Project Vesta- findings, extension and validation for south eastern Australia eucalypt forests

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Abstract

Project Vesta was an experimental study to quantify age-related changes in fuel attributes and fire behaviour in dry eucalypt forests typical of southern Australia. Experimental fires were conducted during dry summer conditions at two sites with understorey fuels ranging in age from 2 to 22 years since fire in south-western Australian eucalypt forests. New fire behaviour models have been developed that predict rate of spread and difficulty of suppression according to wind speed, fuel moisture content and variables that reflect the abundance and condition of leaf litter, understorey fuels and bark. The improved understanding of relationships between fuel age and potential fire behaviour in dry eucalypt forests gained from Project Vesta provides a better basis to assess the benefits of various fuel management alternatives that may be employed to reduce difficulty of fire suppression and protect assets from damage during high intensity wildfires. One of the key needs for extending Project Vesta findings is to validate the fire behaviour model in a range of forest fuel types in southeast Australia. This is important not only for planning prescribed burning programs, but also for determining, monitoring and managing suppression of wildfires.

Introduction

Fuel load is the principal fuel characteristic used in Australian forest fire danger rating systems to predict fire behaviour within a particular forest type. Fire behaviour guides for eucalypt forests were first developed in the early 1960's by Alan McArthur of the Commonwealth Forestry and Timber Bureau (1962, 1967) and George Peet of the Western Australian Forests Department (1965). Both fire behaviour guides predict that the rate of forward spread (R) is directly proportional to weight of fine fuel (w) according to a simple linear relationship of the form:

$$R = a\mathrm{w}$$

where *a* is a constant defined for the particular fuel type (McArthur 1962, Peet 1965).

Experimental evidence for this relationship between rate of spread and fuel load came from measurements of small experimental fires lit in open eucalypt forests with fuels comprised of leaf litter and occasional low shrubs. Fires were generally ignited at a point source and allowed to develop for periods of up to one hour or so.

Later editions of the Forest Fire Behaviour Tables for Western Australia (Sneeuwjagt and Peet 1998) allowed for the condition and density of understorey shrubs to be taken into account when estimating the available fuel quantity, but retained the assumption that rate of spread depended directly on fuel load.

Fire intensity is defined as the rate of heat released per unit length of fire front (Byram 1959), and is calculated by the following equation:

$$I = HwR$$

where I = fire intensity (kW m^{-1}),
H = the heat yield of the combustion of the fuel (kJ kg^{-1}),
w = weight of fuel consumed (kg m^{-2}) and,
R = rate of forward spread of the fire front (m s^{-1}).

Fire intensity is a useful practical measure of the difficulty of suppression of a forest fire and is positively correlated with flame length, and with the spotting distance of firebrands transported ahead of the flame front (Ellis 2000).

The relationship between fuel load, rate of spread and fire intensity has provided a simple but powerful argument in support of the practice of fuel reduction burning in eucalypt forests. If the rate of spread is directly proportional to fuel weight, then halving the fuel weight also halves the rate of spread and reduces the intensity of the fire by a factor of four (McArthur 1962). In the simplest case of a freshly burnt area the logic of this proposition is self-evident: where there is no fuel there can be no fire. However, it may be less evident in situations where the vegetation consists of a number of potentially flammable components that may or may not become involved in combustion according to the severity of the burning conditions. Examples of these potential fuels include shrubs, tree canopies and bark on the stems of standing trees. Techniques for rating the relative hazard of these fuels have been developed (McCarthy *et al*. 1999) but such ratings have not readily been used for making quantitative predictions with existing fire behaviour models.

There is considerable uncertainty about how fuel characteristics affect fire behaviour with or without fuel reduction, particularly under extreme fire weather (Cheney 1996). Cheney *et al*. (1993) found that rate of spread of the head fire was not correlated with fuel load in uniform grass swards that had been harvested to different levels to change fuel loads. Burrows (1994, 1999) and Gould *et al*. (1996) were unable to correlate the variation of fuel load with the block and short-term (7 minutes) measures of spread of experimental fires in jarrah forest. However the data could not support conclusion about the impact of fuel load on fire spread because the sampling intensity for fuel load and the measures of wind speed were inadequate for comparison with short-term measures of spread on fires that travelled up to a kilometre from ignition (Cheney *et al.* 1996)

In 1995, the Western Australian Department of Conservation and Land Management and CSIRO Forestry and Forest Products Bushfire Research and Management Group embarked on an experimental program (Project Vesta) that was designed to address the effect of age-related fuel characteristics on fire behaviour in eucalypt forests. The purpose of this paper is to describe how the key findings of Project Vesta can inform the debate about the effectiveness of hazard reduction burning for wildfire control.

