Firebrand Generation from Burning Vegetation[1]

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ABSTRACT

A series of real scale fire experiments were performed to determine the size and mass distribution of firebrands generated from Douglas-Fir (*pseudotsuga menziesii*) trees. The experiments were performed in the Large Fire Laboratory (LFL) at NIST. The Douglas-Fir trees used for the experiments ranged in total height from 2.6 m to 5.2 m and the tree moisture content was varied. An array of pans filled with water was used to collect the firebrands that were generated from the burning trees. This ensured that firebrands would be quenched as soon as they made contact with the pans. The firebrands were subsequently dried and the sizes were measured using calipers and the dry mass was determined using a precision balance. For all experiments performed, the firebrands were cylindrical in shape. The average firebrand size measured from the 2.6 m Douglas-Fir trees were 3 mm in diameter, 40 mm in length. The average firebrand size measured for the 5.2 m Douglas-Fir trees was 4 mm in diameter with a length of 53 mm. The mass distribution of firebrands produced from two different tree sizes under similar tree moisture levels was similar. The only noticeable difference occurred in the largest mass class. Firebrands with masses up to 3.5 g to 3.7 grams were observed for the larger tree height used (5.2 m). The surface area of the firebrands scaled with firebrand weight.

ADDITIONAL KEYWORDS
Tree Burns, Firebrand Collection, Size and Mass Distribution

BRIEF SUMMARY

The goal of this study is to investigate firebrand production from burning vegetation. A series of experiments were conducted to collect firebrands produced from burning Douglas-Fir trees of varying height and moisture content. The size and mass distribution of the firebrands produced was determined.

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INTRODUCTION

Wildland-urban interface (WUI) fires have caused significant damage and destruction to housing communities within the USA. The magnitude of this destruction is incredible; the recent 2003 Southern California fires produced some 2 billion dollars in insured losses (Government Accountability Office 2005). A more thorough understanding of the fire spread dynamics in the WUI would allow for more accurate predictive capabilities that could be used in firefighting resource management. Such improvements could alleviate the amount of damage and destruction caused by these fires.

A major complication for fire spread in communities is the generation of firebrands. Firebrands are generated as structures and vegetation burn in WUI fires. Firebrands that are produced are entrained in the atmosphere and may be carried by winds over long distances (up to several kilometers in some cases). Ultimately, hot firebrands with significantly long burn-out time land on fuel sources far removed from the initial fire, resulting in fire spread. This process is commonly referred to as spotting. Understanding how these hot firebrands are formed and the mechanisms by which they can ignite surrounding fuel beds is an important consideration in mitigating fire spread in communities.

Unfortunately, a very limited number of experimental studies have been performed to investigate the size distribution of firebrands produced from burning vegetation and structures. Waterman (1969) burned full scale segments of different roof assemblies and the firebrands produced were trapped by a screened chamber and fell into a quenching pool. The firebrands collected were generally disk shaped. Waterman (1969) did not perform any experiments concerning firebrand generation from vegetation.

An advance in WUI fire research would be the development of a model to predict: the generation of firebrands from burning vegetation and structures, their subsequent transport through the atmosphere, and the ultimate ignitability of materials due to their impact (Babrauskas 2003). Of these, firebrand transport has been studied most extensively (Tarifa *et al*. 1965, 1976; Muraszew and Fedele 1976; Albini 1979, 1983; Tse and Fernandez-Pello 1998; Woycheese 2000, 2001). These models have generally assumed firebrand sizes to perform transport calculations, since little quantitative data exists with regard to firebrand size or firebrand mass produced from vegetation and structures. Experimentally determined regime maps that relate firebrand size and firebrand mass distribution generated from common vegetation species are required. Naturally, such regime maps are also a function of vegetation moisture content, vegetation geometry (*i.e*. size and shape), as well as ambient wind conditions. Firebrand generation regime maps are also required to study ignition of fuel beds by firebrands (Manzello *et al.* 2006).

The present paper is focused on determining the size and mass distribution of firebrands generated from burning vegetation. To this end, a series of real scale fire experiments were performed to investigate firebrands generated from Douglas-Fir (*Pseudotsuga menziesii*) trees. The total height of trees used for the experiments ranged from 2.6 m to 5.2 m and the tree moisture content was varied from 10 % to 50 % (determined on a dry basis). Firebrands were collected using water filled pans to ensure that the firebrands would be quenched as soon as they made contact with the pans. The firebrands were subsequently dried, the sizes were measured using calipers, and the dry mass was determined using a precision balance. The Douglas-Fir trees were also mounted on load cells during burning to determine the temporally resolved mass loss profiles. The mass loss data was used to compare the amount of total mass burned to the total amount of mass collected as firebrands.

