Forests, not fuels

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Abstract

For decades, forest flammability has been linked to fuel load – the weight of fine twigs, leaves, and bark in a forest. Accordingly, the paradigm of fuel reduction by burning has pervaded Australian thinking, providing a single answer to every question of fire risk reduction. At its core however lies only a rough theory described by the author as potentially "subject to drastic change as more data becomes available".

In the 50 years since the publication of this leaflet, peer-reviewed science for forest fires has focused exclusively on West Australian Jarrah, until the publication of the Forest Flammability Model (FFM) in 2016. Unlike the earlier models, the FFM uses a mechanistic approach, mathematically determining the influence of every component on fire behaviour, rather than limiting the drivers to those already assumed to be important. This has the effect of allowing the more influential drivers to become visible. In the first validation of flame height predictions ever performed for an Australian bushfire model, the FFM demonstrated seven times greater predictive power when it considered the species of plants present, compared to using fuel load alone.

The implication of this is that the solution to fire risk is not fuel reduction, but ecosystem management. Different species respond differently to fire, so fire can have positive or negative effects on flammability. Further modelling work using the FFM to predict flammability dynamics is presented, and comparisons are made with dynamics measured from fire histories, demonstrating the need for ecological underpinnings of fire management.

Introduction

Frequent fire is a key threatening process to more than one third of threatened wildlife species, and more than half of the threatened plant species in NSW [1]. Coupled with the impacts of fire and smoke on human life and infrastructure, there is a clear need to understand the factors that drive bushfire risk. These factors can be either external such as weather and terrain, or internal drivers of ecosystem flammability. It is our understanding of flammability that ultimately determines management practice.

The importance of this has been highlighted by the onset of objective techniques for measuring prescribed burn effectiveness. Prescribed burning is the primary tool used to reduce landscape flammability, yet the largest study of it to date found that it was associated with only a slight reduction in wildfire area for four of the 30 bioregions covering SE Australia. In all others, there was either no measurable effect, or it was implicated with an increase in wildfire. In all areas, prescribed burning produced an overall increase in fire (planned + unplanned), as even in the most effective locations, roughly three ha of prescribed burning was necessary to reduce wildfire area by one ha [2].

Although this technique has weaknesses, such findings suggest that our current approach to managing flammability needs to be improved. Doing so requires a better understanding of what determines it, and that is the subject of this paper.

Flammability

Flammability has three components – the ease and therefore often the frequency at which something can ignite (ignitability), how well it will burn (combustibility), and how long it will burn for (sustainability) [3]. Combining these into a single measure is not straightforward. Is a grassy woodland more flammable because it ignites easily, or is dense forest more flammable because it produces larger flames? Different components of plants and forests also have different levels of ignitability, combustibility and sustainability. Is the flammability of the whole system a sum of its parts, or is it more complicated than that?

The scientific method for understanding such things is to generate a hypothesis or model, then test its predictions against observed reality. A model can vary widely; at one extreme, it could incorporate every possible factor to produce an accurate but unusable tool. On the other, it could be limited to only those potential drivers that are easily-accessed, producing a user-friendly model that is wrong. Somewhere in that range, we could hope for one that is accurate enough to be useful, yet still practical. A scientific approach must however accept that this may not be possible. If reality is just very complex, then we need to adjust to it. In Einstein's words: "make things as simple as possible, but not simpler."

Fuel loads

At the core of the Australian understanding of flammability is the concept of fuel loads – the weight of fine twigs, leaves and bark in a forest. Fuel load is a relatively simple thing to measure, although the collection, drying and weighing of fuels is time consuming. The issue has also been confused by debate over exactly what fine fuels should be measured. The traditional approach has been to limit this to surface leaf litter [4], however some are now adding in the fine materials in low vegetation and bark [5].

The basis for using fuel load is the work of McArthur – often seen as the pioneer of fire research in Australia. McArthur however considered his work to be at an infant stage, and his assertion that fuel load was the primary driver of flammability was based on only nine data points measured in West Australian Jarrah forest, published in a leaflet without the standard quality control of peer-review [6]. As he warned: "…many of my observations and comments are tentative and may be proved wrong or subject to drastic change as more data becomes available" [7].

Regardless of the definition of fuel load that is used however, the implications for management are the same. The greatest weight of fuel is in the layer of leaf litter, and this accumulates over time until eventually reaching a point of equilibrium [8]. Consequently, the flammability of a forest can always be reduced by burning the forest, and this paradigm of fuel-reduction burning has underpinned Australian fire management for more than 50 years [9].

Published science however gives little reason to accept this hypothesis [10]. When McArthur's experiments in Jarrah fuels were repeated formally, fuel load was found to have no effect on rate of spread, and only a very minor effect on flame heights [11,12]. By this time however, the concept of fuel load had become a paradigm, and such contrary evidence has been widely dismissed.

