Background briefings on emerging issues for
fire managers from AFAC and Bushfire CRC.

bushfire CRC afac

FIRE NOTE

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FIREBRAND BEHAVIOUR AND THE PROBABILITY OF FUEL BED IGNITION

DEFINITION: FIREBRAND
A firebrand is an object that becomes airborne and has the potential to create a spot fire.

SUMMARY

Spotting is a poorly understood phenomenon. It is linked in complex ways to changes in bushfire behaviour in response to variations in fuel, topography and weather, as well as interactions with the atmosphere. Spotting is a major contributor to fire spread, the failure of containment lines and the damage and loss from fire. Spotting also increases the hazards faced by firefighters.

Spotting depends on the availability and characteristics of firebrand material, the ease with which it can be lofted and transported, and the probability that a firebrand will ignite a fuel bed on landing. Two types of spotting behaviour can have devastating consequences: intense, short-distance spotting can lead to multiple simultaneous ignitions; and very long distance spotting can initiate new fires tens of kilometres downwind from the source fire.

This project is developing understanding of the spot fire ignition potential of firebrands under a range of fuel and weather conditions. This will be achieved in two parts: (i) understanding the behaviour of firebrands such as eucalypt bark in flight, and (ii) identifying the probability that a firebrand will ignite a fuel bed after its flight.

The results of this research project will enable fire managers to better understand the process of spotting, assist in identifying when spotting will be a hazard and provide a basis for predicting its occurrence and maximum distance.

▲ *Dr Peter Ellis demonstrates how the CSIRO vertical wind tunnel allows untethered firebrand samples (circled) to be burnt at their terminal velocities in the laboratory, as though they were actually in flight. This is convenient for taking measurements and observations.*

ABOUT THIS PROJECT

Firebrand potential and spot fire initiation is part of the larger project on Fire development, transitions and suppression, described in *Fire Note* 94.

AUTHOR

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DEFINITION:
TERMINAL VELOCITY
Terminal velocity is the maximum downward speed that an object will reach when it falls from a sufficiently large height.

BACKGROUND

The process of spotting is inextricably linked with fire behaviour. The ease of lofting and transport of a firebrand is determined by its shape and its terminal velocity while burning. Firebrands with relatively low terminal velocities (five metres per second or less) will be more efficiently lofted than those with relatively high terminal velocities (eight metres per second or more). Maximum spotting distance is determined by flameout and burnout time of the firebrand during flight. Flameout time is the length of time that a firebrand remains flaming during flight, while burnout time is the total combustion time.

The probability that a firebrand will ignite a fuel bed is influenced by its state (flaming or glowing) and its mass when it lands. These characteristics can only be measured by burning firebrands at their terminal velocity. Experiments conducted during this project will be carried out in a vertical wind tunnel, which allows a firebrand to be studied while burning at its terminal velocity.

The significance of spotting depends on the distance that burning firebrands are transported and the likelihood that they will ignite a viable spot fire when they land on a fuel bed. This is known as spot fire ignition probability.

Figure 1 (top right) is a conceptual diagram that shows the significance of the probability of ignition of the fuel bed by firebrands. The Forest Fire Danger Index (FFDI) increases as moisture content of the fuel bed decreases and wind velocity increases. This also increases the probability of fuel bed ignition by firebrands. The probability of ignition by a flaming firebrand is greater than that of a glowing one, although very small glowing firebrands still have some probability of resulting in spot fires when the FFDI reaches high or above. As the FFDI increases, the probability that ignition points will become established spot fires increases, while spotting distances also tend to increase.

The process of ignition of a fuel bed by a firebrand is complex and poorly understood, but the factors influencing it can be represented diagrammatically (Figure 2, bottom right).