MATERIALS AND METHODS

Figure 1 is a photograph of a burning Doulgas-Fir (*Pseudotsuga menziesii)* tree used for the firebrand collection experiments. This particular photograph was taken for a 5.2 m Douglas-Fir tree. Douglas-Fir was selected as the tree species for these experiments since it is a common tree species in the Western USA, a location where spotting has often occurred (Albini 1979; Government Accountability Office 2005). The maximum girth dimension was 1.5 m wide and 3.0 m wide, for the 2.6 m and 5.2 m tree heights, respectively. The trees were size selected from a local nursery, cut, and delivered to the Fire Laboratory (LFL) at NIST. Subsequently, the trees were mounted on custom stands and the trees were allowed to dry. During the experiments, no wind was imposed on the trees.

The moisture content of the tree samples was measured using a Computrac[3] moisture meter. Needle samples as well as small branch samples (three heights, four radial locations at each height) were collected for the moisture measurements. The measurements were taken on bi-weekly basis. The moisture content, determined on a dry basis, is given as:

$$Moisture\,Content = \frac{M_{wet} - M_{dry}}{M_{dry}} * 100 \qquad (1)$$

where M_{wet} and M_{dry} are the mass of the tree samples before and after oven drying, respectively. The tree moisture content was varied from 10 % to 50 %. The uncertainty in these

[3] Certain commercial equipment are identified to accurately describe the methods used; this in no way implies endorsement from NIST

measurements is estimated to be ± 10 %. The uncertainty in the tree moisture content is dependent upon the spatial variability within the tree as well the uncertainty of the analyzer used. More than 30 days of drying time was required to reach moisture content levels at or below 30 %. The justification for this moisture range is given below.

A total of nine Douglas-Fir trees were burned to collect firebrands; six 2.6 m trees and three 5.2 m trees. The trees were ignited using a custom burner assembly specifically designed for these experiments. For the smaller sized trees, the burner was circular in shape (80 cm in diameter). For the larger trees, the burner was hexagonal in shape (span of 122 cm). The heat release rate of the burners was determined using oxygen consumption calorimetry. The HRR was measured as 30 kW and 130 kW for the 80 cm diameter burner and 122 cm span burner, respectively. The burner surrounded the tree at its base and was fueled with natural gas. The total ignition time was 15 s; required for the tree to sustain ignition. This time was determined adjusting the ignition time and observing the dynamic burning process using sacrificial trees. Both digital still photography and standard color video (standard 30 frames per second) were used to record the ignition and burning process of the Douglas-Fir trees.

Figure 2 displays a schematic of the firebrand collection pan assembly. An important issue during the experimental campaign was that the hood assembly (9 m by 12 m) in the LFL needed to be switched off to collect the firebrands. If the hood system was operated, the firebrands generated would be drawn into the hood; thus no firebrand collection was possible. This presented considerable safety challenges. A series of scoping experiments were performed using small trees (on the order of 1.8 m) in order to determine the experimental protocol necessary to conduct experiments with the larger tree sizes. Based on these scoping experiments, the 5.2 m trees were the largest size tree that could safely be burned in the LFL. When testing the 5.2 m trees, the entire 9 m by 12 m hood was filled with flames during the testing.

A total of 26 rectangular pans (water filled) were used to collect firebrands. Each pan was 49.5 cm long by 29.5 cm wide. The arrangement of the pans was not random; rather it was based on scoping experiments to determine the locations where the firebrands would land. After the experiments were completed, the pans were collected and the firebrands were filtered from the water using a series of fine mesh filters. The firebrands were subsequently dried in an oven held at 104 °C for eight hours. The firebrand sizes were then measured using precision calipers (1/100 mm resolution). Following size determination, the firebrands were then weighed using a precision balance (0.001 g resolution). For each tree burned, more than 70 firebrands were dried and measured. In all, more than 400 collected firebrands were sized and weighed.

Two different load cells were used in order to resolve the disparate initial mass loading for the two tree heights considered. The voltage from the load cells was recorded using custom data processing software as the trees burned.

