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Assessing firebrand collection methodologies

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Executive Summary

Fuel mastication (mulching) is a widely promoted fuel treatment to mitigate the threat of wildfires in the wildland-urban interface. Mulched fuels produce a different type of fuelbed that may exhibit different fire behaviour when compared to untreated forests. Many have raised the question of whether mulched fuels create more firebrands than untreated forests.

Firebrands are burning pieces of wood that are projected beyond the perimeter of a wildfire. When they land they can ignite the fuelbed and create a spot fire. Spot fires advance the spread of forest fires and are a characteristic of extreme fire behaviour, but they are not well studied. To better understand spot fires, we need a better understanding of how firebrands are produced.

To research firebrand production, we need to first assess the different methods for collecting firebrands. This study evaluated four methods on a small experimental fire: (1) pans with water, (2) pans with water and with a screen, (3) a tarp and (4) a cloth sheet coated with fire retardant. Our results showed that of the two pan methods, the pan with screen collected fewer firebrands, but the firebrands were heavier than the firebrands collected in the pans without the screen. The tarp almost entirely melted and was an unsuccessful method. The sheet coated with fire retardant was successful in creating a record of firebrand deposition through the presence of recognizable burn marks. Results from the sheets showed that most burning firebrands are relatively small and that as firebrand size increases the frequency of firebrand deposition decreases. An analysis of the sheets and the video footage revealed that an average of 4% of firebrands collected are burning at the time of collection.

The advantages of the pan methods were that they captured the firebrands and kept them intact for analysis. The disadvantages were that they required more time to set-up and they did not allow us to distinguish between burning (or glowing) firebrands and extinguished firebrands. The advantages of the sheets were that they only collected data for burning (or glowing) firebrands and they were easy to set up. The disadvantage was that the sheets did not preserve the firebrand itself for analysis.

We recommend that future research continue to explore firebrand collection methods as an important step toward understanding firebrand production. Firebrand production is an important area of research to expand the current knowledge base on spot fires. This in turn is beneficial to help create more accurate models of forest fire behaviour, which can help wildfire managers in their decision-making. An understanding of firebrand production in mulched fuels can help evaluate the effectiveness of mulch as a forest fuel treatment.

INTRODUCTION

Mastication (mulch) is being used and promoted as part of FireSmart to create fireguards by reducing and removing fuels around communities and private properties. Lower branches of trees are removed, which reduces ladder fuels and raises the canopy to reduce the potential for crown fires by increasing the flame length required for a surface fire to transition to a crown fire. The pruned branches are mulched and spread on the forest floor. Forest stands around communities are also thinned and the felled trees are mulched. This creates a fuel type that is different from that of an unmanaged forest. Accordingly it is important to understand fire behaviour in mulched fuels.

Firebrands are burning pieces of woody debris—of any size—that get lifted into the air, carried by wind, land on an ignitable fuelbed ahead of the main fire front, and create a small fire. These small fires—called spot fires—can grow large and merge with each other, increasing the rate at which the fire front advances. Spot fires are a characteristic of extreme fire behaviour. This is an important area of study because a better understanding of spot fires can help guide forest fire behaviour modeling and predictions, and will ultimately help forest fire managers make better operational decisions. Spot fires are well described in terms of their creation and management tools, but Potter (2011) identifies a knowledge gap in the number, size, and density of firebrand production in forest fires. This is an important knowledge gap to fill in order to understand to what extent, if any, spotting differs between mulched forests and untreated forests, particularly because the majority of mulched fuels are near communities. But to evaluate spotting between different fuel types, we need to first identify a suitable technique for collecting firebrands.

OBJECTIVE

The purpose of this study was to evaluate and compare four different techniques for collecting firebrands.