FIGURE 1: FIREBRAND IMPACT BY FOREST FIRE DANGER INDEX

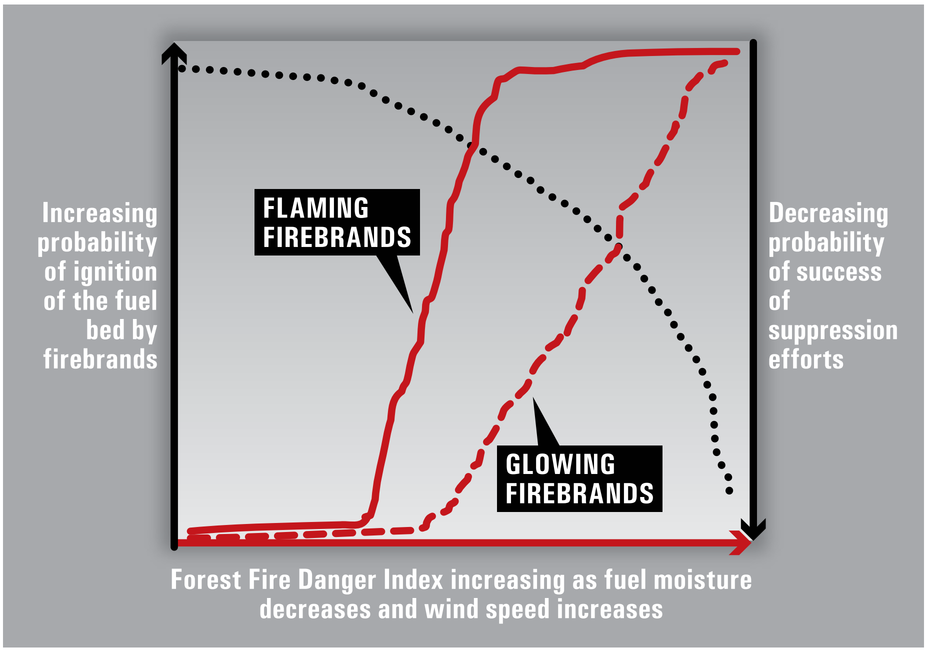
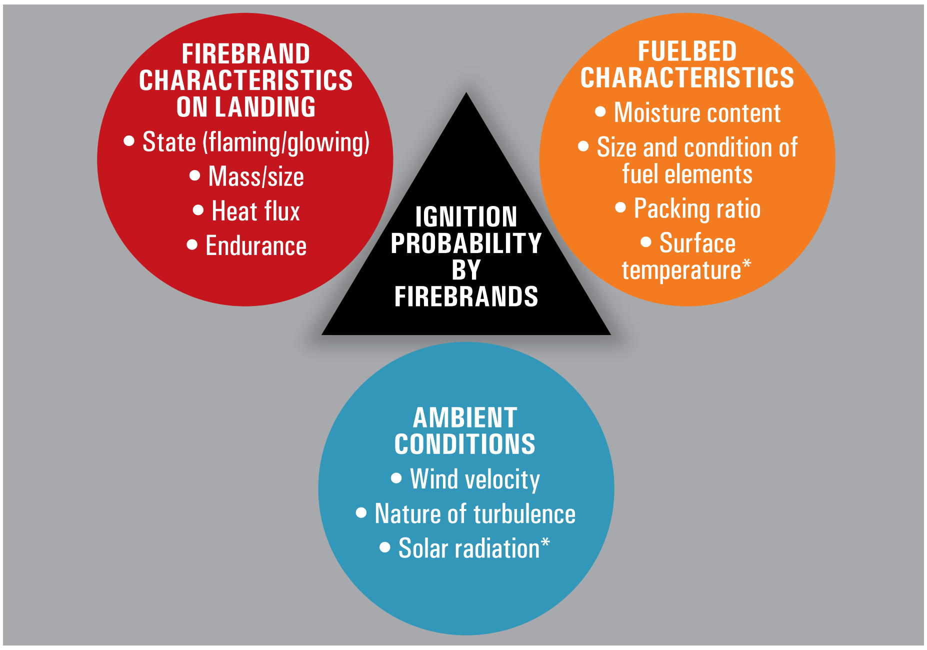


FIGURE 2. FACTORS INFLUENCING THE PROBABILITY OF IGNITION OF A FUEL BED BY FIREBRANDS



***The surface temperature of the fuel bed depends on solar radiation as well as ambient temperature and wind.**

BUSHFIRE CRC RESEARCH

The first stage of this project was two literature reviews looking at firebrand aerodynamic and combustion behaviour, and fuel bed ignition by firebrand material. This information is being used to devise experiments to be undertaken during the project.