At the level of management application, CSIRO's "Project Vesta" found that flammability did not consistently increase with time since fire, but varied between different stands of Jarrah forest depending on the life-history of understorey species [13]. Where this was dominated by a short-lived shrub, the median rate of spread was less in older forests than in regenerating stands. Such findings suggest that prescribed burning could be ineffective or even counter-productive if applied in stands with an understorey of this shrub.

Figure 1. Large flames only occur when plants ignite.

A methodical approach

Since 2004, the NSW NPWS has worked to both build a model that was not exclusive to Jarrah forest, and to gain a clearer understanding of ecosystem flammability. This required support of a research program involving four universities and the Bushfire Cooperative Research Centre. The model constructed from this (Forest Flammability Model FFM [14,15]) integrates the known influences of flammability into a mechanistic framework, to scale from leaf traits into full fire behaviour.

By considering all possible influences rather than focusing on those assumed to be more likely, the FFM has identified the main drivers of forest flammability in those areas studied so far. The simplest and most significant observation is that flammability is not driven by fuel loads, but by the species of plants present. Large flames only occur when plants ignite (Fig. 1), so the central question in fire behaviour is whether those plants will ignite or not. There are three aspects to the answer for this: *the gaps between plants* (how far away is the plant from the flame?); *the flammability of the plants* (how large is the flame from those plants burning, and how ignitable are the next plants?); and *the sheltering effect of plants* (will the plants overhead slow the wind down?).

All of these factors are affected by the species of plants, and their conditions for growth. For example – the Black Saturday fires in Victoria had the most severe fire weather ever recorded in Australia, yet crown fire was rare in mature Mountain Ash (*Eucalyptus regnans*) forest during that event [16]. Fires are rare in these to begin with because the lower plants have high moisture contents (plant flammability) and the surface fuels are shaded and moist (overstorey shelter). These factors were overcome by the severe drought, but while the forest was then able to burn, the gaps between the lower plants and the canopy were too large to ignite a crown fire.

To test how well the model worked across different forests and conditions, we compared its flame height predictions with the flames that were measured in the Brindabella Ranges during the 2003 fires. The forests ranged from low, dry formations to Alpine Ash and subalpine woodlands, but the FFM predicted the results with an impressive level of accuracy [15]. If it predicted a 10m flame height for example, the actual flame height would be between 10 and 10.4m in height about 50% of the time [17]. For perspective - Project Vesta [18] predictions of a 10m flame corresponded to actual flames of 2.3 to 10m, and predictions from the McArthur Meter [19] corresponded to flames of 14 to over 30m height.

The reasons for this come down to the questions of plant ignition just described. Neither of these models have information on the important drivers of fire behaviour, so both made numerous, large errors (Figs. 2 & 3). When the FFM used only surface fuels, it was only able to explain 11% of the variability. When it included plants and their species-specific traits, it explained 80% - a seven-fold improvement.

Figure 2. Site 94 – a *Eucalyptus dives* forest burnt downhill, with very little near surface fuel. For these reasons, Project Vesta predicted 40cm flame heights. The FFM however calculated that, despite the light fuels, the canopy was low enough to ignite, and correctly predicted passive crown fire.

Figure 3. Site 67 – a *Eucalyptus dives* – *E. dalrympleana* forest with an *Acacia dealbata* understorey burnt downhill and against the wind. Due to dry conditions and a heavy (15.4t/ha) surface fuel load, the McArthur Meter predicted 4.4m flames. The FFM however calculated that given the steep angle of the backing flame, the *A. dealbata* would not ignite. The result was a correct prediction of surface-only fire that killed but did not ignite the wattles.

Forests, not fuels

The implications of this for fire management are significant. As already mentioned, fuel loads in mature forests are heavier than those in recently burnt forests, so if fuel load was the driver, then burning would always reduce the flammability. Plants however have multiple responses to fire. Some are burnt or scorched; others are germinated. Some recover from epicormic shoots along the stems, but others regrow from basal sprouting or seed. Fire may reduce the immediate flammability of a forest, but it also sets it on a trajectory that is determined by the ecology of that ecosystem.

The first effect of a fuel-load paradigm is that the impacts of growing fire frequency on ecosystems are underestimated. Alpine Ash (*E. delegatensis*) forests illustrate how this works.

Like Mountain Ash, mature Alpine Ash forests are unlikely to experience crown fires due to the height of the tree canopies above the ground (Fig. 4). Canopies are however readily scorched and killed, and the species then recovers from seed. If that regrowth is re-burnt before sexual maturity at around 20 years, the Ash trees become locally extinct. The combination of more frequent dry periods where fire can spread, with the advent of massive widespread lightning ignition events in the Australian Alps such as 2003 and 2006 has so increased the frequency of fire in Ash forests that some projections expect a massive loss of the forests this century [20].

