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Assessing Fire Hazard on Public Lands in Victoria: Fire Management Needs, and Practical Research Objectives

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Summary

Bushfire hazard is discussed in relation to the specific needs of managers of public land in Victoria, the complexity of the physical influences of fuel on fire spread, the limitations of existing models, and the priorities to be addressed by research.

The ideal classification system would incorporate the effects of all fuel components on fire behaviour and difficulty of suppression, taking account of appropriate weighting factors for each component. Bark, scrub and surface fuels should be assessed separately in a classification system which relates directly to the expected difficulty of fire control and in which the categories match the thresholds of hazard that are used by land managers to determine the need or otherwise for protection works, especially fuel reduction burning. The classification system should be applied operationally in the short term, validated progressively and supplemented later by other research into fuel accumulation rates and the effects of fire regime on fuel arrangement.

A possible basis for classifying scrub fuels, which complements the existing planning process for rating surface fuels in Victoria and utilizes parts of the "Red Book" model from Western Australia, is outlined.

Introduction

Managers of public land in Victoria need to know the fire hazard* on particular sites so that they can predict fire behaviour during suppression operations, identify sites on which fuel modification works are needed as a protection measure, and set priorities for implementing protection works. They also need to have a basis for communicating about hazard levels with other land managers and the public, in terms that are clear, relevant and preferably accepted by all parties. The managers' main interest in fire hazard is as a measure of the expected difficulty of wildfire control.

Fuel, the condition of which determines fire hazard, is commonly quantified in terms of the load or quantity (expressed in units of tonnes per hectare) of leaf litter, twigs and grass on the ground (see McCaw 1991 for a discussion of fuel measurement). Fire planning for public land in Victoria identifies particular zones of protection priority and seeks to keep fine fuel loads below specified levels. However, some of the key factors which affect suppression difficulty and damage potential, such as fire intensity, fire rate of spread, flame height, physical obstruction and the distance and frequency of spotting, also depend directly on elevated fuel components such as scrub** and bark, which, per unit fuel load, have different impacts on fire behaviour. These components cannot be adequately characterised or compared with each other by their quantity alone and a meaningful mechanism of accounting for them in hazard assessments is needed.

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* Hazard is concerned with the condition of the fuel and takes into consideration such factors as quantity, arrangement, current or potential flammability and the difficulty of suppression if fuel should be ignited. Risk refers to the relative chance or probability of fires starting and is determined by the presence or absence of causative agencies. (Luke and McArthur, 1978)

** *Scrub* refers to vegetation such as heath, wiregrass and shrubs, which grows either as an understorey or by itself in the absence of a tree canopy.

An appropriate fuel assessment method would provide an improved means by which the Department of Conservation and Environment (DCE) could reliably determine, in relation to objective planning criteria, whether or not the fire hazard at particular sites needed to be fuel reduced. Some controversy and the premature or delayed conduct of fuel reduction burns could then be avoided, with consequent financial, ecological and protection benefits.

The aim of this discussion paper is to propose a research framework for developing a hazard assessment method which can be implemented efficiently in operational practice.

Background

(a) The influence of fuel on heat transfer and fire spread

The fuel load determines the maximum amount of energy that a fire may release. The mechanism, rate and actual amount of that release, and the consequent effect on fire behaviour and difficulty of suppression, are determined by other fuel factors and weather.

The method of transfer of energy released by one surface fire, in terms of the ratio of convection to thermal radiation, has been measured to be approximately 2:1 (Packham, 1970). The pre-heating and combustion of elevated fuels may change the relative proportions of transfer by these two mechanisms, with consequent effects on fire behaviour and damage.

Fuel moisture content has a profound effect on flammability. Litter bed fuels typically burn readily with moisture contents of 10 per cent, but may be impossible to ignite at moisture contents above 20 per cent (Luke and McArthur, 1978). The reason relates to more than just the increased energy that is required to bring the fuel to ignition temperature, because the heat that would be released from burning a fuel with a moisture content of 20% is still several times more than would be needed for all of that moisture to be vapourised (Pompe and Vines, 1966). Water vapour greatly retards the generation of heat radiation from burning fuel, thereby reducing the amount of pre-heating of adjacent fuels and hence the sustaining of combustion within those fuels (King, 1973). By implication, live fuels, although they may be consumed by fire, have quite different heat release characteristics per unit dry weight than do dry fuels, and have quite a different impact on fire behaviour.

