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## **A comparison of bushfire fuel hazard assessors and assessment methods in dry sclerophyll forest near Sydney, Australia**

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# A comparison of bushfire fuel hazard assessors and assessment methods in dry sclerophyll forest near Sydney, Australia

## Abstract

Over the last decade, fire managers in Australia have embraced the concept of 'fuel hazard', and guides for its assessment have been produced. The reliability of these new metrics, however, remains to be determined. This study compared fuel hazard ratings generated by five assessment teams using two Australian hazard assessment methods, in two dry sclerophyll forest sites on Sydney's urban fringe. Attributes that underpin hazard scores, such as cover and height of various fuel layers, were also assessed. We found significant differences between teams on most variables, including hazard scores. These differences were more apparent when fuel hazard assessments focussed on individual fuel layers than when teams' assessments were summarised into an overall fuel hazard score. Ratings of surface (litter) fuel hazard were higher when one assessment method was used than when assessors employed the other; however, ratings of elevated (shrub) and bark fuel hazard were relatively consistent across assessment methods. Fuel load estimates based on the two hazard assessment methods differed considerably, with differences between teams also significant. Inconsistency in scoring fuel hazard may lead to discrepancies in a range of management applications, which in turn may affect firefighting safety and effectiveness.

## Keywords

methods, assessment, assessors, hazard, fuel, bushfire, comparison, near, forest, australia, sclerophyll, sydney, dry

## Disciplines

Life Sciences | Physical Sciences and Mathematics | Social and Behavioral Sciences

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Title: A comparison of bushfire fuel hazard assessors and assessment methods in dry sclerophyll forest near Sydney, Australia

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Additional keywords: fuel assessment, fire management

## **Abstract**

Over the last decade, fire managers in Australia have embraced the concept of 'fuel hazard', and guides for its assessment have been produced. The reliability of these new metrics, however, remains to be determined. This study compared fuel hazard ratings generated by five assessment teams using two Australian hazard assessment methods, in two dry sclerophyll forest sites on Sydney's urban fringe. Attributes which underpin hazard scores, such as cover and height of various fuel layers, were also assessed. We found significant differences between teams on most variables, including hazard scores. These differences were more apparent when fuel hazard assessments focused on individual fuel layers than when teams' assessments were summarised into an overall fuel hazard score. Ratings of surface (litter) fuel hazard were higher when one assessment method was used than when assessors employed the other, however ratings of elevated (shrub) and bark fuel hazard were relatively consistent across assessment methods. Fuel load estimates based on the two hazard assessment methods differed considerably, with differences between teams also significant. Inconsistency in scoring fuel hazard may lead to discrepancies in a range of management applications, which in turn may impact firefighting safety and effectiveness.

**Brief summary:** This study compared fuel hazard ratings generated by five assessment teams using two Australian hazard assessment methods in two dry sclerophyll forest sites on Sydney's urban fringe. We found significant differences between teams on most variables, including hazard scores. Inconsistency in scoring fuel hazard may lead to discrepancies in a range of management applications.

## Introduction

Sound wildland fire management requires an understanding of wildland fuel, and a way to determine its state in time and space. Fuel assessments vary across the globe, partly because models for predicting fire danger, behaviour and effects differ in their fuel inputs. In the United States, where applications are often based on semi-physical models, fuel inputs address a range of characteristics e.g. load, depth, surface area to volume ratio, heat content (Burgan and Rothermel 1984; Sandberg *et al.* 2007). While direct field assessment of fuel attributes is sometimes undertaken, this can be difficult and time-consuming. Effort has therefore gone into characterising fuel prototypes or models, descriptions of vegetation with given values on the necessary fuel parameters (Ottmar *et al.* 2007; Riccardi *et al.* 2007; Arroyo *et al.* 2008). Thus the primary task at stand or site level often becomes one of determining the appropriate fuel prototype (Anderson 1982; Scott and Burgan 2005; Sikkink *et al.* 2009). In Australia, where fire behaviour models are mostly empirical (McArthur 1967; Sneeuwjagt and Peet 1998; Fujioka *et al.* 2009), fuel inputs tend to address a limited range of strata and characteristics (e.g. surface litter load, shrub height) thereby aiding direct measurement in the field.

However fuel assessment in Australia is changing (McCarthy *et al.* 1999). For many years, the focus was on direct measurement of fuel load (dry weight per unit area) particularly that of fine litter fuel (e.g. Peet 1971; Fox *et al.* 1979; Raison *et al.* 1983; Simmons and Adams 1986), often defined in Australia as those fuel particles less than 6 mm in diameter (Luke and McArthur 1978). Litter fuel load is a required input to the McArthur (1967) empirical rate of spread model for eucalypt forests; this model is still widely used in Australia today. In recent decades, however, the Australian view of fuel has expanded to include a wider range of layers and characteristics. Forest fire

behaviour models have recently been developed that utilise fuel variables other than litter load (Cheney *et al.* 1992; Gould *et al.* 2007a), and assessment methods for documenting ‘fuel hazard’ across multiple fuel layers, have emerged (McCarthy *et al.* 1999; Gould *et al.* 2007b; Hines *et al.* 2010; Gould *et al.* 2011).