LITERATURE REVIEW

Copies of these literature reviews can be found on the project page on the Bushfire CRC website. A summary of results is given below.

Firebrand combustion and aerodynamic behaviour

This literature review found little research has been published on materials notorious in Australia for spotting – notably the bark of eucalypts. Most previous work investigated the firebrand potential of samples from European and North American timbers, because twigs and roofing shingles were considered to be likely firebrands. However, flakes of eucalypt bark will potentially be more effective firebrands due to their lower density, more aerodynamic shape and lower terminal velocities.

The potential of the bark of Messmate Stringybark (*Eucalyptus obliqua*) to be a firebrand material was studied by Ellis (2000). The research found this material to be a very potent firebrand up to distances of several kilometres due to its ease of ignition, low terminal velocities of five metres per second or less, long flameout times of up to one minute or more, and burnout times up to five minutes.

Ellis (2010) also demonstrated that many thin flakes of eucalypt bark (between 20 centimetres and 40 centimetres long) had low terminal velocities of four metres per second or less due to their large surface area and relatively small mass. The low terminal velocities of many samples was due to a rapid spinning motion caused by their shape.

The phenomenon of very long distance spotting, such as observed in the Black Saturday bushfires in 2009, would require burnout times of tens of minutes, and has been previously attributed to Ribbon Gum (*Eucalyptus viminalis*) and Candlebark (*Eucalyptus rubida*) eucalypts. However, there is no published evidence that these barks

TABLE 1. ISSUES IN THE DESIGN OF EXPERIMENTS TO INVESTIGATE FUEL BED IGNITION AND INITIAL SPOT FIRE GROWTH.

PROBLEM (CONSIDERATION)	DESIRED CONDITION	POSSIBLE SOLUTION
How will laboratory 'wind' compare with natural wind? How to transfer laboratory results to the field and compare results between experiments?	Creating realistic laboratory 'wind' that replicates natural wind flow over fuel bed surface in the field.	Characterise surface wind in the open and under open forest. Examine feasibility of producing a natural wind in the laboratory tests. Acknowledge potential effects due to differences between laboratory 'wind' and natural wind.
How to include radiation in the experiments?	Natural solar radiation.	Set a laboratory standard of 1 kW m^{-2} and use lamps which approximate the characteristics of natural light.
How to compare ignitibility of different fuel beds?	Variations in heat flux for samples of natural material.	For some tests use standard or artificial firebrands to produce a consistent flaming or glowing ignition source. Such a methodology would help to determine differences in ignition probability between different types of fuel beds by removing the large variability between firebrand samples of natural material.
How to relate ignition probability for a particular firebrand material measured in the laboratory with that in the field?	Replicate the characteristics of a firebrand sample burning in the laboratory and one which has been transported by air in the field.	Difficult to achieve because field testing, particularly in high fire danger conditions, is not permitted. If feasible, construct a device which combusts the samples at an air velocity equal to their terminal velocity.
How to relate ignition probability for a particular fuel bed type measured in the laboratory with that in the field?	Differences between the characteristics of a fuel bed that has been dried artificially in the laboratory and one that has dried naturally in the field.	Difficult. It may be necessary to recognise that there will be potential differences, but that they are likely to be small.
How to compare ignition success by different firebrands?	Variation in ignitibility between different fuel beds of given moisture content.	For some tests use a standard fuel bed to allow comparison.

can combust for such times at their terminal velocities.