Fuel flammability is also influenced by chemical composition. Fuels containing relatively high levels of certain mineral elements (such as Calcium) are less flammable - an effect which has been attributed to the interference of these elements in the combustion process (e.g. King and Vines, 1969). Fuels which contain volatile oils are notably more flammable - an effect which has been attributed to the early combustion and heat release of these oils, and consequent pre-heating and removal of foliage moisture (e.g. Pompe and Vines, 1966). The contribution of live fuels to heat release and fire behaviour can be expected to depend partly on the chemical composition of those fuels.

The flammability of a fuel complex depends partly on the dimensions and arrangement of the fuel particles. Thin or "fine" particles ignite more readily and release their heat more quickly than do thicker particles of an equivalent total weight. A fuel complex where the particles are closely packed, or widely spaced, will be less conducive to the rapid and efficient spread of fire between particles, because either the oxygen supply will be limited or the heating of adjacent particles will be less efficient. Combustion will be at its most efficient somewhere between the two extremes. Elevated dead fuels are more exposed to air movement and solar radiation, so they tend to dry out more quickly than do litter bed fuels, and therefore be more flammable. In the event of fire, elevated fuels are well positioned to absorb convective and radiant heat from the combustion of adjacent or underlying fuels, and consequently may be easier to ignite and may burn more fiercely. Fuel complexes where the fuel particles are elevated, fine, evenly distributed and moderately spaced (such as a swarth of grass or heath) are likely to burn relatively quickly and release high levels of flame and radiated heat.

The loose, fibrous bark of "stringybark" eucalypts readily ignites and supports the movement of fire up the tree trunks. The resulting flames may add substantially to the horizontal transfer of radiated heat and assist with the ignition and combustion of other elevated fuels such as the tree crowns. Wind and convection may also dislodge pieces of burning bark from stringybark and "ribbon bark" species and carry the firebrands ahead of a fire front to cause spot fires, thereby breaching control lines and increasing fire rate of spread. The presence of loose eucalypt bark can dramatically increase fire suppression difficulty.

In summary, the effects of elevated fuels on fire behaviour and hence suppression difficulty are very complex, are difficult to quantify and are incompletely understood. They affect attempts to predict fire behaviour by limiting the comprehensiveness of any theoretical modelling and by magnifying the difficulties of achieving results from empirical experiments.

(b) Fuel inputs to fire behaviour models

Most of the models for predicting fire behaviour in forests and grasslands take some account of fuel factors.

The Rothermel model (Rothermel, 1972), used primarily in the United States, uses a limited theoretical framework and laboratory evidence to model the effects of fuel factors such as height, moisture content, surface-area-to-volume ratio and particle arrangement. In Australia, however, the greater majority of fire and land management agencies believe that the model is inaccurate, and only a few agencies use it.

Fire researchers in Canada, focusing on the spread of fires on the surface and through the crowns of conifer forests, have recognised the effects of "bridge" or "ladder" fuels between the forest floor and tree crowns (e.g. Van Wagner, 1977; Stocks, 1986). Conifer fuels (and hence the research results) appear, however, not to be very applicable to the complex range of live scrub fuels found in native forests of Australia.

The McArthur forest and grass fire danger models (Luke & McArthur, 1978), which are widely used in Australia and which are based on empirical research, account explicitly for the fuel factors only of moisture content and quantity. They do not provide explicitly for the effects on fire behaviour of variation in scrub and bark fuels.

The most comprehensive and detailed fire behaviour model in Australia is the "Forest Fire Behaviour Tables for Western Australia" (Sneeuwjagt and Peet, 1985), known as the "Red Book". This model provides a system for estimating the quantity of some Western Australian scrub fuels that are available for burning, based on the scrub type, height and density, and the expected fire severity.

Importantly, it then provides correction factors (shown in Table 1), based on foliage particle size, density, arrangement and percentage of dead material, for estimating the effective fuel quantity for the prediction of rate of spread. For example, every 1 t/ha of "high" flammability scrub with 20% dead material is considered to have the equivalent effect on rate of spread as would 3 t/ha of litter fuel. The data supporting the correction factors are limited, and a link between rate of spread and the effects of scrub on suppression difficulty or fire damage needs to be established, but the approach recognises that not all elevated fuels are equal and has considerable merit in hazard rating.