METHODOLOGY

Collection Methods

We assessed four methods of collecting firebrands. The first method used metal baking pans (48 cm x 73 cm or 3,504 cm^2) filled with water. This is the most frequently used collection method in prior studies (Clark *et al.* 1998, Ohlson and Tryterud 2000, Lynch *et al.* 2004, Manzello *et al.* 2006 and Suzuki *et al.* 2012). The second method was a modification of this first method whereby an aluminum screen was positioned perpendicular to the pan across its entire downwind edge. This was to capture firebrands blown horizontally. The pan was 24 cm x 73 cm and the screen was 24 cm x 73 cm. This created a surface area of 3,504 cm^2. These two methods allowed for the physical collection of firebrands. The pans were countersunk into the ground a few centimeters and were pinned down to prevent being blown away. The screen was installed after the pan was in place and the water was added.

The next two methods essentially involved collecting burn marks on material from hot firebrands. We chose a polyethylene tarp (48 cm x 73 cm) and a cloth sheet coated in fire retardant (48 cm x 73 cm). These designs were similar to the work of Manzello and Foote (2014) and Vodvarka (1969). The sheet was made of 50% cotton and 50% polyester, and the fire retardant we used was CobraShield FR-41. Both the tarp and sheet were pinned to the ground with 30 cm spikes to prevent them from being blown out of position.

Study Area

We conducted this study at the Canadian Boreal Community FireSmart Project, which is 40 km north of Fort Providence, Northwest Territories. We took advantage of three experimental fires that were being conducted for other studies.

Experimental Fire 1 (Plot C3) June 23, 2015:

For this burn, we set up one of each collection method. Time limitations did not allow us to set up repetitions. We placed the pans, a tarp, and a sheet 14 m east (downwind) of the estimated fire perimeter and spaced them 1 m apart in a row parallel to the estimated fire perimeter. Half of Plot C3 had been treated (thinned), so we aligned our data collection gear with the centerline of the untreated portion of the plot (a C3 fuel type). We positioned one video camera approximately 10 m behind the collection methods.

Experimental Fire 2 (Plot I3) June 24, 2105:

We positioned two sheets 11.7 m east (downwind) of the estimated fire perimeter and spaced the sheets 30 m apart. We placed one camera on each sheet to capture a close-up view that would help us determine whether the firebrands were needles, leaves, twigs, bark, or wood pieces. Again, we were unable to set up repetitions because of time limitations.

Experimental Fire 3 (Triangle Plot) June 25, 2015:

We positioned two sheets 10.5 m north (downwind) of the estimated fire perimeter and spaced the sheets 1 m apart. We placed one camera on each sheet to capture a close up view that would help us identify whether firebrands were needles, leaves, twigs, bark, or wood pieces. We were unable to set up repetitions because of time limitations.

Analysis

We analyzed the pan methods the same way: the contents of the pans and the screen were collected, separated by type (needles, leaves, twigs, bark/woody), counted, and then weighed to record the wet weight. We then calculated percent composition by firebrand type and the average weight per firebrand. After the initial analysis, the firebrands were stored in unsealed Ziplock bags so they could dry out and be easily transported. Within one week the firebrands had begun to grow mould. The firebrands also began to breakdown into smaller fragments, likely due to becoming brittle after being burned and then dried.

We analyzed the burn marks on the tarp and the sheet by counting the burn marks by size class (greater than 10 mm^2, between 5 mm^2 and 10 mm^2, and less than 5 mm^2). We also analyzed the video footage (total of four) to determine the total number of firebrands that landed. We then compared that to the number of burn marks we counted to give us a percentage of firebrands that were still burning when they landed (which we considered having the potential to start a spot fire). Statistical analysis was not performed on any of the results due to the small sample size.

Results

Experimental Fire 1 (Plot C3) June 23, 2015

The treated and untreated portions of Plot C3 exhibited different fire behaviour likely due to different fuel types created by the thinning treatment. In the untreated area (where our collection gear was located downwind) the fire became a vigorous surface fire with torching after 20 minutes and a full crown fire with spot fires after 30 minutes. It burned beyond the plot and burned through the area where we had set up our collection methods (14 m from the estimated perimeter). Video analysis revealed that the fire created spot fires beyond the area where we had set up our collection methods. The main fire and the spot fires then burned into each other around the area of the collection methods making it difficult to determine where the firebrands had originated. Our results are summarized in Table 1.