Also, one of the aims in the Bushfire CRC research program is to extend the validity of the result from Project Vesta to south eastern Australia. Fuels of different ages in selected eucalypt forests in south eastern Australia (both dry and wet sclerophyll forests) will be surveyed in detail and compared with those with the experimental site sites in Western Australia used during Project Vesta. This will be an ongoing research program in model validation from either wildfire data and/or experimental burning programs.

The Project Vesta experiments

During the summers of 1998, 1999 and 2001 experimental fires were lit at two sites in the Jarrah forest of south-west Western Australia. The experimental site at McCorkhill block 20 km west of Nannup had a shrubby understorey dominated by *Agonis parviceps* which grows to a maximum height of about 2 m. In areas unburnt for 8 years or more this understorey can become sufficiently dense to restrict wind speed in the forest, and can provide a ladder fuel that increases flame length. In contrast, the site at Dee Vee Road 30 km north of Collie had a sparse understorey of *Bossiaea ornata* which rarely exceeds a height of 0.5 m. At each site a number of replicate plots were established in areas of forest unburnt for between 2 and 22 years. Plots were 200 m x 200 m in size and were separated by bulldozed tracks.

Fuel and vegetation characteristics were assessed at up to 32 sample points in each plot. Five fuel strata were recognised, as follows:

- overstorey canopy and bark,
- intermediate canopy and bark,
- elevated shrubs,
- a near-surface fuel layer comprised of twigs, bark suspended leaves and low shrubs,
- surface litter.

Fuel characteristics assessed at each point included the depth, cover and loading of surface litter and near-surface fuel, and the height of elevated fuel. Each fuel strata was described by a fuel hazard score following the concept of McCarthy *et al*. (1999). Fuel hazard was rated against a set of standard descriptions that reflected increasing potential flammability on a scale from 1-4. A percent cover score was also assigned to each fuel stratum. Samples of surface litter and near-surface fuel were harvested and oven dried to determine loadings in t ha^{-1}. Sampling intensity was designed to estimate the mean surface fuel loading with a standard error of less than ± 15 per cent. Elevated shrub fuels were also harvested from a small number of quadrats in each fuel age to determine loadings of live and dead material <6 mm diameter. Bark consumption was determined from measurements of the reduction in bark thickness and the height of charring on the stems of ten Jarrah trees in each plot.

Wind speed was measured during each fire using four sensitive cup anemometers suspended from portable aluminium towers at a height of 5 m above ground. For each plot, four towers were placed at 40 m intervals in a line in the forest upwind of the plot to be burnt. The distance between the anemometers and the ignition line was generally about 40 m. Wind speed was also measured using an anemometer mounted 30 m above ground in a forest clearing within 1 km of the experimental plots. For the purpose of fire spread analysis wind speeds from these instruments were combined into 10-minute means.

Experimental fires were conducted under dry summer conditions of moderate to high forest fire danger. On each burn day fires were ignited simultaneously in plots of each fuel age (5 ages at McCorkhill, 4 ages at Dee Vee). Ignition lines 120 m long were lit with drip torches on the upwind edge of each plot, working outwards from the centre point of the ignition line to complete the lighting operation in two minutes. Observers described the behaviour of each fire as it spread through the plot and recorded the rate of spread using tags and electronic timers. Fire behaviour ranged from slow-spreading surface fires to high intensity fires (7000 kW m^{-1}) with sporadic crowning activity. Eleven sets of experiments were conducted at McCorkhill, and 12 sets at Dee Vee making a total of 104 fires.

Influence of fuel on fire spread

Rate of spread data from experimental fires were reduced to a zero slope equivalent using the slope function of McArthur (1967), and were standardised to a surface litter moisture content of 7 percent using the function of Burrows (1999). In some case wind speed data exhibited a post-ignition increase that was not detectable in the observations made some distance away from fires at the 30 m tower. This effect was more evident in older fuels and higher intensity fires, and persisted for up to an hour after ignition. It is likely that the enhanced wind speed was due to a change in convective activity around experimental fire plots after ignition. Wind speed data measured at each experimental plot were adjusted to a pre-fire equivalent value using a function that related the proportional increase in speed to fire intensity.

Following standardisation, the rate of spread data showed a strong relationship with wind speed. For a given wind speed the fires at McCorkhill tended to spread faster than those at Dee Vee, suggesting that differences in fuel characteristics between the two sites affected rate of spread. When stratified by wind speed classes, rate of spread data showed a positive relationship with surface fuel load although correlations were mostly <0.5, and an effect of surface fuel load was not evident in all wind speed classes.

A range of other fuel variables were screened using the same approach, including variables derived from the product of hazard scores, percent cover scores, and fuel height. Several of the derived fuel variables were strongly correlated (>0.7) with rate of spread across all wind speed classes and were superior to variables based on a single attribute of the fuel. Derived variables strongly correlated with rate of spread included:

- product of near-surface fuel height and hazard score,
- product of near-surface fuel height and percent cover score,
- product of elevated fuel height and hazard score,
- product of elevated fuel height and percent cover score.