RESULTS AND DISCUSSION

Prior investigations using Douglas-Fir trees have focused on measuring heat release rates (HRR) as a function of moisture content (Babrauskas 2002; Baker 2005). These measurements were used to assess flammability of trees located close to homes and structures. It was reported that for Douglas-Fir trees with moisture content (determined on a dry basis) greater than 70 %, it was not possible to sustain burning after ignition. Within moisture content limits of 30 % to 70 %, a transition regime occurs where Douglas-Fir trees will only partially sustain burning after an ignition source is applied. Below 30 % moisture content, the Douglas-Fir trees were observed to burn intensely; typically the entire tree was engulfed in flame within 20 seconds after ignition (Babrauskas 2002; Baker 2005).

Therefore, the firebrand collection experiments were performed in the following manner. Douglas-Fir trees of 2.6 m were ignited at a moisture content of 50 % (within transition regime); three replicate experiments were performed. Similar to previous work, it was observed that the Douglas-Fir trees would only partially burn. Furthermore, at the 50 % moisture content level, firebrands were not produced. From these results, experiments were then performed using 2.6 m trees with moisture contents below 30 %. A similar methodology was adopted for the 5.2 m Douglas-Fir trees. In summary, under the conditions of these experiments, Douglas-Fir trees do not produce firebrands if the moisture content is larger than 30 % and no wind is applied (Babrauskas 2002; Baker 2005).

Figure 3a displays a digital photograph of the firebrands collected from the Douglas-Fir tree burns. For all experiments performed, the firebrands were cylindrical in shape. The average firebrand size measured (based on three similar experiments; 210 firebrands measured in total for each height) from the 2.6 m Douglas-Fir trees (10 % moisture content) were 3 mm in diameter, 40 mm in length. The average firebrand size measured (based on three similar experiments) for the 5.2 m Douglas-Fir trees (18 % moisture content) was 4 mm in diameter with a length of 53 mm. Figure 3b displays the distribution of the diameter and length of all firebrands collected.

The mass distribution obtained for the 2.6 m Douglas-Fir trees is displayed in figure 4(a). A large percentage (83 %) of the firebrands collected and weighed were less than 0.3 g in weight. Manzello *et al.* (2007) have found that cylindrical firebrands constructed from Douglas-Fir are able to cause ignition of fuel beds under such mass loadings. The largest mass of firebrands measured for the 2.6 m Douglas-Fir trees were in the range of 2.1 g to 2.3 g.

The mass distribution obtained for 5.2 m Douglas-Fir trees is displayed in figure 4(b). Overall, the mass distribution of firebrands produced from the two different tree sizes under similar tree moisture levels was similar. The only noticeable difference occurred in the largest mass class. Firebrands with masses up to 3.5 g to 3.7 grams were observed for the larger tree height used. The surface area distribution was also calculated assuming cylindrical geometry and plotted versus the measured mass for the collected firebrands. For each of the firebrands collected, the firebrand diameter was determined by averaging the thinnest cross section of the firebrand to that of the thickest cross section of the firebrand. These data are shown in figure 5. The surface area of the firebrands scaled with firebrand mass.

During burning, the Douglas-Fir trees were mounted on top of load cells. For the 2.6 m Douglas-Fir tree experiments performed at 10 % moisture content, the average initial tree mass ranged from 10 kg to 11 kg. Upon completion of the tests, the final tree mass ranged from 6 kg to 7 kg. The average firebrand mass collected in the pans, based on three similar experiments, was 18 g. Therefore, of the 4 kg of mass lost during burning, 0.45 % was measured as firebrands at the pan locations. For the 5.2 m Douglas-Fir tree experiments performed at 18 % moisture content, the average mass lost during burning was 24 kg. A mass of 50 g was measured as the total mass collected as firebrands. Therefore, the ratio of firebrands collected to mass lost during burning was 0.2 % for the 5.2 m trees.