Here we investigate the repeatability of two methods for assessing hazard in Australian bushfire fuel, in Sydney Coastal Dry Sclerophyll Forest (Keith 2004), one of the most fire-prone vegetation types on Australia's eastern seaboard.

The Overall Fuel Hazard Guide (McCarthy *et al.* 1999) was developed by the Department of Sustainability and Environment (DSE) in the state of Victoria. The aim of this DSE guide is to predict the probability of first attack success in suppressing a wildland fire given specified weather conditions and resources (Wilson 1992; McCarthy *et al.* 1999). Fine fuel condition is assessed in three layers – surface (litter), elevated (shrub) and bark (flammable bark on tree trunks) – and hazard ratings for these layers combined into an overall hazard rating for a site. Theoretical underpinnings for the Victorian fuel hazard assessment system are outlined by Wilson (1992), while McCarthy and Tolhurst (1998) and Plucinski *et al.* (2007) provide empirical support for links to first attack success. Derivative fuel hazard assessment guides tailored to geographic regions outside Victoria have been developed for the state of South Australia (South Australian Department for Environment and Heritage 2008), and for the Sydney region (McCarthy 2002). The Sydney guide is virtually identical to the DSE guide (McCarthy *et al.* 1999); we used the latter in our study because it is the version most widely used and is the original source of the hazard assessment protocols and ratings.

The second fuel hazard assessment system was developed as part of Project Vesta, a series of fire behaviour experiments in dry eucalypt forest in Western Australia (Gould *et al.* 2007a). This system, which was informed by the Victorian work but developed separately, was designed to provide quantitative measures of fuel hazard, with a view to empirically assessing the relationship between these composite fuel parameters and fire behaviour measures. The Vesta guide (Gould *et al.* 2007b) assesses hazard in the same three fuel layers as the DSE system, with the addition of a near-surface layer of grasses, low shrubs, creepers, collapsed understorey and suspended litter. Vesta hazard scores are used to predict rate of spread and other parameters in the empirical fire behaviour models developed from the Vesta experiments. Fuel inputs to the Vesta models do *not* include fuel load (Gould *et al.* 2007a). Evaluation of the Vesta hazard score assessment methods is required in a wide range of environments (e.g. eastern Australian forests), to assess the general validity of the Vesta fire behaviour models.

Both the DSE and Vesta hazard assessment schemes rely on visual estimation of aspects of vegetation structure such as cover, height and the proportion of dead material in different fuel layers. While visual estimates are quicker than direct sampling methods that involve counts or measurements, they may be less accurate (Zhou *et al.* 1998). The subjectivity involved when visually estimating parameters such as cover may lead to variability between assessors (Smith 1944; Sykes *et al.* 1983; Klimes 2003). For example, in Australia Gorrod and Keith (2009) found considerable observer variation in field assessments of vegetation condition, which entailed estimating cover, while van Hees and Mead (2000) reported greater observer than natural variation in assessments of species cover in Alaskan forests. In terms of fuel assessment, in the United States Sikkink and Keane (2008) have documented considerable differences between assessors

in fuel load estimates generated using local visual assessment methods. In the United Kingdom, Davies *et al.* (2008) found significant differences between observers on three of five fuel parameters measured in a heathland fuelbed, although these differences were small relative to variation between samples and fuel types.

Although not designed for this purpose, fuel hazard ratings are now widely used by fire managers in Australia to estimate fuel load, and then fire behaviour using the McArthur models (McArthur 1962; McArthur 1967; Noble *et al.* 1980). Direct measurement of fuel load through cutting, drying and weighing of samples is time-consuming, making the option of estimation from hazard scores attractive. Both fuel hazard assessment guides considered in this study provide figures for converting hazard ratings to fuel load in tonnes per hectare (t/ha). In both cases, the basis of these conversions is unclear.

In this study we ask:

- Do assessment teams differ in their ratings of fuel hazard and related variables such as cover and height?
- How do two fuel hazard assessment methods (McCarthy *et al.* 1999; Gould *et al.* 2007b) compare in terms of hazard rating for each fuel layer?
- How do differences between assessment teams and methods influence estimates used by fire managers, specifically estimates of fuel load ?

## **Methods**

### *Study sites*

Two sites were chosen to represent the range of variation in the most widespread of the dry sclerophyll forest types that dominate the natural vegetation around Sydney, NSW,



Australia. Both were located in the Royal National Park (RNP) south-east of the city centre (Fig. 1), and were on low-fertility soils derived from sandstone (Keith 2004). Tree species *Angophora costata* and *Eucalyptus gummifera* occurred on each site, along with an understorey of primarily sclerophyllous shrubs. Climate in the RNP is warm temperate, with an average annual rainfall of approximately 1,000 mm spread throughout the year (Bureau of Meteorology 2010).

