units in the Boer Mountain Bike Park (BM1 and BM2), and along a hydroelectric power line east of Burns Lake.

Notes: Hydroline unit was named after funding from the Forest Enhancement Society (FES); treatment units selected based on their proximity to the "severe" Fuel Hazard Threshold (FHT) (Wildfire Management Branch 2012), located within the Burns Lake Community Forest.

The FES treatment unit consisted of ten blocks spanning approximately 100 ha near a major hydroelectric power line leading into the village of Burns Lake. Though most of the blocks within the unit were in the "high" FHT, the BLCF elected to hazard abate to the "severe" FHT level of 5 t/ha due to limited access into the unit, steep slopes, and proximity to infrastructure values. This unit was named after the BLCF successfully applied for funding through the Forest Enhancement Society of

British Columbia (FES BC) in 2016 to support the treatment costs in creating a fuelbreak, which Alexander (2019) describes as a wide area where vegetative fuels are altered with the intention of limiting fire spread and intensity. Blocks within the FES unit were clearcut harvested in snow-free conditions and were then mechanically raked, with debris piled to be burned (Figure 5).

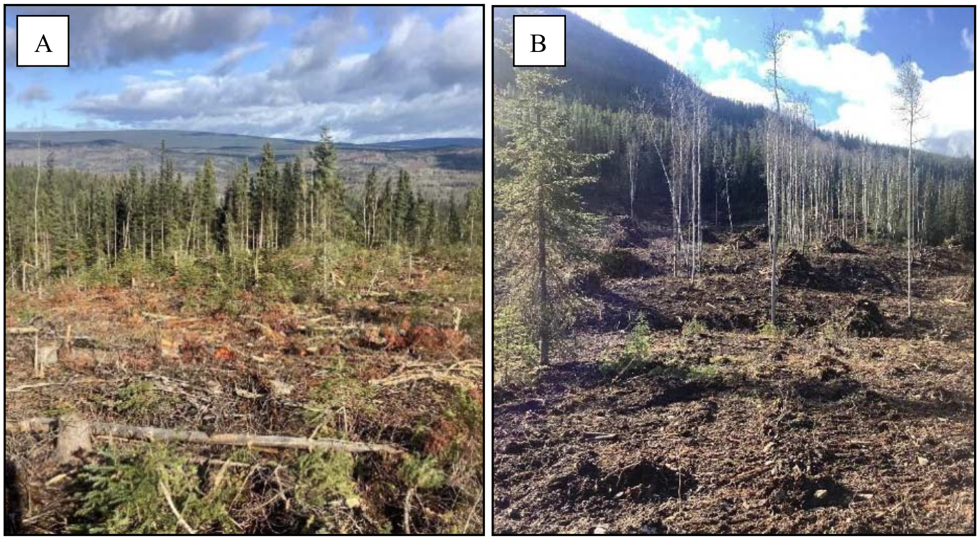

Figure 5. Hazard abatement in the Forest Enhancement Society (FES) treatment units within the Burns Lake Community Forest (Image A) after clearcut harvesting and before mechanical raking and (Image B) after being mechanically raked.

Note: Images do not show the same location. *Photo credit:* Burns Lake Community Forest 2016.

The Boer Mountain Bike Park units (BM1 and BM2) were identified in 2017 and were exclusively located within the "severe" FHT. These units were in proximity to the community and hosted recreation features such as bike trails and a campground. There were two blocks (13.4 ha total) in BM1 and twenty blocks (145 ha total) in BM2. Partial harvesting was employed to retain live stems and maintain the aesthetic quality of the unit. Specialized Ponsse harvesters (Ponsse n.d.) were used for cut-to-length timber removal, followed by a mechanical raking treatment in snow-free conditions, and debris was piled to be burned (Figure 6).