Table 1. Pan collection results for Plot C3 on June 23, 2015 by firebrand type for pans with and without vertical screen. These results represent one sample pan each.

	Quantity		Percent Composition (%)		Total Weight (g)		Percent of Weight (%)		Avg Weight per Firebrand (g)	
Firebrand	Pan w/o Screen	Pan with Screen	Pan w/o Screen	Pan with Screen	Pan w/o Screen	Pan with Screen	Pan w/o Screen	Pan with Screen	Pan w/o Screen	Pan with Screen
Needles	1748	1166	93.9	93.5	10.6	8.7	78.5	59.6	0.01	0.01
Leaves	43	23	2.3	1.8	0.1	0.7	0.9	4.9	0.003	0.03
Twigs	16	7	0.9	0.6	0.5	1.2	4.0	8.0	0.03	0.17
Bark	55	51	3.0	4.1	2.3	4.0	16.6	27.5	0.04	0.08
Total	1862	1247	100.0	100.0	13.5	14.6	100.0	100.0	0.01	0.01

Note: "w/o" denotes "without"

In the pan with water but without the screen, there were 1862 firebrands. Most of these were needles (93.9%) with the remaining firebrands being a small quantity of leaves, twigs, and bark or woody fragments. In the pan with water the total weight was 13.5 g with needles being the majority of the mass (78.5%). The average weight per firebrand was between 0.003 g and 0.04 g.

In the pan with water and with the screen, there were 1247 firebrands. Most of these were needles (93.5%) with the remaining firebrands being a small quantity of leaves, twigs, and bark or woody fragments. In the pan with water with screen the total weight was 14.6 g with needles being the majority of the mass (59.6%). The average weight per firebrand was between 0.01 g and 0.17 g.

Overall, the pans—both with screen and without—produced similar results. The pan with the vertical screen lead to the collection of 615 fewer firebrands (1862 for pans without a screen and 1247 for pans with a screen) though the total mass of firebrands collected was similar indicating that the firebrands were on average larger. The weight composition of the firebrands in the pans without screens was 78.5% needles compared to 59.6% for the pans with screens. The pans with screens collected heavier firebrands with the weight of bark and twigs being 27.5% (4 g) and 8% (1.175 g) compared to the pan without screen 16.6% (2.25 g) and 4% (0.545 g). Since this experiment was only conducted once, it is difficult to determine with any certainty if this finding is a meaningful difference between collection methods.

The tarp we had laid out to capture burn marks had almost entirely melted. This outcome was considered as a possibility based on limited early trials. Since no burn marks could be counted it was removed from further analysis.

The retarded-treated sheet collected 124 burn marks. Of the burn marks, 4 (3.2%) were greater than 10 mm^2, 19 (15.3%) were between 5 mm^2 and 10 mm^2, and 101 (81.45%) were smaller than 5 mm^2.

Experimental Fire 2 (Plot I3) June 24, 1025

This fire did not sustain flames much beyond the ignition line. The fire behaviour was a low intensity surface fire with minimal torching. While the sheet placed adjacent to the south half (of the plot (Figure 1) had only 1 burn mark (which was smaller than 5 mm^2), the sheet placed adjacent to the north half of the plot had 32 burn marks, of which 5 (28%) were greater than 10 mm^2, 9 (15.6%) were between 5 mm^2 and 10 mm^2 and 18 (56.25%) were smaller than 5 mm^2.