The first site was located on a ridgetop plateau (34.055°S, 151.047°E) in woodland with tree heights of 12-15 m and a tree canopy cover of around 20%. This ridgetop site had burnt 7.8 years previously in an intense wildfire (Jacobson 2010). Site two was on gently sloping ground bordering a creek (34.045°S, 151.068°E). Here, trees were taller (20-25 m) with a canopy cover of around 40%. This creek site had last burnt 5.1 years previously, when it had been subject to a planned fuel reduction burn (NSW Office of Environment and Heritage, unpubl. data).

### *Assessors and assessment*

All fuel assessments were carried out on a single day in October 2009. Ten assessors, divided into five teams of two, recorded fuel hazard estimates and related data on each site. Most assessors were land managers who had done fuel assessments in the past, and all were familiar with fire and its effects on vegetation. The extent of training in the use of fuel hazard assessment methods varied across the group: some had attended formal training workshops, others had learned 'on the job'. All had recently attended a session designed to alert them to likely sources of observer bias in the hazard assessment process. Overall, we considered the group typical of NSW land managers conducting fuel hazard assessments as part of their day to day work.

In each site, each team assessed the vegetation in five fixed circular plots which had been marked to ensure consistency. Within each site, plots were at least 30 m apart. Surface, near-surface and elevated fuel characteristics were assessed within a 5 m radius of the centre of each plot, while a 10 m radius was used for assessing bark characteristics. These methods generally reflect sampling guidelines in the Vesta guide (Gould *et al.* 2007b).

Assessors rated the vegetation by assigning a hazard rating (Low, Moderate, High, Very High or Extreme) to each of the fuel layers using both the DSE (McCarthy *et al.* 1999) and Vesta (Gould *et al.* 2007b) methods; each of these manuals provides guidance, using text and photos, as to the attributes which characterise each hazard level. Data on underpinning attributes such as percent cover and height were also collected for each fuel layer (Table 1). Litter depth was measured to the nearest mm using a fuel gauge of the type described in the DSE Guide; in each plot, teams took five random litter depth measurements. Foliage projective cover was estimated visually. ‘Typical’ height of the near-surface and elevated fuel layers was measured with a semi-rigid tape measure. For all variables, the two assessors in each team worked together to produce a single set of data for the team.

For each team in each site, values recorded in plots were averaged to give values at a site level. To determine ‘mean’ site-level hazard ratings for each team, plot-level hazard ratings were allocated a numeric fuel hazard score. DSE hazard ratings were converted to integers of 1 (Low) to 5 (Extreme) in line with current practice (McCarthy and Tolhurst 1998; Plucinski *et al.* 2007; Tolhurst *et al.* 2007). Vesta hazard ratings were converted to numeric equivalents given in Gould *et al.* (2007b). Plot-level scores were then averaged, and the average converted back to the nearest hazard level.

Additional parameters were derived from the field measurements. In the DSE system the near-surface fuel layer is not considered separately, but acts as a modifier of surface fuel hazard ratings. The *DSE adjusted surface fuel hazard rating* was calculated by increasing the DSE surface hazard rating by one level where near-surface cover was  $\geq 40\%$  (McCarthy *et al.* 1999). This adjusted rating was used when calculating the *DSE overall fuel hazard rating* (McCarthy *et al.* 1999) and for estimates of fuel load.

### *Fuel load estimates*

Fuel load estimates were obtained by using the conversion tables in the respective assessment guides, and were averaged across plots to provide site level estimates. For estimating fuel load using the Vesta system, we used the mid-points of the ranges given in the guide, except for Extreme surface fuel hazard as it has no mid-point; we used a value of  $18 \text{ t ha}^{-1}$  ( $1.8 \text{ kg m}^{-2}$ ).

### *Analysis*

The effect of assessment team on fuel hazard scores and related variables was tested for significance, at each site individually, through fitting a linear mixed model to the plot-level data. To account for the fact that each plot was assessed several times, plot was entered as a random factor. Additionally, for each site, coefficients of variation (CVs; Zar 1999) were computed for each numeric variable: this provided a standardised measure of between-team variability.

Similarity in hazard ratings allocated using the two assessment methods was evaluated at site level. Comparison of DSE and Vesta hazard ratings was possible for the fuel layers common to both techniques: surface, elevated and bark. We noted the number of instances where ratings were identical, and where this was not the case, the direction and magnitude of the discrepancy.

For fuel load estimates, differences between assessment methods (DSE or Vesta) and assessment teams were again tested through fitting a linear mixed model to the plot-level data, with plot as a random factor. AIC (Akaike's Information Criterion, Burnham and Anderson 2002) values were used to determine the model of best fit out of five candidate models: Method \* Team, Method + Team, Method alone, Team alone, and a null model. The model with the lowest AIC value was considered the most likely to be accurate, with models with an AIC within two points of this most likely model also considered possible (Burnham and Anderson 2002).

