

FIRE NOTE

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FOREST FLAMMABILITY: HOW FIRE WORKS AND WHAT IT MEANS FOR FUEL CONTROL

This *Fire Note* is a summary of a PhD study conducted by Philip Zylstra through the University of New South Wales' Australian Defence Force Academy and the NSW Department of Environment, Climate Change and Water. The model was developed to fill significant knowledge gaps in fire behaviour and management identified by fire managers and field personnel.

BACKGROUND

Fire management in Australia has long been subject to debate about the best way to manage fuels. Many early settlers observed indigenous people using fire but very few took the time to learn or appreciate the stories, symbols in the landscape and indicators in the flora and fauna that provided Aboriginal practitioners with precise prescriptions and management for different places.

Some evidence has been documented (Zylstra 2006, 2008) illustrating that Aborigines varied the frequency of their burning according to the different forest types.

The reality is that our understanding of fuels and their role in fire behaviour in Australia is still in its infancy. Much focus is given to the management of surface fuels despite the fact that peer-reviewed work has shown these to have little or no influence on rates of spread (e.g. Burrows 1994, McAlpine 1995, Burrows 1999a,b). Work has been carried out on the role of some higher fuel strata (Gould *et al* 2007), however this is limited to Western Australian jarrah forest and as yet there is no work published in the peer-reviewed literature. The role of fuel structure has been recognised in fuel hazards, through both the Victorian Fuel Hazard Guide and Vesta Fuel Hazard guide.

Plants make up the majority of most fuel arrays, so just as indigenous fire managers watched the plants to know whether fire should be introduced or not, effective fuel management may only be possible with an adequate understanding of their fire ecology and the dynamics of moisture and growth.



▲ Regrowth from three year-old snowgum coppice burnt in 2006.

SUMMARY

Forest Flammability is a next-generation fire behaviour model that reveals the complex links between fire behaviour and forest ecology. It calculates the role and importance of different fuel components, species' change, live fuel moisture and other factors. Fire behaviour is calculated as a physical process determined by the flammability of individual fuel components and the transfer of heat between them. This allows more fully informed decisions on fire management to be made, with the potential to take into account weather scenarios and the effects of climate change.

By explaining the role of different fuels and the link between fire ecology and fire behaviour, the model provides strong insights into the costs and benefits of different fuel treatments. As a result, the risk implications of different fire regimes can be quantified so decisions are based on measurable, comparable options. There is also potential for significant improvements in the accuracy of fire behaviour predictions, including sudden escalations in rate of spread, which can have serious consequences for fire crews. Field validation is currently underway across a range of forest types.

ABOUT THIS PROJECT

Project B.1.2 Fire regimes and sustainable landscape risk management

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The Forest Flammability model is an effort to address these gaps in understanding by providing physical explanations for the link between plants and fire behaviour.

BUSHFIRE CRC RESEARCH

The Forest Flammability model employs a “complex systems” approach to modelling fire, which depends on the ability of fire to cross spaces between fuels. Every space between leaves, branches, plants or fuel strata represents a potential barrier to spread either horizontally or vertically: these barriers can be crossed if the convective plume crosses the pathway and provides sufficient heat. This is called a “critical state test”.

The critical state test requires information on the flammability (ignitability, combustibility or flame length and sustainability or flame duration) and geometry of the fuels. The flammability of leaves was studied in the laboratory and the geometry characterised mathematically.

These experiments explained 90% of ignition delay time, 87% of flame length and 72% of flame duration for leaves from a broad range of trees and shrubs. The sub-models were placed into the main model framework, which used the geometry of the plants, the fuel array, the terrain and the weather conditions to examine fire spread.

Complex systems are dependent upon history: past events affect future events. To deal with this, the model estimates fire spread in every plant and stratum at one-second intervals. The amount ignited and the amount that has burnt out within that second is calculated and the flame length adjusted accordingly, then the flame angle is calculated for the new flame before repeating the process. This reveals the rate at which fire accelerates in the fuel, but more importantly, it explains just how far the flame is able to propagate in the fuel array and provides critical information about what will catch fire.

Forest Flammability model validation is currently underway, following four steps:

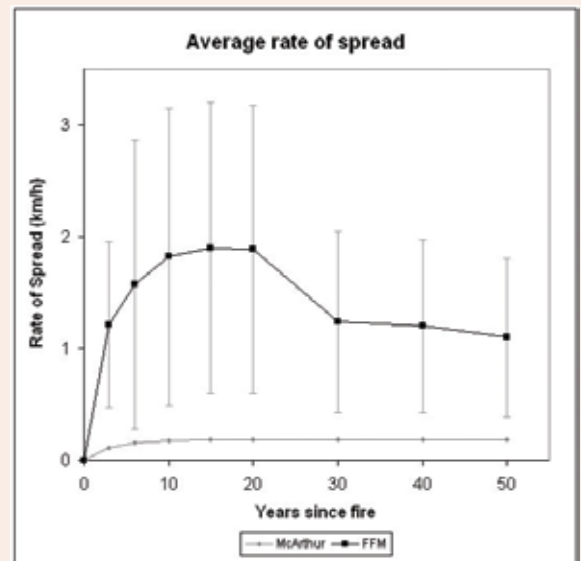
- 1) The model is tested to determine whether its sensitivity to factors such as wind and slope is similar to general observations – e.g. that fires generally burn faster uphill or with a wind behind them.
- 2) The model predictions are compared to general observations of fire behaviour to ensure they do not predict unfeasibly large rates of spread or flame heights.
- 3) The model is tested to determine whether it reproduces “emergent behaviours” often observed, such as the surge and stall spread of some fires or the lack of crown fire under some

FUEL DYNAMICS IN A SNOWGUM FOREST

The Forest Flammability model (black line) shows a significantly greater rate of spread than that predicted by the McArthur Meter (grey line), as the average Fire Danger Index for the summer at this site was only 4. The McArthur meter also shows a rapid initial increase in rate of spread as the fuels age, with fire hazard remaining at a maximum from this point on. This suggests that re-burning the forest will always reduce the fire hazard.

As well as considering the surface fuels which the McArthur Model relies upon, the new Forest Flammability model also looks at the structural and species’ changes in the forest. Young fuels are dominated by the fire-germinated shrub *Bossiaea foliosa* which, together with the *Olearia* species, rapidly produces a complete shrub cover with a grassy ground cover. This arrangement allows for the development of very fast fires and an easy transition to crown fires in the short regrowth of the *Eucalyptus niphophila*. As the *Bossiaea* is replaced by shorter, sparser *Helichrysum* and the space between shrubs and taller trees increases, crown fires become less frequent and rates of spread decrease.

The vertical error bars show that the variability in rate of spread is greater in younger fuels because fires are more unpredictable in dense green regrowth and therefore more dangerous to firefighters.



extreme conditions, where a general trend would cause them to be expected.

- 4) Model results are compared with the behaviour of both experimental fires and bushfires across a range of sclerophyllous forest types. Validation includes fires that behaved in unexpected ways, either with surprisingly high intensity for the conditions, or with significantly lower intensity than expected. For a model to have operational value, the ability to model these scenarios is essential.

RESEARCH OUTCOMES

The Forest Flammability model has been produced in a spreadsheet form. Its capabilities include predicting rates of spread, flame length and flame height as well as more specific predictions, such as the contribution of each fuel stratum to the final fire behaviour and the ways that different species burn. The first three stages of validation have been completed with very promising results, and the model is currently being tested against a series of fires in various fuel arrays typical of south-eastern Australia.

Unlike an empirical model, the Forest

Flammability model does not assume that fire behaviour will follow a particular pattern but looks for a physical mechanism to cause the behaviour. For example, the McArthur Meter, which has been used for fire prediction in Australia for decades, predicts that crown fire will occur on flat ground at a Forest Fire Danger Index (FFDI) of 40 if there is 20 tonnes per hectare of surface fuel available. It does not consider whether the FFDI was caused by strong winds or hot dry conditions and takes no account of forest structure; the expected fire behaviour is identical in all forest types.

By contrast, the Forest Flammability model calculates the availability of all fuels, from the surface litter to the canopy, by modelling the physical capacity of fire to ignite and propagate through plants as affected by the current conditions, the characteristics of those species and their foliar moisture content. This is particularly relevant for much of the mountainous area of south-eastern Australia, where the majority of the forests have been burnt since December 2002 and are therefore in a state of regrowth. A common assumption is that regrowth vegetation is not as flammable as old-growth



▲ Philip Zylstra, a Bushfire CRC researcher and PhD candidate at the University of New South Wales' Australian Defence Force Academy, at work in the field.



▲ Fifty-year-old snowgum forest adjacent to the six-year-old growth. Canopies are mature and *Bossiaea foliosa* has been replaced by a more open layer of *Helichrysum thyrsoideum*.

because it contains little dead material. However, the model predicts that dense, low, green regrowth can produce dangerous fire conditions, where fire spread can suddenly change from low intensity to very fast “heath”-like fires. This has been well supported by field observation in recent years.

Because the model does not assume a smooth increase in fire intensity with worsening

conditions, it is capable of identifying thresholds of sudden change in fire behaviour. These rapid escalations have been responsible for many firefighter fatalities in a number of countries. The ability to predict the likelihood of their occurrence is highly valuable.

However, one of the most important applications of the model is in fuel management. For example, snowgum forest

WHAT IS A COMPLEX SYSTEM?