Experimental Fire 3 (Triangle Plot) June 25, 2015

This fire was considered a success because it sustained flames past the ignition line and did not burn beyond the firebreak. This fire was a high intensity crown fire. The eastern sheet (Figure 2) had 20 burn marks, of which 4 (20%) were greater than 10 mm^2, 7 (35%) were between 5 mm^2 and 10 mm^2 and 9 (45%) were smaller than 5 mm^2. The western sheet had 34 burn marks, of which 6 (17%) were greater than 10 mm^2, 9 (26.4%) were between 5 mm^2 and 10 mm^2 and 19 (55.8%) were smaller than 5 mm^2.

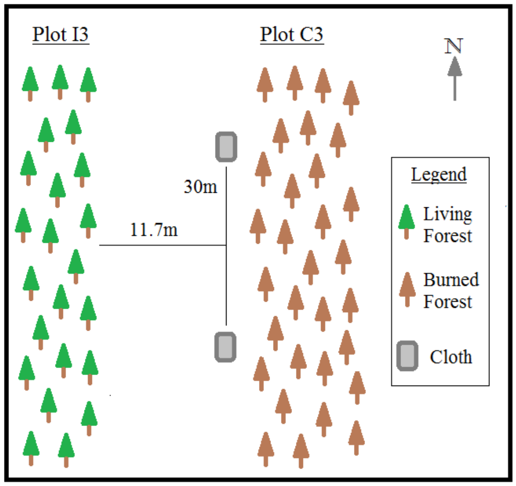

Figure 1. Diagram of Plot I3 that shows two sheets: one positioned north and one positioned south relative to each other. The sheets were positioned downwind of the plot to maximize firebrand collection. Diagram is not to scale.

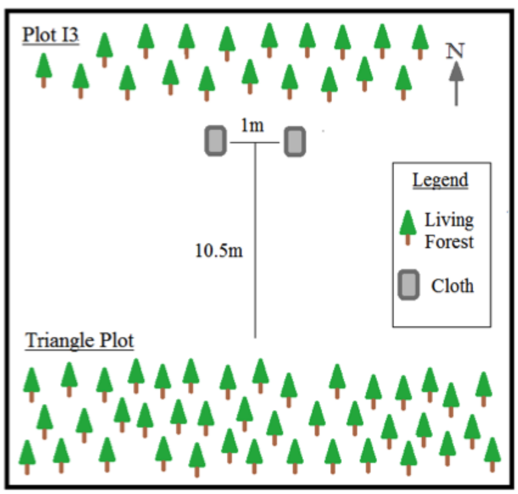

Figure 2. Diagram of the Triangle Plot that shows the two sheets: one positioned east and one positioned west relative to each other. The sheets were positioned downwind of the plot to maximize firebrand collection. Diagram is not to scale.

The size distribution of burn marks on sheets for all fires is summarized in Table 2. Summarized over all three fires the total size distribution for the burn marks is as follows: 19 (9%) were greater than 10 mm^2, 44 (20.9%) were between 5 mm^2 and 10 mm^2 and 148 (70.1%) were smaller than 5 mm^2. The total frequency of burns between the five sheets is useful to assess since they capture the results of a number of fires with varying success rates and intensities. This size distribution of burn marks on the sheets based on five samples can be seen in Table 3.

Table 2. Size distribution of burn marks on sheets for all fires.

Plot	Sheet ID	Distance (m)	Size	Burn Marks on Sheet	Percent (%)
C3	1	14	>10mm^2	4	3.2
C3	1	14	5mm^2 - 10mm^2	19	15.3
C3	1	14	<5mm^2	101	81.5
I3	1S	11.7	>10mm^2	0	0.0
I3	1S	11.7	5mm^2 - 10mm^2	0	0.0
I3	1S	11.7	<5mm^2	1	100.0
I3	2N	11.7	>10mm^2	5	28.0
I3	2N	11.7	5mm^2 - 10mm^2	9	15.6
I3	2N	11.7	<5mm^2	18	56.3
Triangle	1E	10.4	>10mm^2	4	20.0
Triangle	1E	10.4	5mm^2 - 10mm^2	7	35.0
Triangle	1E	10.4	<5mm^2	9	45.0
Triangle	2W	10.4	>10mm^2	6	17.0
Triangle	2W	10.4	5mm^2 - 10mm^2	9	26.4
Triangle	2W	10.4	<5mm^2	19	55.8

Table 3. Size distribution of burn marks on sheets based on five samples.