## **Results**

### *Consistency between assessment teams*

There were significant differences between teams on most fuel variables. This applied to both the component hazard scores and to the underpinning attributes feeding in to them, though not to overall fuel hazard score (Table 1).

In the surface fuel layer, while mean litter depth measures at the ridgetop site did not differ significantly between teams, those at the creek site did differ ( $P < 0.001$ ), with a range from 13.3 to 39.6 mm (Table 1). Estimates of litter cover differed significantly between teams at each site, although the CVs for this variable were low. Differences between teams were significant for both DSE versions of surface hazard score, in each site. DSE ratings for the creek site spanned four levels, from Low to Very High for surface fuel hazard, and from Moderate to Extreme for surface hazard adjusted for near-surface fuel (Table 2). Vesta surface fuel hazard scores did not differ significantly between teams at the ridgetop site, though they did by the creek.

When near-surface fuel parameters were assessed, variability between teams was high, with CVs from 18.6 to 57.2. Differences between teams were significant for all near-surface variables, at each site (Table 1). In the creek site, for example, estimates of mean near-surface height generated by individual teams ranged from 19 to 66 cm. Uncertainty in estimating input variables manifested in lack of agreement between assessment teams when rating near-surface hazard, with Vesta near-surface ratings ranging from Moderate to Very High in the ridgetop site, and from Moderate to High in the creek site (Table 2).

Teams varied significantly in their estimates of cover of elevated fuel on the ridgetop but not by the creek, and in their estimates of height and percent dead in this layer, in both sites (Table 1). Cover of elevated fuel was significantly higher on the ridgetop (mean of 49%) than by the creek (12%). There were significant differences between teams on both elevated fuel hazard score variables (DSE and Vesta) in the creek site, and for Vesta elevated fuel hazard on the ridgetop. However site level hazard ratings for this fuel layer were relatively consistent, with all teams rating DSE elevated fuel hazard at the ridgetop site as High, and four teams agreeing on hazard rating when the Vesta guide was used. Elevated fuel hazard ratings at the creek site ranged over two hazard levels, for both Vesta and DSE (Table 2).

For bark fuel, teams' assessments of bole char varied widely, with CVs between 43.9 and 51.7 and a significant difference between teams for percent char on trees with sub-fibrous bark in the creek site (Table 1). There were significant differences between teams on both bark hazard score variables on the ridgetop, and on Vesta by the creek. At site level, both the DSE and Vesta bark hazard ratings ranged across three of the possible five categories for the ridgetop site, from Low to High, while ratings in the creek site covered two categories (Table 2).

The difference between teams on overall fuel hazard score did not reach significance in either site ( $0.05 < P < 0.10$ ). Overall fuel hazard ratings varied at site scale from High to Very High at the ridgetop site, and from Moderate to High at the creek site (Table 2).

### *Consistency between fuel assessment methods*

Surface hazard ratings derived from the two methods were often inconsistent, with Vesta ratings generally higher than their DSE equivalent (Table 2). In both sites, consensus between teams on surface hazard ratings was higher when the Vesta guide was used than when the process in the DSE guide was followed (Table 2). This difference was reflected in the CVs for the surface hazard scores, which were considerably lower for Vesta than DSE (Table 1).

Consistency in hazard scores generated by the DSE and Vesta methods was greater for the elevated fuel layer. Across the two sites Vesta and DSE ratings were identical on nine of a possible ten occasions, with a one-category difference in the remaining instance (Table 2). In contrast to the situation for surface fuel, CVs for elevated hazard scores were lower for DSE than Vesta (Table 1).

For bark hazard, ratings generated by the two methods were similar, although in the ridgetop site two teams rated bark hazard more highly on the Vesta scale than on its DSE equivalent, while in the creek site one team rated bark hazard lower on Vesta (Table 2). CVs for bark fuel hazard scores were lower for DSE than Vesta (Table 1).

### *Fuel load estimates*

Site-level estimates of fuel load in the ridgetop site ranged from 10.0 to 21.3 t ha<sup>-1</sup> (1.00 to 2.13 kg m<sup>-2</sup>) while those for the creek site spanned an even wider range, from 5.5 to

19.2 t ha<sup>-1</sup> (0.55 to 1.92 kg m<sup>-2</sup>). Mean fuel load estimates based on Vesta ratings and conversion factors were about 50% higher than those calculated using the DSE guide (Fig. 2). In each site, the best model was Team x Method: differences between teams were particularly strong in the creek site when the DSE assessments were used ( $P < 0.001$ ).

## Discussion

### *Assessment teams*

This study found considerable variability between assessors in ratings of fuel hazard and associated parameters, in each of the two sites surveyed. There were significant differences between assessment teams on all component hazard score variables, in one or both sites (Table 1). While overall fuel hazard scores did not differ significantly between teams (Table 1), overall fuel hazard ratings at each site spanned two levels (Table 2).