Ignition of fuel beds by firebrands

There is little published research on the ignition of Australian fuel beds by natural firebrand material. Plucinski and Anderson (2008) measured the ignition probability of fuel beds constructed using natural heath components and an artificial flaming source and established the form of the relationship between fuel bed moisture content and ignition success (shown as the line for flaming firebrands in Figure 1).

Ganteaume *et al.* (2009) measured and modelled ignition probability of flaming and glowing bark samples of Blue Gum (*Eucalyptus globulus*), on fuel beds constructed of leaves of the same species. Ellis (2000, 2011) found that flaming firebrand samples of Messmate Stringybark (*Eucalyptus obliqua*) had a 100% probability of igniting fine, dry pine needles at moisture contents of 8% or less, and modelled ignition probability for small, glowing firebrands as a function of fuel bed moisture content and sample mass. Different methodologies mean that making comparisons of firebrand performance in different experiments is problematic. However, for both species of eucalypt bark, small glowing pieces of much less than one gram in mass had a high probability of igniting fuel beds when combined with wind.

As far as can be ascertained, no research has been conducted into the ignition probability of firebrands combusting at their terminal velocity, as would occur naturally. Nor has any research been conducted on firebrands landing on a fuel bed in an air flow that exhibits natural turbulence, as would occur in a forest. Furthermore, no research has been conducted on ignition probability in fuel beds of Australian forests.

Portuguese researchers have been examining firebrand behaviour of eucalypt barks, particularly that of Blue Gum (*Eucalyptus globulus*). This will be followed with interest.

The literature reviews have shown the lack of research directly applicable to firebrand aerodynamic and combustion behaviour and fuel bed ignition for Australian fuel types. The work being undertaken in this project is designed to redress, at least in part, this gap. However to do so requires careful experimental design and execution, outlined in the following section.

Experimental work

Based on experience and the gaps in knowledge identified by the literature review, experimental work should be conducted in a manner that replicates field conditions as closely as possible. In the first instance, firebrand samples should be representative of both the material (i.e. bark) and state (i.e. burnt with a relative airflow which approximates its terminal velocity, as would be experienced during aerial transport in the field). Secondly, firebrand samples should be dropped onto fuel beds that are in a natural (undisturbed) condition. The fuel moisture content of the fuel bed, air flow over the fuel bed, the temperature and relative humidity should match conditions observed during major spotting events.

Achieving such conditions in a laboratory is challenging, particularly where they have not been quantified in the field or cannot be suitably simulated in a safe and repeatable manner in the laboratory. Factors such as this must therefore be assumed from theorical understanding.

The problems and factors that will be considered in designing and implementing ideal experiments, and the potential solutions that will be trialled before being implemented, are summarised in Table 1 (above).

▲ Research has shown that many thin flakes of eucalypt bark have low terminal velocities of four metres per second or less due to their large surface area and relatively small mass. The low terminal velocities of many samples was due to a rapid spinning motion caused by their shape.

FUTURE DIRECTIONS

Findings from the literature reviews have been used to devise experimental methodologies that address the gaps of previous investigations and give results relevant to Australian fuel types.

Once the experimental methodologies have been validated, the effect of key variables such as fuel moisture and wind on fuel bed ignition probability and spot fire establishment by firebrands needs to quantified. In addition, it will be identified if there are threshold conditions beyond which ignition probability increases significantly. This knowledge will then provide a foundation for a predictive tool for fire and land managers.

END USER STATEMENT

Spotting can cause major problems for firefighters. This project will help firefighting agencies more accurately understand how and when spotting is likely to occur, its maximum distance and its likely effect on different fuel types in various conditions in Australia. This project has the potential to improve the accuracy of fire spread predictions, increase fire suppression efficiency, and improve the ability of firefighting agencies to issue timely and relevant warnings to the community.

– Simon Heemstra, Manager Community Planning, NSW Rural Fire Service

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