Size Class	Burns (number)	Percent (%)
>10mm^2	19	9.0
5mm^2 - 10mm^2	44	20.9
<5mm^2	148	70.1

Analysis of the video on the sheets found that an estimated average of 4% of the firebrands that landed on the sheet left a burn mark, which can be seen in Table 4. Figure 3 and Figure 4 show the difference between the images taken from the video at a high-density point during the fire compared to actual burn marks on the sheet.

Table 4. Number of burns marks, firebrands from video, and percent of burn marks on sheets.

Plot	Sheet ID	Burn Marks	Firebrands from Video	%
I3	2N	32	316	10%
I3	1S	1	97	1%
Triangle	1E	20	792	3%
Triangle	1W	34	1220	3%

Figure 3. The images on the left are from the video with firebrands at a high-density point during the fire (image A and C). The images on the right show the burn marks on the sheets (images B and D). Image A and B are from Plot I3 sheet ID “2N” and images C and D are from Plot I3 sheet ID “1S”.

Figure 4. The images on the left are from the video showing firebrands at a high-density point during the fire (images E and G). The images on the right show the burn marks on the sheets (images F and H). Images E and F are from the Triangle Plot sheet ID "1E" and images G and H are from the Triangle Plot sheet ID "1W".

DISCUSSION

When comparing the percent of firebrands by type between the two pan methods there does not appear to be a large difference between these two methods; however, the screen did collect fewer firebrands with more mass. Due to the sample size, it is difficult to determine whether this is a meaningful difference between collection methods or if it was a product of chance. More research is required to resolve if this is significant difference between methodologies.

Although the polyethylene tarp was an unsuccessful collection method, the treated sheet was successful. Our results showed that the size of the burn marks decreased as the number of burn marks increased (Table 3).

Video cameras positioned to record firebrand deposition in the pans and on the sheets were useful in interpreting and analysing results. A common observation throughout the video review of the sheet results is that a great quantity of firebrands and debris landed on the sheet, but the majority did not leave a burn mark. This was highlighted in the finding that an estimated average

4% of firebrands that landed on the sheet left a burn mark, thus can be thought of as hot enough to cause a spot fire (Table 4). However, the estimated average of hot firebrands to overall firebrands is a rough figure that should be further assessed with more replicates and better camera positioning to give improved image quality. Nonetheless, this is an important consideration when assessing firebrands, particularly for methods such as pans that do not differentiate between burning and extinguished firebrands. It appears that larger burn marks (greater than 10 mm^2) are created by twigs and bark or woody firebrands, but even with the video record this can be difficult to confirm depending on the size and shape of the specific firebrand. Medium and small burn marks (5 mm^2 to 10 mm^2 and less than 5 mm^2) are much more difficult, if at all possible, to determine type of firebrand. This should be further tested with more video recordings with better camera positioning. Video analysis also showed that the size of the burn mark could be greater than the size of the firebrand. Manzello and Foote (2014) speculated the same in their analysis of burn patterns.