CONCLUSIONS

A series of real scale fire experiments were performed to investigate firebrands generated from Douglas-Fir (*Pseudotsuga menziesii*) trees. For all experiments performed, the firebrands were cylindrical in shape. The average firebrand size measured from the 2.6 m Douglas-Fir trees were 3 mm in diameter, 40 mm in length. The average firebrand size measured for the 5.2 m Douglas-Fir trees was 4 mm in diameter with a length of 53 mm. Overall, the mass distribution of firebrands produced from the two different tree sizes under similar tree moisture levels was similar. The only noticeable difference occurred in the largest mass class. Firebrands with masses up to 3.5 g to 3.7 grams were observed for the larger tree height used (5.2 m). The surface area distribution was also calculated assuming cylindrical geometry and plotted versus the measured mass for the collected firebrands. The surface area of the firebrands scaled with firebrand mass. Under the conditions of these experiments, Douglas-Fir trees do not produce firebrands if the moisture content is larger than 30 % and no wind is applied. The data generated from these experiments will be useful for fire models used to predict spotting in WUI fires. Additional parameters, such as wind and the effects of adjacent trees, which have not been investigated here, are necessary to understand firebrand production from burning vegetation.

ACKNOWLEDGEMENTS

The assistance of LFL staff at NIST is much appreciated. In particular, the assistance of Mr. Laurean DeLauater, Mr. Edward Hnetovsky, and Mr. Jack Lee is acknowledged. Mr. Marco G. Fernandez and Mr. J. Shields were also helpful in performing these experiments. Dr. Ronald Rehm of BFRL-NIST is acknowledged for helpful discussions. The reviewers are acknowledged for providing detailed comments to strengthen the quality of the manuscript.

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Figure Captions

Fig. 1 Photograph of a burning Douglas-Fir tree (5.2 m) used for firebrand collection.

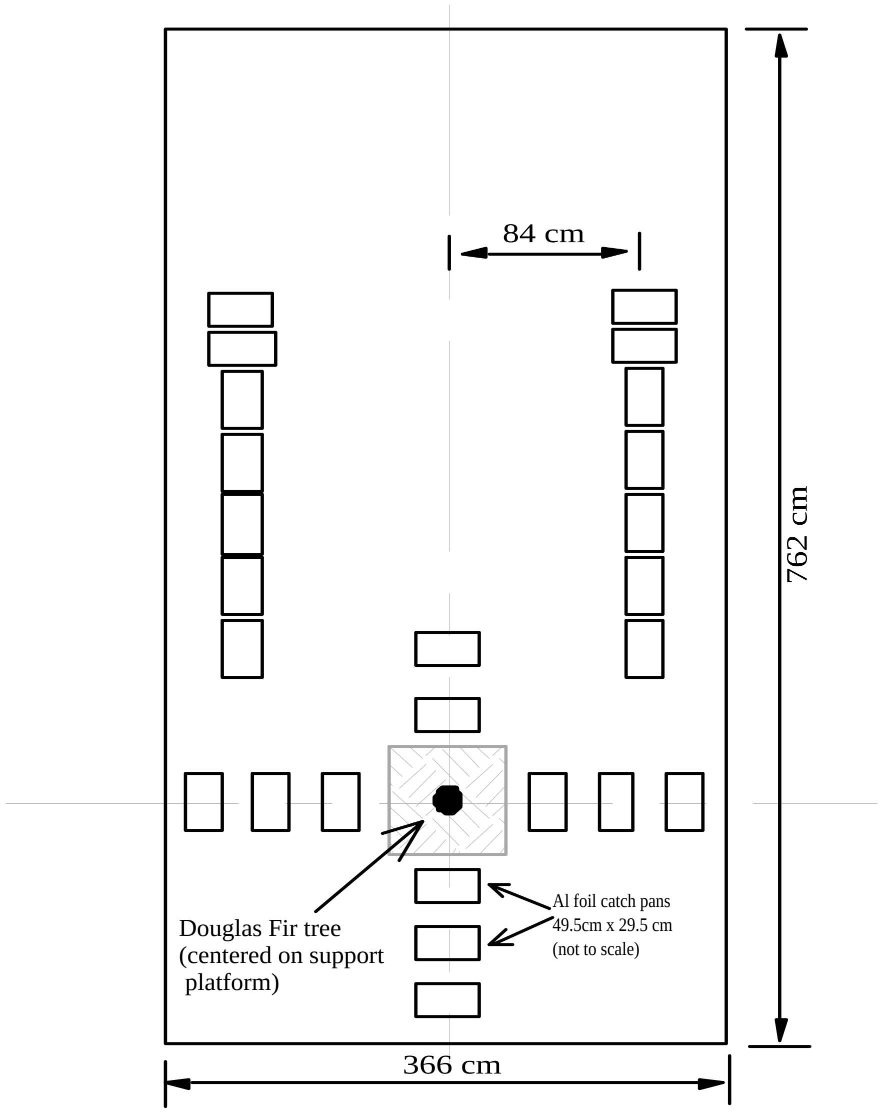
Fig. 2 Schematic of firebrand collection pan assembly.