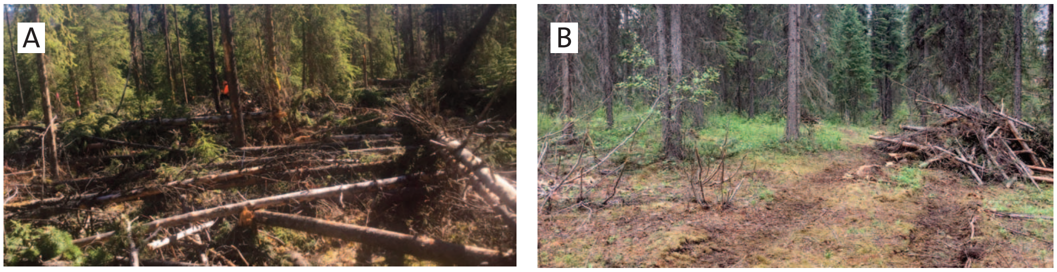

Figure 6. Hazard abatement in the Boer Mountain (BM1 and BM2) treatment units within the Burns Lake Community Forest (Image A) before any treatments and (Image B) after partial harvesting and mechanical raking.

Note: Images do not show the same location. *Photo credit:* Burns Lake Community Forest 2017.

The main goals of this study were to 1) report on the feasibility of meeting FHT targets using methods recommended in the Guide and 2) synthesize the results in a scientifically rigorous peer-reviewed document. The authors sought to determine if and where the 1–5 t/ha threshold was achievable and to use a consistent fuel measurement methodology such that future projects would have a reference point for similar hazard abatement treatments in north-central BC.

Methods

Post-treatment fuel load measurements in the mechanically raked treatment units (FES, BM1 and BM2) were completed in 2021 by a qualified forestry contractor using the methods outlined by Trowbridge et al. (1989), as recommended in the Guide. This method was adapted from earlier work by McRae et al. (1979) and involved the establishment of three 30-m long transect lines arranged in a 60° equilateral triangle. Due to the small size and homogeneity of the block openings within the units, one plot per block was sufficient to capture the fuel load. Where blocks were larger and able to support more fuel plots, a minimum of two per strata were established.

Fine fuels (≤ 7 cm in diameter) contribute the most to rapid fire spread (Wildfire Management Branch 2012) and are the priority for hazard abatement. Fine fuels were measured in increments of 0.5, 1, 3, 5, and 7 cm in diameter using a go-no-go fuel gauge (Figure 7), which the BLCF had made in accordance with the diagram in Trowbridge et al. (1989).

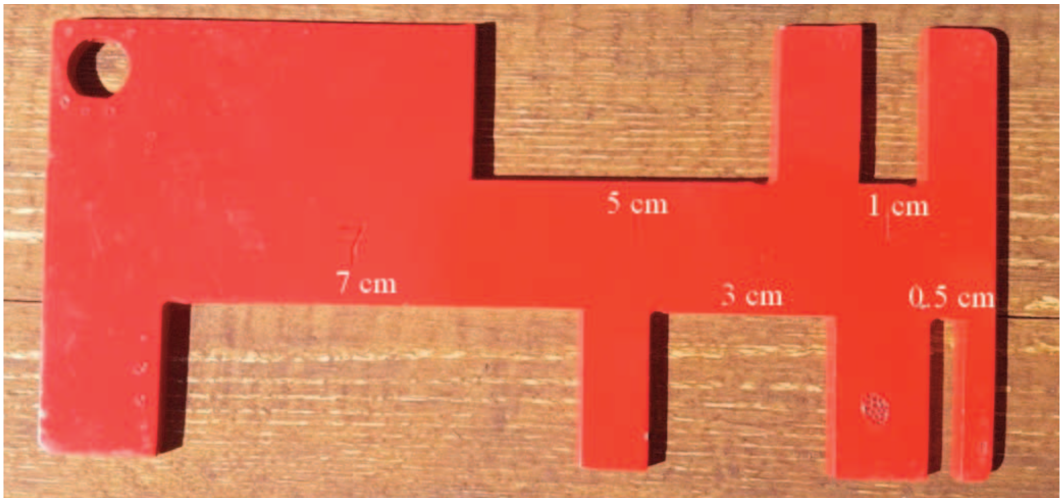

FIGURE 7. Go-no-go fuel gauge used to measure fine fuels ≤ 7 cm in diameter.
Note: Adapted from Trowbridge et al. (1989). *Photo credit:* Burns Lake Community Forest 2021

Large fuels (> 7 cm in diameter) were measured with a measuring tape and the species of each piece was recorded. Debris piles were commonly encountered throughout the units due to the nature of mechanical raking and lack of roadside piling. These piles had been planned for burning prior to the fuel plots being established but were unable to be burned in the seasons following treatment due to weather challenges (early snow-cover, etc). As such, where piles were encountered along transect lines, they were treated as temporary unnatural accumulations of fuel and were excluded from the fuel plot transect lines. This was achieved by moving 1 m off the pile and counting fuels for the length of it before returning to the original line, so as not to bias any final fuel tallies where piles were to be abated.