While much of the inter-team variation may be due to differing perceptions of the extent to which plot characteristics fitted hazard level descriptions, some may reflect differences in application of assessment methods. For surface fuel, for example, DSE hazard ratings in the creek site spanned four of a possible five categories (Table 2), reflecting considerable differences between teams in measurement of litter depth. Teams' approaches to dealing with outcropping sandstone rocks on this site may help explain this variability: some teams may have avoided rocks within the plots, while others did not. Similarly, the marked variability between teams on near-surface fuel parameters (Table 1) may reflect, at least in part, difficulties in distinguishing near-surface from elevated fuel. This problem may have been particularly acute in the creek

site where the understory included living and dead bracken fern (*Pteridium esculentum*) of varying heights, and Gynea Lily (*Doryanthes excelsa*), a large monocot species with leaves up to 2 m long.

Assessors may also have had problems aligning the vegetation with the descriptions in the guides. For example, when allocating a Vesta near-surface hazard rating, elements used in category descriptions (cover, suspended litter, proportion of dead material) often do not consistently fall into the available categories. The near-surface layer in Sydney's forests often supports considerable dead material which could imply a rating of Extreme, although cover may be quite sparse, indicating a much lower rating.

Despite disparities between teams on component hazard ratings, DSE overall fuel hazard ratings and scores were relatively consistent (Tables 1 and 2). It may be that some uncertainties involved in carrying out an assessment, e.g. difficulties in identifying boundaries between fuel layers, are integrated in this summary parameter. A relative overestimate for one fuel layer may be counterbalanced by an underestimate for another. Overall scores may be less sensitive to minor differences in vegetation structure than component hazard ratings.

### *Fuel assessment methods*

The two fuel assessment methods used in this study differs in the way rating categories for the various fuel strata are described. For some fuel elements, these dissimilarities resulted in quite large differences in ratings allocated by our assessment teams.

For surface fuel, the DSE method involves direct measurement of litter depth, while the Vesta guide uses qualitative descriptors complemented by litter depth



indicators which are lower than their equivalents in the DSE guide. The DSE and Vesta ratings for surface fuel allocated by our teams were generally not the same, with surface fuel hazard rated higher when the Vesta guide was used (Table 2).

In contrast to surface fuel, assessors generally though not universally assigned the same rating to elevated and bark fuel, whichever method was used (Table 2). Basic descriptions for these fuel layers are similar in both methods used in our study, although the DSE guide provides more detail. Similarity in ratings across guides for elevated and bark fuel may in part reflect assessment teams' sequential use of the two guides; if separate sets of assessors had used each guide independently, greater differences might have emerged.

### *Fuel load estimates*

In eastern Australia, precise and accurate estimation of fuel load in particular sites is vital for fire management, informing plans for hazard reduction activities. Although fuel hazard assessment schemes were not designed with fuel load estimation in mind, the practice of estimating fuel load from hazard ratings, rather than measuring it directly, is increasingly being adopted by land managers.

Our study indicates that estimates of fuel load obtained through the use of conversion factors in hazard assessment guides are far from precise, with a two-fold difference between the lowest and highest estimates in the ridgetop site, and a more than three-fold difference in the creek site (Fig. 2). The diverse fuel load estimates derived from the assessment results of the different teams could potentially elicit different management responses. For example in urban fringe areas in NSW the threshold for the application of planned fire to reduce fuel hazard is generally considered to sit at around

10 to 12 t ha<sup>-1</sup> (1.0-1.2 kg m<sup>-2</sup>; Gill *et al.* 1987). Whether our sites would be deemed to have reached this threshold would vary considerably among assessment teams, and for some teams, with assessment method (DSE or Vesta).

Estimates based on the Vesta methods were generally higher than those based on the DSE guide (Fig. 2); this reflects both the higher hazard ratings given by some teams on the Vesta scale and differential scaling of the conversion factors in the two systems. Variability between teams was lower when the Vesta methods were used than when the DSE guide was employed (Fig. 2); the main factor here was the greater consistency in surface hazard rating allocated by teams when using the Vesta scoring system.

Can we discern whether the DSE or the Vesta estimates are likely to be more accurate? As direct measurement of fuel load was beyond the scope of this study, no definitive judgement can be made. However a fuel load accumulation model developed by Conroy (1993) for dry sclerophyll woodland around Sydney provides an indication of likely fuel load in our study sites. Conroy (1993) fitted a negative exponential curve to fuel load data derived by cutting, drying and weighing all ground-based plant material less than 6 mm in diameter in 23 sites of varied post-fire age. Model fit to the data was high (i.e.  $R^2 = 0.969$ ). For the post-fire ages of the sites in this study, values from Conroy's model are: 18.3 t ha<sup>-1</sup> (1.83 kg m<sup>-2</sup>) at 7.8 years post-fire (ridgetop site); 14.7 t ha<sup>-1</sup> (1.47 kg m<sup>-2</sup>) at 5.1 years post-fire (creek site). These modelled values suggest that the Vesta-derived fuel load estimates may be more accurate than those derived from the DSE conversion factors (Fig. 2).