(c) Planning for fuel reduction burning in Victoria

The aim of fuel reduction burning on units of public land in Victoria is to keep fuels at levels where, at a stipulated level of fire danger, fire suppression is possible (which is nominally considered to be when the fire intensity is less than about 3000 kW/m - Loane and Gould, 1986). The fuel levels are determined via the following equation:

$$w = kF^{-0.5}$$

Where w is the fuel load,
F is the Forest Fire Danger Index, and
k is a constant.

Table 1. Scrub Flammability Factors used in Western Australia, which are used to determine Scrub Fuel Loading for calculation of rate of spread (Table 7.4.2, Sneeuwjagt and Peet, 1985).

Scrub Flammability	Scrub Foliage Condition		
	>50% dead	20% Dead	Young/green
HIGH Foliage aerated; fine; dense or continuous	5.0	3.0	1.5
MEDIUM Foliage moderately fine; mixed size classes; medium dense.	3.0	2.0	1.0
LOW Foliage dispersed; coarse; sparse; compacted or moist.	1.5	1.0	0.5

Obtain appropriate scrub flammability factor (S.F.F.) from table. Multiply available scrub fuel weight (Table 7.4.1. - not shown here) by S.F.F. to determine scrub fuel loading (S.F.L.)

This equation is derived from the following equations:

$I = HwR$ (Byram, 1959)
$R = k_1Fw$ (Luke and McArthur, 1978)

Where R is rate of spread,
I is the fireline intensity,
F is the Fire Danger Index,
H is the heat yield per unit dry weight of fuel (which is a constant), and
k_1 is a constant.

In Victoria, four zones of Protection Priority are specified, the highest of which are Priority 1 (P1) and Priority 2 (P2) where the prescriptions specify that maximum fine fuel loads be kept below 8 t/ha and 12 t/ha respectively. At these fuel levels fire control on level terrain under ideal circumstances is considered (D. O'Bryan* pers. comm.) to be possible at indices of 50 and 25 respectively. Priority 1 zones are assigned to sites which are close to, and provide strategic protection to, values such as houses and pine plantations.

Bark, scrub and other fuel factors are not incorporated, because:

- litter is a key factor and is much more readily measurable;
- the results of subjective assessments of these other fuel factors (whether correct or otherwise) are difficult to defend or reject;
- resource requirements for comprehensive operational measurements are prohibitive;
- objective measurement or estimation techniques have not yet been developed or evaluated in Victoria;
- a body of validation experiments is not available;
- many formal measurements cannot be used directly in existing models of fire severity, fire danger or difficulty of fire control;
- bark and scrub fuel loadings cannot simply be added to litter fuel loadings for input into existing fire behaviour models, for the reasons discussed earlier.

Management Needs for Hazard Assessment

Fire managers in DCE need both a method for assessing all fuels and a means of relating those assessment results to a prediction of fire behaviour or difficulty of fire control. If either is absent then any operational gains will be severely limited.

In priority order the manager needs the following:

1. A broad system for rating fire hazard, for the purposes of:

   (a) communicating wildfire potential during suppression operations,
   (b) scheduling protection works by being able to determine whether or not the hazard level of particular sites is above or below a nominated threshold value.

   Necessary characteristics of such a system would be that fuels can be assessed:
   - easily (and therefore cheaply),

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- consistently (partly so that discussion or dispute about hazard levels and the need or otherwise to reduce fuels at a particular site can be directed at the classification system and whether or not it has been properly applied, rather than at the assessment result itself),
- meaningfully (i.e. able to be interpreted in terms of suppression difficulty and fire behaviour), and,
- in a form which preferably can be readily communicated, utilized, defended and evaluated - within DCE and by the public, CFA, local government, conservation groups and media.

2. Methods of predicting, for a given fuel type, the number of years that elapse between a fuel reduction burn or wildfire and the re-accumulation of fuel to the threshold level. Predicting the timing of reaching the threshold level is more important than a thorough understanding of fuel accumulation rates above or below that threshold.

3. Data which show whether or not particular fire regimes (such as those of frequent low intensity fires) affect fuel structure (e.g. shrub versus grass), litter accumulation rates and hence the speed with which fuels accumulate to the threshold level.