Plot centres and point of commencement (POC) locations of each transect line were recorded with the mapping program Avenza (8.0 m positional accuracy) and saved for future remeasurement. Fuel load (t/ha) was determined by using tools freely available on the BCWS Government website under "Tools for Fuel Management," including the "Tally Line Intersect Form" and "Line Intersect Calculator." Fine and large fuel loads were averaged between all three transect lines in each plot and added together to get the total average fuel load. Where multiple plots were established, an overall average for all plots within that block was calculated. Fuel loads from all plots were input to a database for analysis.

Results

Between the months of April and August 2021, 41 fuel plots were established in 32 blocks within the BLCF, resulting in 123 transect lines (three transects per plot) of fuel tallies. Fine and large fuels were measured in two blocks ($n=6$ transect lines) within the BM1 unit, twenty blocks ($n=60$) in the BM2 unit, and ten blocks ($n=57$) in the FES unit. Average total fuel load across all transects lines ($n=123$) in post-mechanically raked treatment units was 17.19 (±23.52) t/ha. Of this, fine fuel load was 7.25 (±4.21) t/ha and large fuel load was 9.94 (±21.51) t/ha on average (Table 1).

Table 1. Summary statistics and overall mean and standard deviation (S.D.) for transect lines (*n*) in post-mechanically raked Boer Mountain (BM1 and BM2) and Forest Enhancement Society (FES) fuel treatment units within the Burns Lake Community Forest.

Treatment unit	Post-mechanically raked fuel load (t/ha)			
		Fine fuel load	Large fuel load	Total fuel load
BM1 (*n*=6)	Min	9.74	5.78	12.38
	Max	16.38	12.45	26.06
	Mean	**12.14**	**8.86**	**21.01**
	Median	11.93	10.46	22.64
	S.D.	2.08	3.92	4.75
BM2 (*n*=60)	Min	0.79	0	0.79
	Max	20.09	179.38	196.09
	Mean	**7.36**	**15.12**	**22.46**
	Median	6.91	7.15	14.94
	S.D.	4.45	26.87	29.28
FES (*n*=57)	Min	1.5	0	1.63
	Max	25.41	36.08	40.70
	Mean	**6.62**	**4.62**	**11.24**
	Median	6.53	2.54	9.29
	S.D.	3.66	6.55	7.94
Overall mean		**7.25**	**9.94**	**17.19**
Overall S.D.		4.21	21.51	23.52

Notes: BM1, Boer Mountain 1; BM2, Boer Mountain 2; FES, Forest Enhancement Society; n, number; S.D., standard deviation; t/ha, tonnes/hectare

The FES unit had a significantly lower ($P=0.003$) average total fuel load (11.24 [±7.94] t/ha) than that observed in both BM units combined. This was due to a significantly lower ($P=0.004$) large fuel load measured in the FES unit, which was 4.62 (±6.55) t/ha on average. Average fine fuel load in the FES unit (6.62 [± 3.66] t/ha) did not differ significantly from both BM units combined. Individually, average fine fuel load in the BM1 unit (12.14 [±2.08] t/ha) was significantly higher ($P=0.001$) and average large fuel load in the BM2 unit (15.12 [± 26.87] t/ha) was significantly lower ($P=0.005$) than in the FES unit. Of the BM units, average fine fuel load was significantly higher ($P=0.001$) in the BM1 unit than in the BM2 unit, and average large fuel load did not differ significantly.

There were no significant differences between average fine and large fuel loads between blocks in either the BM1 or FES units. Blocks within the BM2 unit were more variable, with average fine fuel load being significantly lower ($P = 0.03$) than average large fuel load (7.36 [±4.45] t/ha and 15.12 [±26.87] t/ha respectively) (Figure 8).