Overall, it is clear that the practice of determining fuel loads from hazard scores cannot be relied upon in situations calling for precision and accuracy. We contend that the best way to arrive at an accurate figure for fuel load for a particular site is to

measure it directly through harvesting, drying and weighing fuel samples. Although time-consuming, results should be considerably more reliable than estimates derived from hazard scores, provided a sufficient number of replicate random fuel load samples is taken; Conroy (1987) recommends 15 samples per site. For rough estimation, however, current practice may have its place, so long as its limits are understood and acknowledged.

Land managers, however, rarely have the time to measure fuel load directly; sampling of deep, complex, three-dimensional fuel arrays such as those found in shrubby dry sclerophyll forests is particularly awkward. A compromise position might be to harvest and directly measure litter and near-surface fuel only, and add a estimate for shrubs based on cover or an adaptation of visual obstruction methods (Davies *et al.* 2008). Photo series of the type employed in the Americas to assist managers to estimate fuel load (e.g. Ottmar *et al.* 2001; Wright *et al.* 2006) have not yet been widely developed in Australia, though examples exist (Johnson 2002; Bush Fire and Environmental Protection Branch 2010) which require further evaluation.

### *Management implications*

This study found considerable differences between assessors in estimates of fuel hazard and related input variables. Assessors agreed more closely in their assessment of overall fuel hazard than in their assessments of parameters for individual fuel layers. For individual layers, this study found that hazard ratings assigned to the same site by different assessors can cover up to four of the available five rating options. When translated into derived estimates of fuel load, differences between assessors were considerable.

It is possible that intensive training and on-going support of assessors might ameliorate some of these difficulties. Effects of training were not evaluated in this study, although all assessors had attended sessions designed to enhance consistency in understanding and application of assessment methods. Use of mean or median values from several assessors is another potential strategy for increasing the precision of hazard ratings and related estimates. Sykes *et al.* (1983), in a study of plant cover assessment, found that combining independent estimates from multiple assessors reduced confidence intervals considerably from those returned by individuals. Smith (1944) found that estimate ranges became smaller when assessors discussed their scores in training plots.

Even with training, teamwork and conscientious application of guidelines, inconsistencies between assessors may be unavoidable. This appears to be the case when plant cover is assessed: Smith (1944) found estimates still varied widely between assessors, even though training reduced variation to some extent; Kercher *et al.* (2003) found significant differences between teams of well-trained scientists; Klimes (2003) found that differences between assessors still emerged, despite careful selection and training. Added to inevitable human error is the inherent nature of hazard assessment systems. These systems create summary ratings which take into account a range of fuel characteristics; this is their strength, but also their weakness. Where varying levels of several characteristics (e.g. cover, height, proportion dead) are used to define points on a rating scale, a need to choose between potentially applicable rating categories will inevitably arise.

The need for consistency in fuel hazard assessments may vary depending on their intent. If the aim is to make comparisons, for example across vegetation types or between different times-since-fire, consistency is vital. If the aim is to gain an overview

of fuel status in individual sites, consistency may be less important. However if assessments are tied to fuel or fire management predictions and decisions with legal or safety ramifications, consistency, and accuracy, are of the essence.

The systematic differences in hazard scores allocated using the two fuel assessment methods, particularly, but not only, with respect to surface fuel, also have management implications. Since our study was undertaken, a new fuel assessment manual, with modified guidelines to combine the DSE and Vesta systems, has been produced (Hines *et al.* 2010). The two systems, as used in this study, were developed separately with a view to predicting somewhat different aspects of fire behaviour and control: probability of first attack success in the case of the DSE system, and fire behaviour parameters including rate of spread and flame height for the Vesta system. Both systems are underpinned by empirical relationships between fuel hazard and their respective fire behaviour/suppression parameters (McCarthy and Tolhurst 1998; Gould *et al.* 2007a; Plucinski *et al.* 2007). Compromises made to produce a combined method may affect the nature and strength of the empirical relationships underpinning the original guides. For those wishing to apply or test the Vesta fire behaviour models, unless and until comparative research confirms that ratings allocated using Hines *et al.* (2010) match those allocated using the original Vesta guide (Gould *et al.* 2007b), continued use of the latter is recommended.

## **Conclusion**

The concept of fuel hazard provides a useful summary description of fuel condition which can be applied across many different types of vegetation. However this study strongly suggests that when hazard assessment systems are applied by fire managers in

the field, outcomes may vary widely. Issues to do with compatibility between fuel assessment methods, and their reliability in the hands of different assessors, are unlikely to be limited to Australia. Our study highlights the importance of considering these factors in the development and application of fuel assessment methods, wherever that occurs.