Fig. 3 (a) Digital photographs showing samples of the firebrands collected as a function of tree size and moisture content. Experimental conditions: Tree Height 5.2 m, Moisture Content 20 %. (b) Distribution of diameter and length of all firebrands collected.

Fig. 4 (a) Mass distribution of collected firebrands for 2.6 m Douglas-Fir trees. (b) Mass distribution of collected firebrands for 5.2 m Douglas-Fir trees.

Fig. 5 Calculated surface area plotted as function of the mass of the collected firebrands.

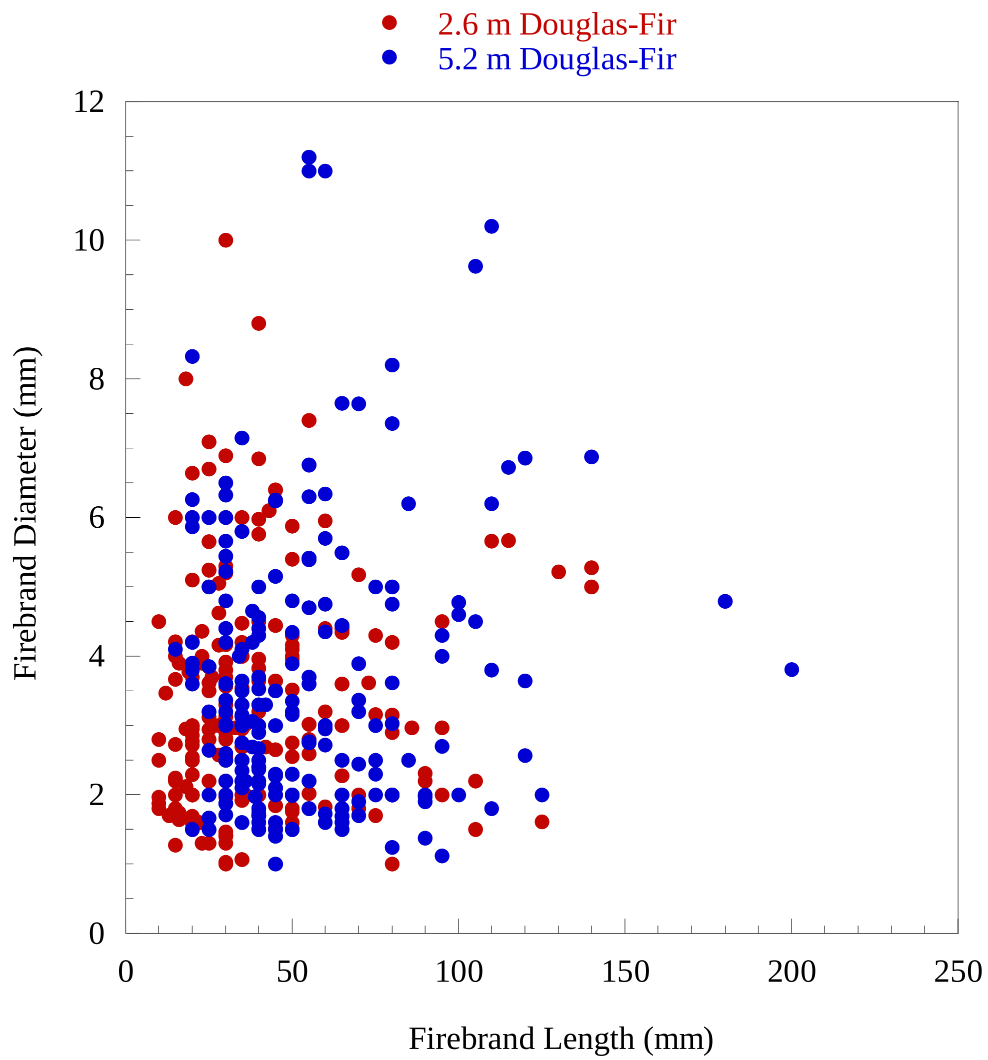
Fig. 1



TOP VIEW
Arrangement of firebrand collection pans

Fig. 2

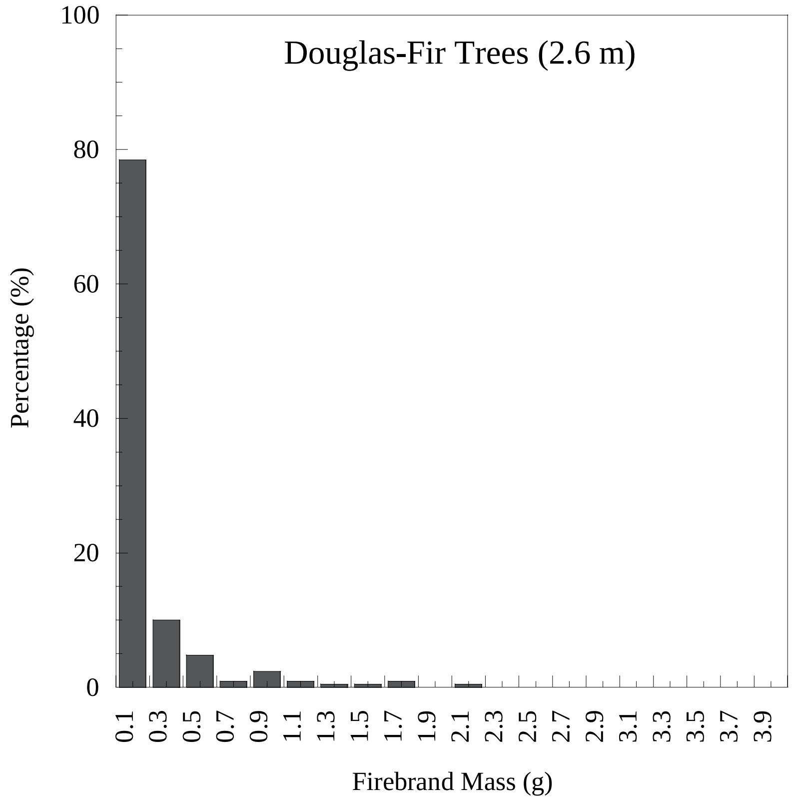
Fig. 3a



2.6 m Douglas-Fir
5.2 m Douglas-Fir
Firebrand Diameter (mm)
Firebrand Length (mm)
0
2
4
6
8
10
12
0
50
100
150
200
250

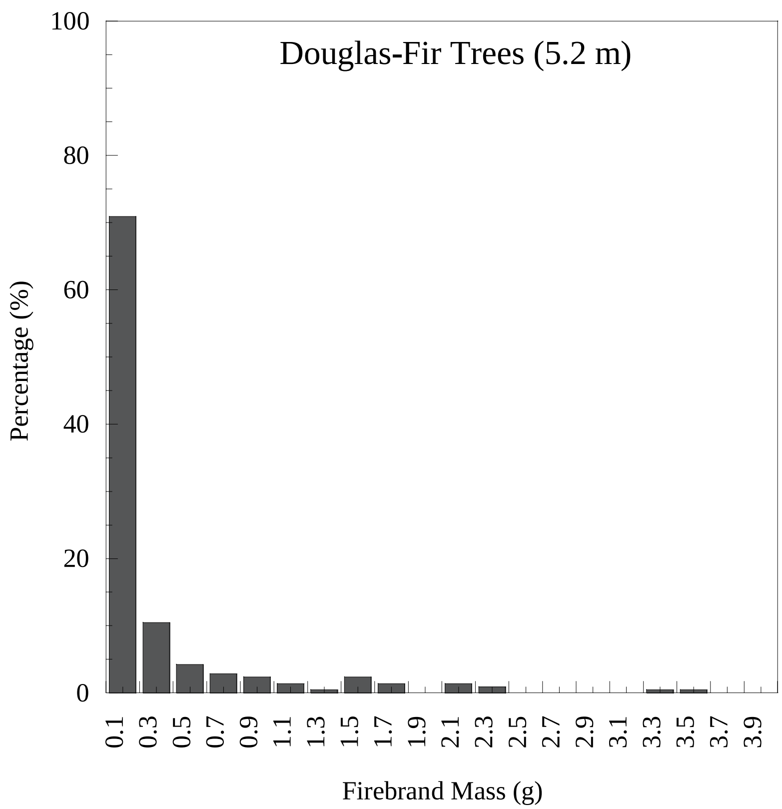
Fig. 3b

(a)