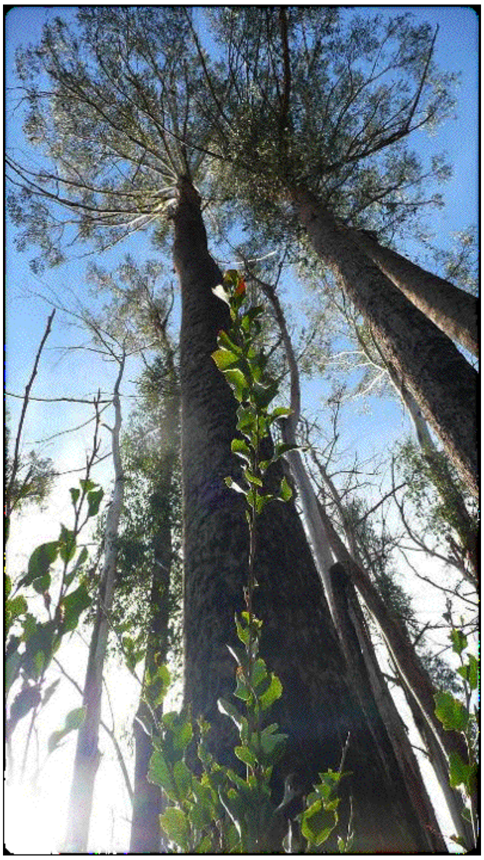

Figure 4. Mature Alpine Ash trees are rarely subject to crown fire due to the separation between tree crowns and ground fires.

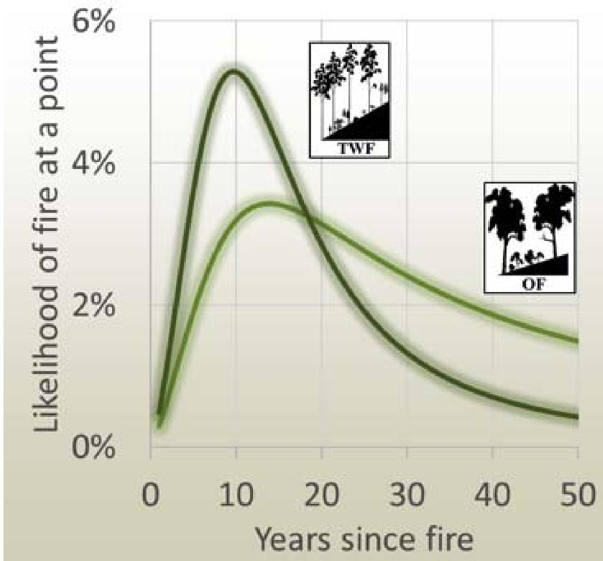

Figure 5. Annual likelihood of fire at a point in Tall Wet Forest (*E. delegatensis* dominant, dark green) and Open Forest (resprouting eucalypt dominant, light green), showing change with time since fire.

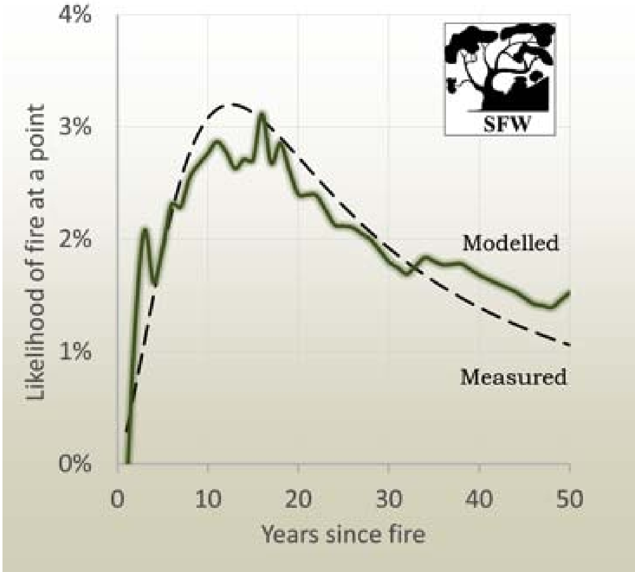

Figure 6. Measured (black line) and modelled (green line) annual likelihood of fire at any point in Snowgum Forest and Woodland, showing change with time since fire.