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**Table 1. Differences between teams in their assessment of fuel attributes**

Mean (standard error), coefficient of variation (CV) and significance of differences between teams (linear mixed model outcomes) for fuel attributes in two dry sclerophyll forest sites near Sydney, NSW. FHS, fuel hazard score. NA, not applicable, as site did not contain stringybark trees. P values: \*, < 0.05; \*\*, < 0.01; \*\*\*, < 0.001. NS, not significant.

Variable	Ridgetop Site			Creek Site		
	Mean (SE)	CV	P value	Mean (SE)	CV	P value
<b>Surface fuel</b>						
Litter depth (mm)	18.4 (1.3)	15.6	NS	26.5 (4.4)	37.4	***
Litter cover (%)	98 (1)	2.1	*	88 (3)	7.8	**
DSE surface FHS	1.9 (0.2)	21.6	**	2.6 (0.4)	36.8	**
DSE adjusted surface FHS	2.7 (0.2)	18.0	**	2.9 (0.5)	42.0	***
Vesta surface FHS	3.0 (0.1)	7.0	NS	3.2 (0.1)	6.8	**
<b>Near-surface fuel</b>						
Cover (%)	48 (7)	33.8	***	28 (7)	54.0	***
Height (cm)	34 (7)	43.3	***	35 (9)	57.2	***
Percent dead	42 (7)	38.2	***	56 (6)	24.1	*
Vesta near-surface FHS	2.8 (0.2)	18.6	**	2.6 (0.3)	23.0	***
<b>Elevated fuel</b>						
Cover (%)	49 (7)	30.7	***	12 (2)	41.2	NS
Height (cm)	181 (10)	12.7	***	128 (19)	33.2	***
Percent dead	3 (2)	136.9	***	13 (6)	98.6	***
DSE elevated FHS	3.4 (0.0)	2.7	NS	1.7 (0.2)	32.2	***
Vesta elevated FHS	3.0 (0.1)	10.0	**	1.5 (0.2)	33.0	***
<b>Bark fuel</b>						
Stringybark bole char (%)	57 (12)	47.6	NS	NA	NA	NA
Subfibrous bark bole char (%)	42 (10)	51.7	NS	46 (9)	43.9	***
DSE bark FHS	2.2 (0.4)	36.7	***	2.5 (0.1)	13.5	NS
Vesta bark FHS	1.4 (0.4)	59.8	***	1.4 (0.2)	24.8	*
<b>Overall fuel hazard</b>						
DSE Overall FHS	3.2 (0.2)	12.7	NS	2.4 (0.2)	21.1	NS

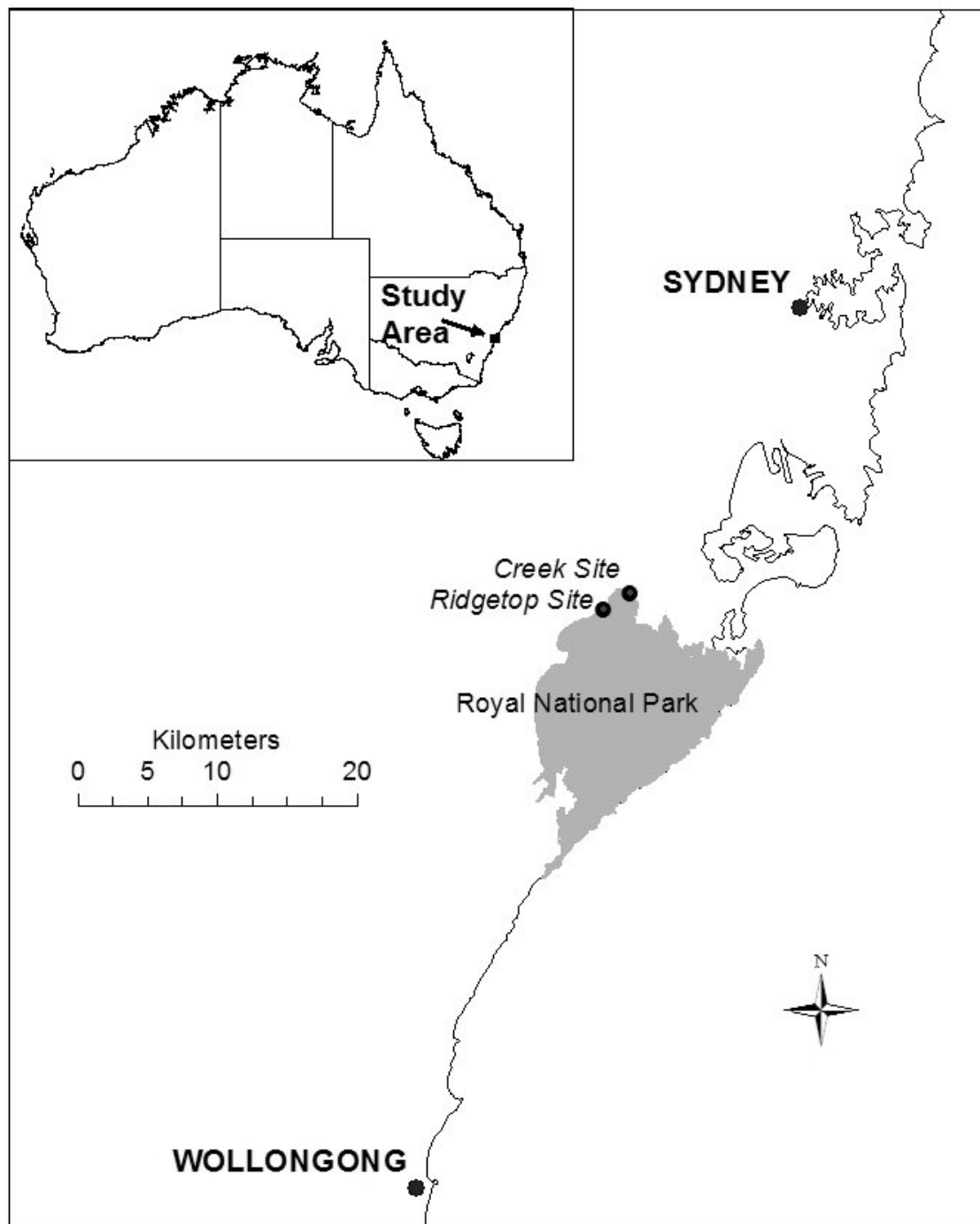
**Table 2. Allocation of hazard ratings by assessment teams**