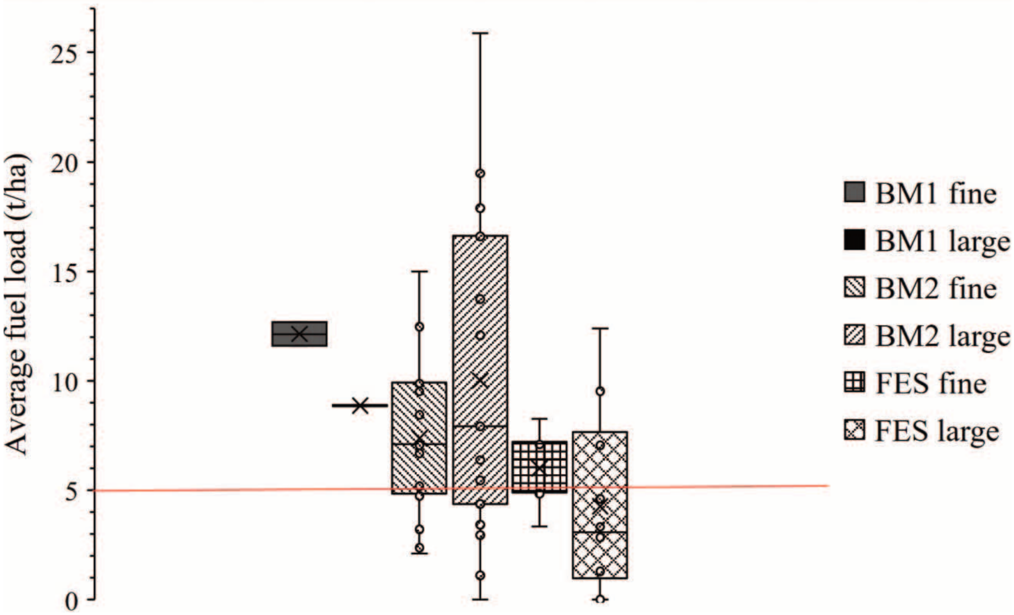

Figure 8. Variation in average fine and large fuel loads for blocks in post-mechanically raked Boer Mountain (BM1 and BM2) and Forest Enhancement Society (FES) fuel treatment units within the Burns Lake Community Forest.

Notes: One outlier was removed from a block in the BM2 unit where large fuel load was more than four times higher than the next highest value (111.83 t/ha). The red line symbolizes the upper limit to the "severe" FHT of 5 t/ha.

Discussion

The data from the fuel plots established in the BLCF were analyzed to determine the effectiveness and feasibility of conducting mechanical raking fuel treatments in priority fire mitigation areas targeting a fuel load of 1-5 t/ha. These analyses provide insight into the expected outcomes of intensive fuel hazard abatement performed with "severe" FHTs by mechanical raking in post-harvested MPB-killed stands within north-central BC. These results also grant an initial understanding of the effectiveness of mechanical raking as a fuel treatment based on fuel load reduction, economic cost and public perception, and environmental considerations.

Fuel hazard abatement in treatment units

Only one third of the blocks within the post-mechanically raked units met the 1-5 t/ha fine fuel load. The FES unit had the lowest average post-mechanically raked fine and large fuel loads compared with the BM1 and BM2 units. This was likely due to the clearcut harvesting system that was employed prior to mechanical raking for the blocks in that unit. Clearcutting facilitated debris removal as equipment could operate with fewer restrictions than partially harvested areas, where denser retention patches and fewer entry points were limiting factors. However, even where clearcutting was used in the FES unit, only 50% of the blocks met the 5 t/ha fine fuel load threshold. In the partially harvested units, neither of the two blocks in BM1 met the target fine fuel load and only 25% of the blocks in the BM2 unit measured below 5 t/ha. These findings would initially suggest that the BLCF did not adequately abate the fuel hazard to the specifications recommended in the Guide. The onus is then on the BLCF to substantiate that abatement was carried out in accordance with the Wildfire Act to the extent practicable. Without sufficient evidence of compliance, the BLCF would be required to undertake additional fuel reduction in blocks that did not meet the target fuel load. For area-based tenures, repeated treatments of similar intensity using mechanical raking would be difficult to conduct without economic losses, environmental risks, or social backlash. Hazard abatement has indirect costs and impacts that, if not accounted for, can hinder how the BLCF operates.