Bark hazard scores and percent cover scores for the intermediate and overstorey strata were not strongly correlated with rate of spread. However, bark loss and char height on Jarrah trees were correlated with fire intensity and the pre-fire thickness of the bark. Linear regression equations fitted to intensity and pre-fire bark thickness explained at least 60 per cent of the variation in bark loss. Estimates of the quantity of bark fuel consumed in a typical Jarrah forest stand ranged from 1-2 t ha^{-1} for fires up to 1000 kW m^{-1}, and 6-8 t ha^{-1} for fires of 6000 kW m^{-1}.

Extension and validation

One of the key needs for fire management is to obtain improved and validated landscape level fire behaviour models. This is important not only for planning prescribed burning programs, but also for determining, monitoring and managing suppression of wildfires and to provide more timely warnings. Validation is taken here to mean checking that the model structure or its outputs are sufficiently close to the workings or observed states of the real systems. The comparison of predictions from the model with observations from either wildfires and/or experimental fires in different forest, together with an assessment of model performance is empirical validation. Forest fire models currently in use are being improved and updated to add capability for modelling fire behaviour in different fuel structures (McCaw *et al.* 2003, Gould *et al.* 2001, McCarthy 1999). This is largely model calibration based on field experiments and will require field validation. Thus, additional information is required to accurately test and validate the new models under different wildfire conditions and different forest structures. The application of aircraft-based remote sensing (IR scanning) shows great promise in quantifying such parameters as fire intensity, rate of spread, residual combustion, spot fire development, smoke dispersion etc.

Two of the major sources of error in prediction in fire behaviour models are probably the use of inappropriate fuel data and inadequate fire weather information. Fuel load is the only fuel parameter required for prediction of fire behaviour by the McArthur fire behaviour tables. The high cost and difficulty of obtaining representative fuel samples after the fire event and the high degree of spatial variability of fuel means it is difficult to obtain an accurate value of the fuel quantity for behaviour predictions. The combination of new tools such as fuel hazard guides or hazard scoring systems with photo guides into new fuel classification systems, as well as potential links with remotely-sensed data, show promise for improving accuracy of mapping the fuel characteristics that are important for predicting fire spread (McCaw *et al.* 2003, Gould *et al.* 2001, McCarthy 1999). The combustion rate of different fuel components (i.e. effect of fuel moisture) is another source of error in modelling fuel effects in the fire behaviour models and is difficult to validate. Another important factor in fire behaviour predictions is the accurate estimates of local weather (such as wind speed in complex terrain) and its spatial variation. Researchers are currently using a combination of terrain modelling and satellite weather data, combined with data from remote weather stations to increase the accuracy of the weather data that is used in fire behaviour models. With more accurate fuel and fire weather inputs into fire behaviour models it will be easier to assess the basic performance of fire models.

Discussion

Fire behaviour modelling plays an important role in fire management in assessing current situations, projecting into the future, and the evaluation of alternative strategies. Project Vesta experiments have improved our understanding of the behaviour of fire in different fuel structures. Also these experiments have confirmed that the rate of spread of fires in open eucalypt forest is affected by a variety of fuel characteristics which change as the age of the fuel increases. Some characteristics of the fuel stabilise within six years after fire and do not change appreciably in older fuels. This was the case for percent cover of surface litter and elevated fuel, and for elevated fuel height at Dee Vee. However, other fuel characteristics continue to change for at least 10-15 years after fire as was observed for near-surface fuel hazard and cover, elevated fuel hazard, and near-surface fuel height. Elevated fuel height also continued to increase with time since fire at McCorkhill where the forest had a shrubby understorey. The amount of bark on standing trees that is potentially available as fuel also increases with time since fire. This is partly because the trees have thicker bark, and also because fires in older fuels tend to be more intense and result in higher char on the stem. Bark may contribute half as much fuel again as there is in the surface and near-surface fuel strata. The higher level of bark consumption in older fuels also has a significant influence on the density of firebrands transported downwind of the flaming zone (Ellis 2003).

These findings support McArthur's proposition that the difficulty of suppression is greater in older fuels not only because of the heavier fuel loadings and higher fire intensities, but also because the fires may spread faster. The Project Vesta experiments showed that surface fuel loading was correlated with rate of spread under some situations, but also demonstrated that other fuel variables can provide better explanatory power for modelling rate of spread. Variables that combine different characteristics of the fuel, such as height and hazard score, provide an opportunity to develop fire behaviour models that can be applied across a relatively broad range of forest types, rather than being specific to a particular fuel type. We consider that in selecting variables for inclusion in a fire behaviour model, weighting should be given to practical issues of field assessment as well as to statistical considerations. For this reason we favour measures of fuel height and fuel hazard score instead of percent cover which can be difficult to assess consistently amongst different observers. Project Vesta findings add weight to the view that visually-based fuel hazard rating systems have potential to replace more labour intensive methods of fuel assessment.