Number of assessment teams (n = 5) allocating various hazard ratings in two sites, using two assessment methods, DSE (McCarthy *et al.* 1999) and Vesta (Gould *et al.* 2007b). Hazard ratings for each team represent site averages, calculated from ratings in five plots per site (see Methods). NA, not applicable, as this assessment system does not generate a rating for this component.

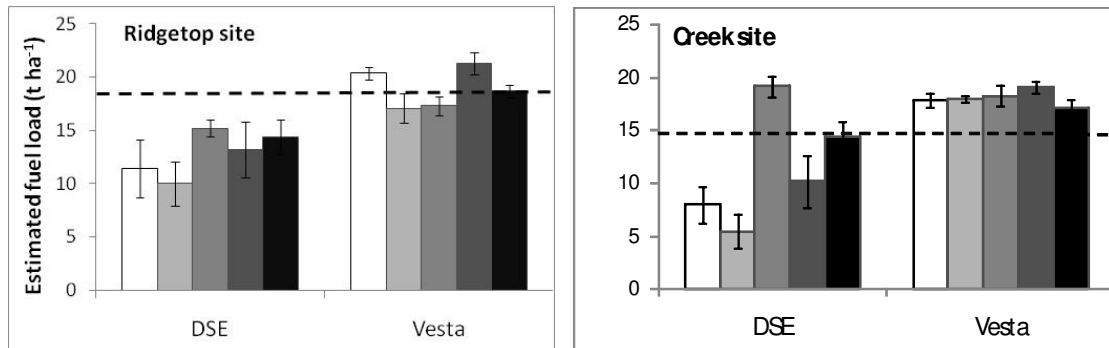
Hazard rating	Surface fuel			Near-surface fuel		Elevated fuel		Bark fuel		Overall fuel hazard	
	DSE	DSE <sup>A</sup>	Vesta	DSE	Vesta	DSE	Vesta	DSE	Vesta	DSE	Vesta
<b>Ridgetop Site</b>											
Low	1	0	0	NA	0	0	0	1	1	0	NA
Moderate	4	3	0	NA	2	0	0	3	1	0	NA
High	0	2	5	NA	1	5	4	1	3	3	NA
Very High	0	0	0	NA	2	0	1	0	0	2	NA
Extreme	0	0	0	NA	0	0	0	0	0	0	NA
<b>Creek Site</b>											
Low	1	0	0	NA	0	2	2	0	0	0	NA
Moderate	1	2	0	NA	2	3	3	3	4	3	NA
High	2	1	4	NA	3	0	0	2	1	2	NA
Very High	1	1	1	NA	0	0	0	0	0	0	NA
Extreme	0	1	0	NA	0	0	0	0	0	0	NA

<sup>A</sup>DSE surface hazard rating adjusted for near-surface fuel.





**Fig 1.** Map showing location of study area south of Sydney, Australia, with location of study sites in Royal National Park (shaded grey).



**Fig. 2.** Mean ( $\pm$  standard error across plots) estimated fuel load (all components including bark) in two dry sclerophyll forest sites near Sydney as assessed by five teams (shaded columns). Estimates obtained using methods for assessing fuel hazard and converting it to fuel load in the DSE (McCarthy *et al.* 1999) and Vesta (Gould *et al.* 2007b) fuel assessment guides. Dotted lines: predicted fuel loads based on fuel accumulation model by Conroy (1993), shown for comparison.  $1 \text{ t ha}^{-1} = 0.1 \text{ kg m}^{-2}$ .

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