Site degradation was a concern that was noted during the fuel measurement process, especially in the FES unit. Mineral soil exposure was prominent following the first abatement process as equipment operators made repeated entries over the same area to attempt reaching the 1–5 t/ha threshold. Similarly, Kalabokidis and Omi (1998) noted that though whole-tree removal and slash modification were effective in reducing fuel hazards, that degree of cleanup could result in nutrient losses from the ecosystem. Repeated disturbance by equipment in already treated units may hinder future understory development and crop tree growth rates due to soil compaction or seedling destruction where subsequent planting has occurred. In the partially harvested BM units, damage to residual trees from mechanical treatments could result in blowdown (Vaillant et al. 2009), which would contribute to future fuel load and possibly negate efforts in reducing wildfire risk. It may be that fine fuel loads in the treatment units were within the target thresholds immediately after mechanical raking, but in the years since treatment, woody debris accumulation from damaged stems or wind in newly opened patches added to what was tallied in 2021. These considerations can be assessed in the years following fuel plot establishment and would provide measurable estimations of fuel accumulation in both clearcut and partial harvest systems, providing more information on the effectiveness of mechanical raking as a fuel treatment.

Outside of fuel load, hazard abatement standards in the Guide do not typically include considerations for wildlife habitat. The BLCF identified concerns around coarse woody debris (CWD) retention, which contributes to soil productivity and ecosystem health (Brown et al. 2003) and is recommended to be maintained even in wildfire mitigation areas, as outlined in the “Chief Forester’s Guidance on Large Woody Debris Management” (BC Wildfire Service 2010). Three blocks in the FES unit had no large fuel recorded along the transect lines following fuel treatment. Should additional hazard abatement be required for blocks to meet the 1–5 t/ha threshold, it is likely that more large fuels would be removed in the process, reducing the presence of essential decaying organic material on blocks. On BLCF sites where environmental concerns could be managed or mitigated, mechanical raking treatments cost approximately $1600–1700 per ha. For communities with limited budgets for fuel abatement, repeat treatments are cost-prohibitive and would be considered a lower priority than untreated locations with higher fuel hazards. Repeat disruption to recreation areas could also trigger public opposition. There was sufficient push-back from the initial fuel treatments within the BM units over concerns for trail preservation and aesthetic quality that were further aggravated by planting operations, so it is likely that the relationship between the BLCF and the community would be damaged should those areas be disturbed again.

Another issue was noted around possible fuel load underestimations in treated units due to the challenges of tallying fuels in debris and burn piles. Debris piles are generally removed as part of the fuel abatement process, and the BLCF had planned to burn the piles in the treated units prior to post-treatment fuel measurements. However, the debris piles that resulted from the mechanical raking were scattered throughout every block in each unit, oftentimes occurring every 5–10 m with dimensions ranging from 1–2 m in height and 3–5 m in length (Figure 9).