Our findings are similar to other studies. Lynch *et al.* (2004) studied firebrands by collecting charcoal in pans containing water and positioned at various distances. They found that 99% of firebrands was collected within 20 m of the fire edge and that most of this was within the fire perimeter positioned 5 m in the fire. Similarly in our study, the sheet with the most burn marks (Plot C3, Table 2) had the fire pass through as it burned beyond the planned fire edge. Our finding that the number of firebrands increased as the size decreased was similarly found by Yoshioka *et al.* (2004), Suzuki *et al.* (2012), and Manzello and Foote (2014). While Yoshioka *et al.* (2004) and Suzuki *et al.* (2012) collected larger firebrands than the present study, both collected firebrands from structure fires, which produce different types of firebrands than the prescribed forest fires of this present study. Ohlson and Tryterud (2000) found an average firebrand mass of 0.112 g and 0.003 g depending on the location, which is similar to our study finding the heaviest firebrand type on average to weigh 0.17 g (twigs) while all other firebrands on average were less than 0.08 g. While Suzuki *et al.* (2012) collected larger firebrands from a structure fire, they found 68% to 85% of firebrands weighted less than 0.1 g to which this present study is consistent. Manzello and Foote (2014) studied burn patterns in the wildland-urban interface looking at burn marks from wildfires in urban features such as a trampoline, building material, and outdoor furniture. They found that 85% of burn marks were less than 5 mm^2 which is similar to this study (20.9% were between 5 mm^2 and 10 mm^2 while 70.1% were less than 5mm^2).

When considering a method to use for firebrand production research each of the methods had advantages and disadvantages. Both variants of the pan techniques had the advantage of keeping the firebrand intact allowing us to identify type and weight. However, both methods were time consuming to set up. In the context of wildfire research, including prescribed and experimental burns, time is a luxury. For more thorough studies, with more replicates per fire, this would be difficult to achieve. Another disadvantage is that the pan method did not differentiate between firebrands that were burning and those that were extinguished when they landed. A camera positioned close up on the pan may be helpful in distinguishing which firebrands, or how many, were hot; however, this would require testing. The retardant-treated sheet had the advantage of being easy to set up in a short period of time. It was also advantageous because the burn marks ensured that the firebrand was burning or glowing when it landed. The main disadvantage to this collection method was that we could not determine the type of firebrand (needles, twigs, etc.). The use of a camera positioned close up to the sheet could be helpful for this purpose; however, more testing is required. Another disadvantage is that we would not be able tell if a single firebrand was leaving two or more burn marks if it tumbled across the sheet. Also, firebrands that are irregularly shaped (i.e., not perfectly cylindrical, which is common) can leave burn marks that appear as two firebrands.

Recommendations for future work include more replicates of the assessed methodology to increase confidence in these findings. In addition, more experiments with the use of cameras is suggested to test the extent to which they can assist with limitations, such as determining the type of firebrand. The knowledge of type of firebrand for burning firebrands would be very useful information, particularly when applied to modelling and prediction.

This study was effective as the first steps towards understanding firebrand production and spot fire creation as a function of different forest fuel types, specifically between mulched fuels and untreated forests.

CONCLUSION

This study of the four firebrand collection methods provides perspective on how to approach the study of firebrands. It allows for a comparison on the advantages and disadvantages of each method. While pans with water help to physically capture firebrands, they are time consuming to set up and do not differentiate between burning and extinguished firebrands. The tarp was an unsuccessful collection method. The sheet coated in a fire retardant was successful for an analysis of burn marks. While it was quick and easy to set up, and allows for making an assessment on burning firebrands, it does not capture a physical firebrand for analysis of type and weight. Further research on collection methods is recommended due to the small sample size of this study. A combination of methods may be the most effective technique to capitalize on the advantages of various techniques. This can help to give a more complete picture of firebrand production.

While firebrand production can be difficult to study, the study of firebrands allow for greater comprehension of spot fires and extreme fire behaviour. A more thorough understanding of spot fires is important in order to help build effective models and make well-founded predictions of forest fire behaviour, specifically on the ability of a fire to cross fireguards. Accurate forest fire behaviour prediction is invaluable for forest fire managers in their operational planning and decision-making.

As part of forest fire management, many jurisdictions are implementing proactive fuel treatments. Mastication (mulching) is a fuel treatment that is being widely promoted as a way to create safer communities from the danger of wildfires. A better understanding of firebrand production in mulched fuels is highly important since they are often adjacent to communities. This is significant since firebrands can be easily blown into communities threatening people and property. Greater insight on firebrand production in mulched fuels will contribute to an informed assessment on the effectiveness of mastication as a fuel treatment.

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