Conclusions

Project Vesta has confirmed that the potential intensity and rate of spread of fires in open eucalypt forests is directly related to the time since last fire. The intensity and difficulty of suppression of fires will increase for at least 15 years after fire because of changes taking place in the characteristics of surface, near-surface and elevated fuel strata. In forests dominated by trees with fibrous bark the spotting potential and difficulty of suppression may continue to increase for considerably longer periods after fire as bark continues to accumulate on trees. For these reason predictions of fire behaviour based solely on the loading of fine surface fuels will tend to under-estimate potential fire behaviour in forests that have been unburnt for some time. Before the findings from Project Vesta can be used with confidence by fire managers, and an effort must be made to determine how well the Vesta fire behaviour model performs when it is used to predict or estimate fire characteristics of interest in the real system i.e. wildfire situation. The validation of fire behaviour models presents many conceptual and practical difficulties.

Validation in essence involves ensuing that a model is adequate for its intended used and is an important and often overlooked in the development of fire models and in the execution of new models.

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References

Bradstock, R. and J. Scott 1995. A basis for planning fire to achieve conservation and protection objectives adjacent to the urban interface. *CALMScience Supplement* 4: 109-116.

Burrows, N. D. 1994. Experimental development of a fire management model for Jarrah (*Eucalyptus marginata* Donn. ex Sm.) forest. PhD thesis, Department of Forestry, Australian National University, Canberra, ACT.

Burrows, N. D. 1999. Fire behaviour in Jarrah forest fuels: 2. Field experiments. *CALMScience* 3: 57-84.

Byram, G. M. 1959. Combustion of forest fuels. In: *Forest fire: control and use*. (ed. K. P. Davis), McGraw-Hill, New York. Pp 61-80.

Cheney, N. P. 1996. The effectiveness of fuel reduction burning for fire management. In Fire and Biodiversity: effects and effectiveness of fire management. Dept. Environ. Sport and Territories. Biodiversity Series Pap. No. 8, 7-16.

Cheney, N. P., J. S. Gould and W. R. Catchpole 1993. The influence of fuel, weather and fire shape variables on fire spread in grasslands. *International Journal of Wildland Fire* 3: 31-44.

Ellis, P. F. 2003. Spotting and firebrand behaviour in dry eucalypt forest and the implication for fuel management in relation to fire suppression and to “ember” (firebrand) attack on houses. 3rd International Wildland Fire Conference and Exhibition Proceeding. 3 – 6 October 2003. Sydney, NSW, Australia.

Ellis, P. F. 2000. The aerodynamic and combustion characteristics of eucalypt bark – a firebrand study. PhD thesis, Department of Forestry, Australian National University, Canberra, ACT.

Gould, J. S. Cheney, N. P. and McCaw, L. 2001. Project Vesta- Research into the effects of fuel structure and fuel load on behaviour of moderate to high-intensity fires in dry eucalypt forest: Progress Report. Australasian Bushfire Conference Proceedings. 3 –6 July 2001. Christchurch. New Zealand. pp 13-21.

Gould, J. S., Cheney, N. P., Hutchings, P. T. and Cheney, S. 1996. Prediction of bushfire spread: IDNDR Project 4/95. Unpublished Client Report, 27 pp.

McArthur, A. G. 1962. Control burning in Eucalypt forests. Forestry and Timber Bureau Leaflet 80. 31 pp.

McArthur, A. G. 1967. Fire behaviour in Eucalypt forests. Forestry and Timber Bureau Leaflet 107. 35 pp.

McCaw, W. L., Cheney, N. P. and Gould, J. S. 2003. Do eucalypt forest fires burn faster and hotter in older fuels? - Implication for hazard reduction burning. 3rd International Wildland Fire Conference and Exhibition Proceeding. 3 – 6 October 2003. Sydney, NSW, Australia.

McCarthy, G. J., K. G. Tolhurst and K. Chatto 1999. Overall fuel hazard guide. Department of Natural Resources and Environment Victoria, Fire Management Research Report No. 47. 28 pp.

Peet, G. B. 1965. A fire danger rating and controlled burning guide for the Northern Jarrah (*Euc. marginata* Sm.) forest, of Western Australia. Forests Department Western Australia Bulletin No. 74. 37 pp.

Sneeuwjagt, R. J. and Peet, G. B. 1998 Forest fire behaviour tables for Western Australia. Dept of Conservation and Land Management, Perth, WA, Australia, 59 pp.