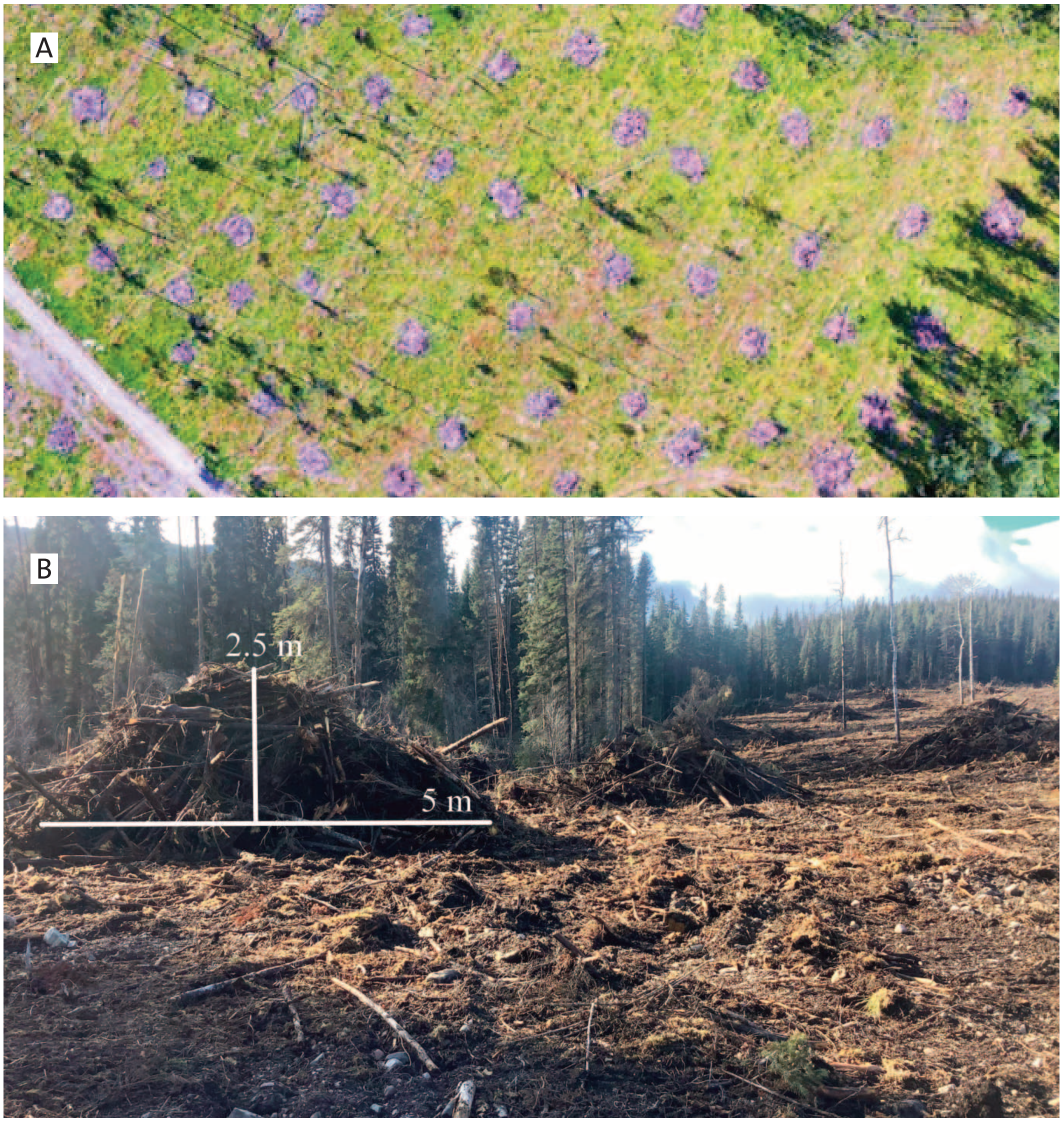

Figure 9. Debris pile size and abundance across the post-mechanically raked Forest Enhancement Society (FES) treatment unit, showing (Image A, enhanced for clarity) an aerial view of the piles distributed across a block and (Image B) the horizontal and vertical extent of the piles.

Photo credit: Burns Lake Community Forest 2021 (Image A) and 2016 (Image B)

Issues with limited weather windows and inadequate venting for burning made abating all the debris piles within a single season difficult, as was also found by Kalabokidis and Omi (1998) in their study on mechanical fuel treatments. Options other than burning the piles, such as chipping or processing, were not available to the BLCF as treatment units were beyond economic thresholds due to trucking distance and limited accessibility, which Hvenegaard (2012) noted as being a limiting factor for alternative pile removal in BC. The fuel measurement process could not be postponed to accommodate pile removal as other forestry operations, such as planting, had to occur within a designated timeframe. Rather than postpone and upset the timeframes of consequential forestry operations, the BLCF elected to avoid the remaining debris piles during the fuel measurement process. However, piles that had been burned prior to fuel measurement had varying amounts of fuel consumed (Figure 10), which left the BLCF uncertain on how to assess when remaining material in burned piles could be tallied as part of the fuel load versus if further abatement was needed.

Figure 10. Debris piles burned successfully (Image A) and unsuccessfully (Image B) within the post-mechanically raked FES treatment unit.

Note: These piles were avoided where they crossed fuel plot transect lines due to uncertainty around if they should be classified as unnatural accumulations of fuel to be removed or natural fuels remaining after initial removal efforts, which may have resulted in biased fuel load tallies. *Photo credit:* Burns Lake Community Forest 2021

The BLCF noted that poorly burned piles had more soil and non-fuel material within them, which likely resulted from equipment having to make multiple passes and scraping mineral soil to achieve the FHT target. It may be that where mechanical raking is used, debris piles could be abated differently or located more strategically within treatment units to ease removal, similar to what Mott et al. (2021) recommended from their literature review on post-harvest slash mitigation.