4. Improved models for predicting wildfire rate of spread for making fire control decisions, both tactical and strategic. The relatively low priority that is assigned to this need is a reflection of the managers of fire suppression being generally more concerned with the degree of difficulty of direct attack and the availability and location of control lines for direct and indirect attack. This is partly related to the increasing capability for the direct monitoring of headfire location by aerial or other reconnaissance (e.g. infra red technology), which has reduced the need for "predicting the present".

Fire hazard research in DCE should be structured to produce information which addresses these priorities and which:

1. can be operational in the short to medium term (e.g. 1-5 years),

2. provides data that can be used for developing a more thorough understanding of fuel dynamics in the longer term,

3. contributes to a thorough understanding of fire behaviour.

Proposed Research framework

The research objective is to provide a system of hazard assessment which provides meaningful measures of suppression difficulty.

The system should:

1. be easy to use, and generate repeatable results

2. address each of the fuel components of litter, scrub and bark. Whether or not the components are integrated into a single index is of secondary importance, but if they are kept separate then an accompanying guide should also be developed to assist the manager in jointly interpreting the assessment results for the separate components. The hazard scale that is established for each component should be equivalent, in terms of fire suppression difficulty, to the scale for each of the other components.

3. reinforce the existing fire planning system so that the integrity of Fire Protection Plans, which have been prepared throughout the State with considerable effort and consultation, is retained.

4. focus on the assessment of hazard in relation to critical levels (threshold values) rather than on the prediction or description of whole scales of hazard accumulation.

5. utilize existing models, data and experience where appropriate.

The development process should be structured so that initial results can be used operationally in the short term (1-2 years). Detail would be less important than relevance and implementation.

The above requirements would best be met by a classification system rather than a set of equations. Photographs could be used to illustrate the categories for each fuel component. The structure could be prepared and implemented relatively quickly, with the validation and refinement occurring subsequently.

Research would need progressively to verify the following assumptions in the classification system:

- that, for each fuel type, the suppression difficulty assigned to each hazard category for each fuel component (especially elevated fuels) is correct, based on observations of the behaviour and control of wildfires;
- that physical measurements (e.g. height, bulk density) of elevated fuels are consistent with the hazard categories. The approach taken by Sneeuwjagt (1971) may prove useful;
- that rate of spread as measured in burning experiments is affected by scrub fuel to the extent indicated by the classification system. These data would help validate, or understand deficiencies, in a possible assumption that scrub fuels affect suppression difficulty in proportion to the impact of those fuels on rate of spread;
- that the guidelines for integrating the assessment of each of the three fuel components, to provide an overall hazard assessment for a given site, are valid.

Research should then seek to determine the number of years that fuel levels for each fuel component take to accumulate to the threshold level, in each fuel type. This time interval may depend on the vegetation species present, weather and site conditions, and the severity of each fire event.

An outline of the possible basis of a scrub hazard classification system is outlined in Appendix 1. It may be an appropriate starting point.

Conclusion

Fire hazard, which is a critical factor in determining the difficulty of fire control, needs to be assessed in terms of its components of surface, scrub and bark fuels. Existing fire behaviour models, with the partial exception of the Forest Fire Behaviour Tables in Western Australia, are not adequate for this purpose. Fire hazard research should be directed at producing a meaningful hazard classification system which can be used operationally in the short term, and be validated progressively with input from research and field operations.

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Appendix 1: Outline of a possible basis of a Hazard Classification

The current system of Protection Priority zones in Victoria states that fire hazard, in terms of fine fuel loads, should be kept within a specified range, as shown in Table A1. If the fuel loads are kept within those specified limits, then fire control is considered (D. O'Bryan* pers comm) to be "possible" under fire danger (i.e. weather) conditions up to a specified level of Forest Fire Danger Index (FFDI), which may be referred to as the "Reference FDI".

Table A1. Relationship between fine fuel load, Protection Priority and the fire danger conditions under which fire suppression is expected to be successful.

Max. Fine fuel load (t/ha)	% of area to be fuel reduced	Protection Priority	Reference FDI*
8	up to 90%	P1	50
12	up to 80%	P2	25
12	up to 50%	P3	-

* denotes the Forest Fire Danger Index below which fire control should be successful

Factors other than FDI also affect the difficulty of fire control. These include the speed and type of suppression response, the topography, short term variability in fire behaviour, and the actual combination of weather conditions that make up the nominated Reference FDI. For the purposes of this discussion paper the difficulty of fire control is defined in relation to a nominal set of reference conditions. The "Reference First Attack" is specified as being: direct attack by a 50kW bulldozer (D3 class) and a small tanker (400 litre capacity) and crew, within 30 minutes of detection of a single fire burning on flat terrain with good access, when the Drought Factor is 10 and the wind speed is 20km/h. This Reference First Attack provides a more precise basis for assessing whether or not fire control is possible for a given level of Reference FDI.