If flammability was related to fuel loads, then more frequent fire would reduce those fuels and have a mitigating effect on climate change, but unfortunately this is not the case. For the past 58 years of mapped fire records across the Australian Alps National Parks, regenerating Ash forests have burnt more than eight times as often as have mature forests (Fig. 5, [21]). This means that the period when regrowing Ash is most vulnerable to fire corresponds to the age when it is most likely to burn.

More frequent fire therefore creates more flammable Ash forests and increases the spread of fire in the landscape, while causing localised extinctions. But the effect has even more far-reaching implications. Regrowing Ash forests are temporarily more flammable, but still have the capacity to develop into mature, fire-resistant forests. If they are re-burnt too soon however, loss of *E. delegatensis* as the dominant canopy tree can convert near-pure stands into much more flammable heathland formations. If on the other hand, the forest contains a significant proportion of other tall resprouting species such as *E. dalrympleana, E. viminalis* or *E. rubida*, these will gain dominance and the ecosystem will collapse from a tall wet forest of obligate seeders into an open forest of resprouters. This has much longer-term effects on landscape flammability, as the ecosystem loses its capacity to form a fire-resistant mature forest. In the past 58 years across the Alps, mature open forests burnt twice as often as mature Ash (Fig. 5, [21]). Loss of Ash forests represents what is effectively a permanent increase in landscape flammability.

The second effect of a flawed understanding of flammability is that it can drive ineffective management, or even perverse outcomes. If mature, low flammability forests are deliberately burnt for fuel reduction, their natural resistance to fire contagion is temporarily destroyed.

Past flammability trends such as those in Fig. 5 are informative enough to provide broad guidance, but any statistical analysis is limited. The number of mapped fires and level of recorded detail is usually too small to allow an analysis that can reveal details about

- Specific plant communities. Often, communities need to be grouped to provide enough data.
- Effects of different fire behaviours. The angle of the flame, the time that it stays burning in one site and heating the soil, or the dimensions of the flames can greatly affect the impact on the ecosystem.
- Timing of fires. Plants are affected in different ways depending on their biology and the time of year when a fire occurs.

Consequently, these trends are able to provide broad trends regarding the average response of ecosystems to fire, but detailed modelling is needed to see what is hidden behind the averages and understand the details of a healthy fire regime for each community.

By explaining the drivers of flammability, the FFM provides a tool to achieve this. Specific details of plant biology and responses to fire behaviours can be integrated to predict the changes in the community, and these translate into concrete predictions of fire risk. Predictions of annual mean fire behaviour made using the FFM for regrowing Snowgum forest [14] closely fit the measured flammability dynamics [21,22], and with adequate ecological knowledge, these can be re-worked to predict what might occur under hypothetical conditions. Specific prescriptions can be developed to address targeted issues, and as more becomes known about the ways that future climatic changes will affect plant morphology or species' dominance, it will be possible to model this future and plan advanced strategies to mitigate the undesirable impacts.

Next steps

The FFM exists as a software tool, the only peer-reviewed bushfire model for SE Australia, and the first Australian bushfire model to have had flame height predictions validated. Putting it to work however will require investment in software development, collation of species' traits in databases, and integration with vegetation mapping and remote-sensing technology. These are all achievable goals if they are adequately resourced, however there exists a strong culture of conservative fire knowledge in Australia, and this has already resulted in aggressive attempts to circumvent the science and shift the discussion away from peer-reviewed literature. Progressing fire management into a field that is grounded in sound science will therefore also require significant social investment.

Conclusion

Increasing fire frequency alters the flammability of the landscape. If a forest is understood as a collection of fuels that accumulate over time, then the implication is that more frequent fire will reduce the flammability of that forest by limiting the build-up of fuels. If, however, the forest is understood as a dynamic interaction of species with different effects, then flammability dynamics will differ between every forest, and potentially, between different fires.

Some broad trends can be measured to partially explain this, but our response will be increasingly effective the more that we move away from generalisations and embrace the complexity. Our forests are not "the bush", they are ironbark, spotted gum; Snowgum with a *Bossiaea* understorey or one dominated by *Olearia* species. They don't love fire or hate it; they thrive best within specific fire regimes. Such a detailed understanding can only be gained through detailed modelling, and the FFM provides a tool with which this can be done. Further work is needed to put it into practice however, and this includes significant social investment to address the depth to which simplistic views have become entrenched.

Phil Zylstra is a fire behaviour scientist and ecologist who since 2000, has worked within the NSW National Parks and Wildlife Service, and the University of Wollongong Centre for Environmental Risk Management of Bushfires. Pioneering the first model to explain the mechanisms by which species-level plant traits influence fire behaviour, his work has challenged paradigms and provoked fierce controversy, yet remains the only peer-reviewed fire behaviour model for south-east Australian forests. He is a Visiting Fellow at the University of Wollongong Centre for Environmental Risk Management of Bushfires.

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