A consistent fuel measurement system would enhance BC's surface fuel database, promote the establishment of a more coherent methodology, and, if forest professionals were required and not just advised to use the same fuel measurement procedures, more reliable comparisons into the effectiveness of fuel treatments across the province could then be made. The lack of an official method in BC also makes it difficult to assess pre- and post-treatment fuel loads between projects or across industries, as the methodology used is up to the professional to decide and can vary between individuals. When it comes to wildfire prevention and wildfire risk reduction, BC should be enforcing more consistent procedures to enhance how post-hazard abatement treatments are measured.

Limitations and considerations around the fuel hazard threshold

The effectiveness of mechanical raking as a fuel treatment may be limited when used for intensive hazard abatement. It appears to be better suited for abating below 10 t/ha rather than 5 t/ha, based on our average fine fuel loads of 7.25 (±4.21) t/ha. However, since the BLCF did not measure pre-treatment fuel load in a scientifically rigorous way, using a consistent methodology the authors are unable to comment on the degree to which fuel load was abated from mechanical raking, with only the post-treatment measures to form the basis of these assumptions. If the FHT targets were more flexible or considered other landscape features, the authors predict that mechanical raking would be a viable option for fuel treatments. As an example, Brown et al. (2003) suggested a fine fuel load of 11 t/ha or less when considering optimal CWD quantities of 22–67 t/ha in relation to fire hazard. These targets better account for wildlife and soil concerns without compromising wildfire risk reduction (Brown et al. 2003) and increase the versatility of treatments where fine and large fuel loads are more diverse or difficult to manage. If the fuel load threshold was increased from 5 t/ha to 10 t/ha for the BLCF, the number of successfully abated blocks in this study would have increased from 31% to 81%. Additionally, the cost of mechanically raked treatment units in the BLCF would decrease by an estimated 25% had the fuel targets been 10 t/ha instead of 5 t/ha. Piles would be less prolific, more CWD would be maintained, and decreased mineral soil disturbance would also be expected.

Selecting areas to treat based on a FHT may not be appropriate for landscapes where wildfire suppression has resulted in heavier fuel loads, particularly where forest reserves are extensive. Abbott and Chapman (2018) suggested land-use plans consider where forest reserves exist in proximity to communities and how these areas may impede on wildfire risk reduction. Conditions supporting crown fire ignition persist in regions with no hazard abatement, and snags in grey-attacked MPB stands can lead to spotting even after the fire front has passed (Page et al. 2013). Fire ignition in unmanaged channels, such as forest reserves along riparian buffers, can spread to additional untreated areas, completely bypassing treated units (Omi 2015). In the smaller blocks of the BM units where partial harvesting was employed, the effectiveness of hazard abatement may not be as significant in reducing wildfire intensity as in the larger, clearcut blocks of the FES unit. However, though the arrangement of the blocks in the FES unit may create a more effective fuel-break than the randomly distributed blocks in the BM units, the lack of canopy cover may lead to more fuel drying and surface-fire-supporting microclimates. In the BM units, where more overstory was maintained from partial harvesting, fuels may experience less drying from wind and solar influences, as Coogan et al. (2021) allude to when finding a balance between crown fire reduction and surface fuel intensity. Even in extreme wildfire events, fuels and vegetation have a strong influence on burn severity, and Prichard and Kennedy (2014) found that landform was an important consideration for climatically driven wildfires. Graham et al. (2004) also noted the importance of the spatial arrangement of vegetation influencing wildfire ignition and spread, and that consideration of slow versus fast burning fuels is integral in the wildfire planning process.

Flannigan et al. (2009) also noted that human-caused fire occurrences were strongly linked to the ignition potential of surface fuels, so maintaining canopy cover to promote fuel moisture—especially in areas where the public frequents—may be more important than reducing fine fuels to specific loads. Rather than harvest more areas in the BM units or resort to clearcut systems, the BLCF may consider connecting the blocks with shaded fuelbreaks, which Alexander (2019) describes as forested areas where thinning and pruning are used to reduce ladder fuels whilst maintaining enough canopy cover to hinder surface fire spread in shaded microclimates. Daniels et al. (2020) also support the retention of larger trees and snags for wildlife and CWD objectives in areas close to or within the WUI, whilst removing smaller stems in thinning treatments to mimic these shaded fuelbreaks.