Fuel factors other than fine fuel load (such as bark and fuel arrangement) also determine the impact of fuel on the difficulty of fire control. The concept of Reference FDI can be made more useful by applying it more generally to fire hazard rather than just to fuel load.

In Table 2, Hazard Categories H1 to H4 are listed against an expanded range of Reference FDIs. Weather conditions that correspond to each Reference FDI are also shown. Hazard level increases from H1 (where the Reference First Attack can succeed even when the FFDI is greater than 50) to H4 (where the Reference Initial Attack can be expected to fail once the FFDI reaches 12).

The Hazard Categories in Table A2 can be applied separately to each fuel component. For litter fuels, 8 t/ha and 12 t/ha can be considered to apply already to H2 and H3 respectively. For bark and scrub fuels a new classification of levels of hazard is needed.

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Table A2. Hazard categories in relation to the "Reference FDI".

Hazard Category	Reference FDI*	Example of weather conditions for FDI level			
		Wind (km/h)	Temp (^oC)	R.H. (%)	Drought Factor
H1 (moderate)	50+ (eg 80)	20	44	5	10
H2 (high)	up to 50	20	38	10	10
H3 (very high)	up to 25	20	30	23	10
H4 (extreme)	up to 12	20	25	40	10

* The boundaries between the Hazard Categories H1 to H4 correspond respectively to the boundaries between the fire danger levels of Moderate, High, Very High and Extreme fire danger respectively, on the McArthur Mark 5 Forest Fire Danger Index.

For scrub fuels, the Western Australian scrub flammability data in Table 1 can be applied, as shown in Table A3, to show how the fuel loads that are necessary to reach a given hazard category can be lower for scrub fuels than they are for litter fuels. Each scrub fuel quantity (eg 1.6 t/ha) is calculated by dividing the litter fuel load (eg 8 t/ha) by the corresponding Scrub Flammability Factor (eg 5.0) from Table 1. The data suggest, for example, that the presence of 2.4-3.4 t/ha of scrub fuel which is aerated, fine, dense and more than 50% dead generates a rate of spread, hence suppression difficulty, equivalent to that of 12-17 t/ha of litter fuel.

The approach to hazard classification that is described in this appendix needs validation and is not meant to be accurate. It does not allow, for example, for any changes in stand density (hence windspeed) that may be associated with variation in elevated fuels, or for any role of litter fuel in initiating or sustaining combustion in the elevated fuels. However, the concept of Hazard Categories, and the recognition of the greater hazard of scrub fuels, are more important than the illustrative fuel loads in Table A3. The figures in Table A3 need validation by research.

Table A3. Quantities (t/ha) of scrub fuel which correspond to each of the Hazard Categories from Table A2, as derived from the correction factors shown in Table 1.

Hazard category	Equivalent litter fuel load (t/ha)	Scrub flammability*	Actual Scrub fuel load (t/ha) according to Scrub foliage condition		
			>50% dead **	20% dead	Young/green
H1		High	0-1.6	0-2.7	0-5.3
(moderate)	0-8	Medium	0-2.7	0-4	0-8
		Low	0-5.3	0-8	0-16
H2		High	1.6-2.4	2.7-4	5.3-8
(high)	8-12	Medium	2.7-4.0	4-6	8-12
		Low	5.3-8.0	8-12	16-24
H3		High	2.4-3.4	4-5.7	8-12
(very high)	12-17	Medium	4-5.7	6-8.5	12-17
		Low	8-12	12-17	24-34
H4		High	>3.4	>5.7	>12
(extreme)	>17	Medium	>5.7	>8.5	>17
		Low	>12	>17	>34

* Low is defined as "foliage dispersed; coarse; sparse; compacted or moist". Medium is defined as "foliage moderately fine; mixed size classes; medium dense". High is defined as "foliage aerated; fine; dense or continuous".

** The component of elevated fuels which comprises dead eucalypt litter should be included in the ">50% dead" category.

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