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The effect of woody debris on surface fire behaviour

Models of forest fire spread generally only consider the contribution of fine fuels (i.e. <6 mm in diameter). A recent study in the CSIRO Pyrotron showed that the presence of larger fuel elements such as twigs and branches 6–50 mm in diameter greatly affect the speed of a fire compared to when these elements are not present. This is not an issue for empirically-based fire spread models in which such fuels are included implicitly but may cause theoretically-based models that do not explicitly incorporate the effect of these fuels to over-predict a fire's spread rate.

Fine and coarse fuels in a bushfire

The vegetation burning in a bushfire can be classified according to various attributes such as shape, density, location, structure, moisture, or how it contributes to the behaviour of the fire. In a forest, fine dead fuels, mostly comprising fallen leaf, bark and twig material 6 mm or less in diameter, are those fuels that respond rapidly to changes in the thermal environment due to their high surface area relative to their mass. They are often described as 1-hour fuels as they respond quickly to changes in their environment. As a result, they also ignite readily, are rapidly consumed by fire and have long been held to be the primary source of energy driving the behaviour of the flame front in a forest fire.

In contrast, coarser dead fuel elements (i.e., >6 mm diameter), such as fallen branches, boughs and toppled stems (collectively known as down woody material or woody debris), have much lower ratios of surface-area to mass and take longer to respond to changes in their environment (often described as 10-hour (>6—25 mm) or 100-hour (>25—75 mm) fuels). Consequently, these fuels often take longer to ignite and combust, generally igniting during or soon after the passage of the flame front, and thus are not thought to contribute to the dynamics of a fire, even while contributing significantly to the total fuel load.

In Australia, operational fire spread models are empirically-derived and only directly consider the contributions from the combustion of fine dead fuels on the forest floor to fire spread. Other systems, such as those of the US and Canada, allow the incorporation of the positive and negative contributions of the combustion of other fuels, such as coarser dead fuels and fine live fuels, to total heat release and fire propagation.

Figure 1. Fire actively spreading through a typical forest with woody debris on the forest floor.

Experimentation to test a hypothesis

Experiments were conducted in the CSIRO Pyrotron to test the hypothesis that the presence of woody debris in the fuel bed does not affect the behaviour of a fire burning through forest litter fuels. Three treatments of fallen branch material (6—50 mm in diameter): 2, 6 and 12 t/ha dry mass, were laid over a continuous fine litter fuel bed of 10 t/ha dry mass (Fig. 2). The arrangement of debris was random across the fuel bed both in location and orientation.

A litter fuel bed with no woody debris was used as the experiment control. Experiments were conducted as heading or backing fires in burning conditions representative of prescribed fire: wind speed of equivalent to about 11 km/h in the open, fine fuel moistures 10—13% oven dry weight.

Figure 2. Plan view of an experimental fuel bed with 12 t/ha of woody debris scattered randomly over 10 t/ha of forest litter.

Results

A total 14 heading and 6 backing fire experiments were completed in the study. For heading fires, the presence of woody debris increased flame angle and, for the heaviest treatment, increased flame height. No change was observed in these quantities or in rate of spread for backing fires, nor in in the backing rate of spread across all treatments.

In contrast, the rate of spread of heading fires in the control was statistically significantly different to that in the treatments (Figure 3). Heading rate of spread of fires in fuels with woody debris was about 45—50% that of fire in the control, regardless of the amount of woody debris. Fires with woody debris were observed to reach their steady-state rate of spread within 1 m of ignition, whereas the control fires continued to accelerate, albeit with a rate of acceleration that decreased as the fire progressed.

Operational implications

The study of fire spread in woody debris *in situ* with litter fuels enabled the ignition and combustion of such fuel as would be found in nature. While the presence of woody debris directly affected the rate of spread of a heading fire, increasing the amount of debris did not change the fire's speed. For fires in fuels taller than the woody debris (e.g. near-surface fuels), the reduction in rate of spread due to woody debris may not be as significant.

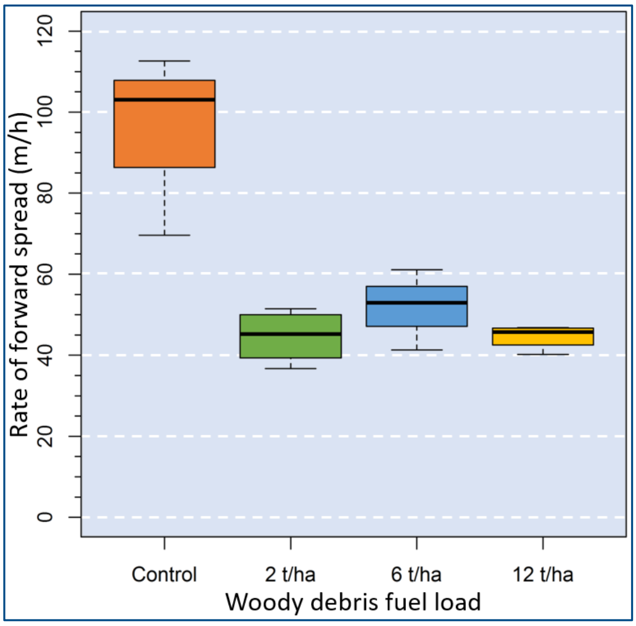

Figure 3. Boxplot of the rates of spread observed in the control experiments (no WD) and the treatments with WD.

Predictive models based on the empirical study of fire in mixed fuels will implicitly incorporate any effect of the presence of woody debris on rate of spread. However, physically-based models of fire that assume contributions only from fine surface fuels may over-predict a fire's speed where woody debris is present. Conversely, models that assume a *positive* contribution of woody debris due to increased fuel load may over-predict the rate of forward spread more significantly. Models that assume an increased sink of heat in the fuel bed due to woody debris presence may under-predict rate of spread since no effect of increasing woody debris fuel load was observed.

More research is required to determine the precise effect of branch orientation and size as well as different burning conditions (e.g. fuels layers, moisture content and wind speed) on rate of spread.

Further reading

Sullivan AL, Surawski NC, Crawford D, Hurley RJ, Volkova L, Weston CJ, Meyer CP (2018) Effect of woody debris on the rate of spread of surface fires in forest fuels in a combustion wind tunnel. *Forest Ecology and Management* 424, 236–245. doi:10.1016/j.foreco.2018.04.039

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