Douglas-Fir Trees (2.6 m)
Percentage (%)
100
80
60
40
20
0
0.1
0.3
0.5
0.7
0.9
1.1
1.3
1.5
1.7
1.9
2.1
2.3
2.5
2.7
2.9
3.1
3.3
3.5
3.7
3.9
Firebrand Mass (g)

(b)



Douglas-Fir Trees (5.2 m)
Percentage (%)
100
80
60
40
20
0
0.1
0.3
0.5
0.7
0.9
1.1
1.3
1.5
1.7
1.9
2.1
2.3
2.5
2.7
2.9
3.1
3.3
3.5
3.7
3.9
Firebrand Mass (g)

Fig. 4

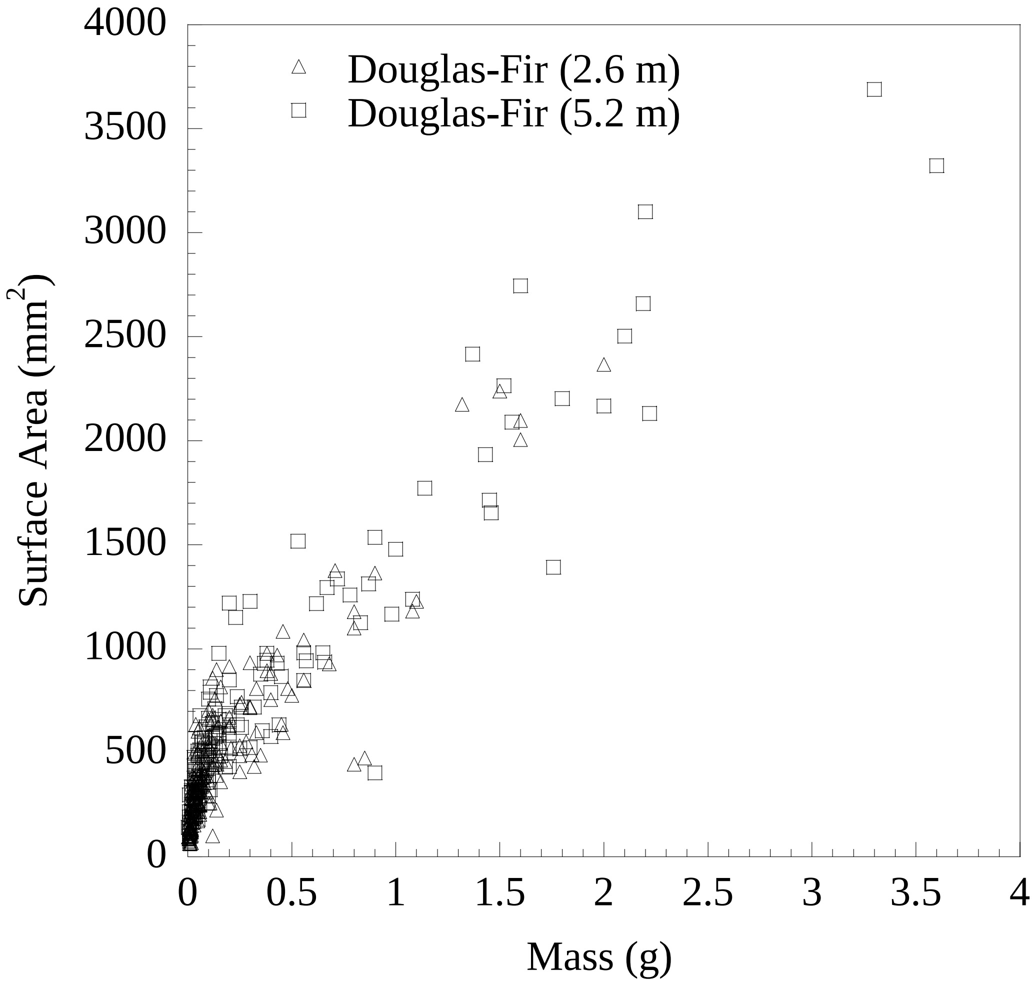

Douglas-Fir (2.6 m)
Douglas-Fir (5.2 m)
Surface Area (mm^2)
Mass (g)
0
500
1000
1500
2000
2500
3000
3500
4000
0
0.5
1
1.5
2
2.5
3
3.5
4

Fig. 5