“Complexity” is a term used to describe those arrangements where many parts can interact without a central guiding direction. One example is many small particles moving around in completely random directions, bound by only one rule: if one particle hits another, the two particles stick together. Because the process is random, we might eventually expect an amorphous blob to form but computer simulations have shown that what forms instead is a snowflake-like shape. Complexity means that complex “emergent behaviours”, such as the shape of a snowflake, a crash on the stock market, the magnitude of an earthquake or the behaviour of a fire, are produced by multiple decisions or “accidents” without a central guiding process. In short, you can’t model complexity with an equation or a trend; you need to understand the individual decisions that produce the emergent behaviour.

in many areas commonly responds to fire with basal sprouting from the trees and dense germination of leguminous shrubs. Although the effect of this dense regrowth on fire behaviour is obvious to firefighters, its effect on the rate of spread has not been captured by available fire behaviour models. But analysis of the changing forest structure by the Forest Flammability model shows a definite period of high flammability in the early regrowth stages, followed by a decline as the forest matures. An analysis of this for one site is shown in the breakout box on page 2.

In contrast, the McArthur Meter suggests for every fuel array that after a short build-up phase suppression difficulty will remain at a maximum indefinitely, implying that any fuel array can always be made safer by burning it. But by understanding the way in which changing forest structure and composition affects fire behaviour, the Forest Flammability model demonstrates that fire suppression difficulty in this particular forest declines after a certain time. As a result, managers can quantitatively measure the comparative value of different burning frequencies. Because the model is specific to a given forest type, there is no longer any need for broad generalisations or ‘rules of thumb’; fire can be introduced or excluded as the forest requires.

As the model is not an empirical study of a particular forest type, it can be used in a broad range of environments once the fuel parameters have been collected. At

this stage it has been trialled for prescribed burn planning and incident management in sclerophyllous forests such as stringybark, snowgum and box types, but investigation is underway to extend its application to other environments such as Mediterranean heathlands.

HOW THE RESEARCH COULD BE USED

The model is not yet in full operational use, however there are potential applications in the following areas:

Fire Behaviour

The understanding of fire behaviour provided by this model gives invaluable insights into the factors affecting flammability in different environments. By understanding the way key plant species burn under differing soil moisture, weather and slope conditions, it is possible to fine-tune preparedness in different areas for days that may be rated low-risk by a more generalised fire behaviour model. Understanding the triggers for sudden escalations in fire intensity, particular to different fuel arrays, also enables Incident Management Teams to make more educated and confident decisions about the placement of fire crews.

Setting Research Directions

Because the model is not a single equation but a compilation of sub-models, describing factors including the flammability of leaves, the angle of a flame, the vertical variability of wind in a forest or the temperature profile of a heated plume, the model can be improved over time as better sub-models are developed. This means the model does not become obsolete with advances in fire science, but instead can provide a platform for testing and applying new advances to fire management.

Fuel Dynamics and Local Knowledge

The Forest Flammability model provides

END USER STATEMENT

“Most firefighters are aware that sudden ‘unexplained’ changes in fire behaviour often occur, particularly when certain thresholds are reached in both weather and fuel variables. These threshold values often involve the interaction of slight changes in wind speed or direction, or subtle changes in fuel structure and composition with the flame zone and heat plume of a fire. The Forest Flammability model is an innovative approach that propagates fire through a fuel array using routines for the various elements driving the ignition process, such as fuel ladders and wind strength. The model will allow agencies to more accurately predict fire behaviour in different plant communities and age classes, and facilitate more informed and effective measures of fuel management.”

– **Bob Conroy**,
Executive director, Park Management,
NSW Department of Environment,
Climate Change and Water

an important link between fire behaviour and fire ecology. The restoration of this link means local knowledge about the response of particular environments to fire can again be employed and the effectiveness of fire management operations improved. The model also adds value to other work: for example, the implications for fire management of ecological and structural studies, such as the Bushfire CRC “Highfire” project, can be more effectively interpreted than with a generic approach. Also, the impact of fuel management operations on bushfire risk can be quantified so decisions on the management of assets – from homes to

water catchments – can be made with a fully defensible, scientific basis.

Climate Change

It is well established that climate change is likely to produce an increase in what are broadly considered to be “bad” fire weather conditions. However, the Forest Flammability model may provide a platform to extend climate change studies of fire well beyond these generalisations into many other avenues: quantifying, for instance, the effects on fire regimes of factors such as changing leaf morphology; the shift between fast-growing warm-season plants that benefit from increased CO₂ and slower year-round growing plants; species’ change resulting from altered fire regimes and the specific role of different weather parameters, such as prolonged heatwaves, in the future fire climate. Understanding the response of fire behaviour to plant ecology may also reveal important positive or negative feedback loops in the carbon cycle.

FUTURE DIRECTIONS

The model is currently being written up for a peer-reviewed journal, where it will be available for all end-users. Options for the development of a preferable software platform are also being explored.

Before the model can be used operationally, it is necessary to compile a database of measurements for the relevant plant species along with survey information and post-fire succession data for the communities and sites being studied. It is envisaged that much of this work can be contained in a centralised database to minimise unnecessary repetition.

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