Landscape-level fuel management should consider the layout and relation of fuels (Omi 2015; Hoffman et al. 2020; Daniels et al. 2020), as well as spotting distance potential given certain forest cover types (Beck & Simpson 2007; Perrakis et al. 2018). However, this undertaking is currently limited by land and resource management constraints, as discussed by Daniels et al. (2020), and would require legislative permissions to achieve provincial-level hazard abatement objectives. Hoffman et al. (2020) suggest land managers consider a strategic approach in identifying a network of fuel treatment units to implement hazard abatement at the landscape level. When planning for future wildfire scenarios, Marshall et al. (2020) mention that the placement of fuel treatments across a landscape should consider suppression impacts as readily as community and economic impacts. This could involve employing treatments that target different fuel loads depending on fuel continuity and landscape features, or, as Beverly et al. (2010) did in Alberta, assessing ignition exposure potential in the WUI to enhance strategic protection planning. A more comprehensive review of vegetation and site characteristics and how they interact with fuel treatments, as was done in the case studies by LM Forest Resource Solutions Ltd. (2020), can also provide more information regarding wildfire behaviour in areas where the "severe" FHT targets may be more to difficult to meet.

Moving forward with hazard abatement in British Columbia

The BCWS released a document in early 2022 called "2022 Fuel Management Prescription Guidance," which has a stronger emphasis on fuel treatments in landscape and higher-level plans (BC Wildfire Service 2022a). However, this document still references the Guide when making recommendations for surface fuel loading in the "severe" FHT, enforcing the 5 t/ha target. Regarding methodology, a companion guide called the "Fuel Management Survey Data Collection Standard" was also released that provided more information on what fuel treatment data should be gathered for statistically sound sampling and provided detailed procedures for plot establishment in pre- and post-treatment units (BC Wildfire Service 2022b). This new guide appears to address some of the considerations noted in this case study, including more consideration of vegetation and landscape-level planning, and a single method for tallying fuels. The application of recommendations in these new guidebooks may address some of the problems encountered in this study and provide clarity for other professionals seeking to conduct fuel treatments.

Additional studies that review hazard abatement projects following the BCWS guidebooks are encouraged, as the recommendations made in this report are based on the data from the fuel plots established in the BLCF and are specific to the Burns Lake area. Statistical inferences are limited due to the nature of the study, but these findings may help guide other forest professionals in their hazard abatement work. Surface fuel treatments aimed at wildfire risk reduction will continue to be relevant in BC for the foreseeable future, and case studies such as this will provide much-needed information on which treatments are effective and where improvements can be made. Additionally, as far as the authors could discern, the use of mechanical raking as a fuel treatment has not been publicly reported on in BC, much less scientifically assessed as an option for fuel treatments. This project may encourage its use as a method for hazard abatement where prescribed fire is not a viable option.

Conclusion

This BLCF case study demonstrates that current fuel hazard abatement targets may not be achievable in some post-harvest locations due to a range of procedural and methodological challenges. The FHTs listed in the Guide severely limit where hazard abatement can occur on a landscape and requires fuel loads be reduced to levels that are nearly impossible to achieve given available treatment methods. Attempts to meet the 5 t/ha requirement proved economically and operationally taxing for the BLCF and introduced environmental concerns and public disapproval around treatments in recreational sites. Increased flexibility around target fuel loads would make the fuel hazard abatement process more accessible and achievable, particularly where fuel treatment options are limited. The success of mechanical raking as a fuel treatment is difficult to measure given that the authors could not find relevant studies that used similar equipment for hazard abatement purposes and thus could not compare the work completed in the BLCF with other parts of the province. More projects should consider the use of and reporting on mechanical raking in fuel reduction, especially where prescribed fire treatments are limited or difficult to implement.

Measuring and monitoring fuel hazard abatement is a critical issue in BC, and it is hoped that this study makes a positive contribution to the ongoing discussion. However, it is important to note that this study was restricted to the fuel type and forest composition of the Burns Lake area: further studies following consistent methodologies are needed in other regions. Consistency in fuel measurement processes should be established to facilitate or enable analysis and statistical comparisons of fuel treatments across the province of BC. Existing methods can be improved or new procedures developed such that data collection is achievable at the operational level whilst enforcing the scientific rigour needed for future studies. In this way, BC communities can take larger, more meaningful steps to meet the ongoing challenge of wildfire hazard abatement.

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