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FIRE NOTE

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SIMPLE INDICES FOR ASSESSING FUEL MOISTURE CONTENT AND FIRE DANGER RATING

CONTEXT

The researchers undertook a detailed investigation of risk management tools, such as fire danger indices, used in southeastern Australia. Based on this investigation the researchers examined the structure of existing indices and compared their output with that of extremely simple and intuitive ones.

BACKGROUND

A number of fire danger rating systems, which integrate selected quantifiable factors contributing to fire danger, have been developed to provide numerical indices relating to fire protection needs. It is important to note that fire danger indices have no real physical manifestation – they are just indices. Calculation of fire danger indices generally rely on information relating to the moisture content of fuels, fire weather and drought effects. In southeastern Australia, fire danger is assessed with reference to the McArthur Mark 5 Forest Fire Danger Index (*FFDI*), or the (modified) Mark 4 Grassland Fire Danger Index (*GFDI*). These indices are typically implemented with circular slide rules or via their equivalent mathematical formulations. McArthur (1967) also provided tables for estimating the moisture content *m* of eucalypt litter as a function of temperature and relative humidity. McArthur's tabular relationship was translated into a mathematical equation by Viney (1991). Matthews (2009) subsequently showed that the Mark 5 Forest Fire Danger Index could be equivalently formulated in terms of the fuel moisture content of eucalypt litter, as modelled by Viney.

The mathematical expressions used to estimate fuel moisture content and fire danger rating are, with few exceptions, very complex. Typically they involve complicated functions, interaction terms, and coefficients (usually written to three or four decimal places) that have been derived via regression techniques. As such, these tools offer very little intuition about the concepts they are supposed to encapsulate, and they can be difficult to calculate in a field setting.

SUMMARY

The flammability of wildland vegetation is strongly dependent upon the moisture content of fine dead fuels. Consequently, the ability to assess the moisture content of these fuels to within a reasonable degree of accuracy is an important part of wildland fire management. Similarly, fire danger rating systems are also essential tools for fire management. Indeed, many critical decisions are made by fire managers on the basis of the dryness of the fuel or fire danger rating. In fact, estimates of fine fuel moisture content can be combined with information on wind speed, vegetation type and drought effects to provide a measure of fire potential or fire danger rating. This note describes a simple and intuitive linear index, which has proven to be remarkably effective in assessing the moisture content of fine dead fuels such as eucalypt litter. The note also describes two ways that the simple index can be used to assess fire danger rating.

ABOUT THIS FIRE NOTE

This is a summary of the research conducted as part of Project B6.3: Managing the risk of fire in the high-country (HighFire Risk).

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BUSHFIRE CRC RESEARCH

The researchers considered simple, linear models of fuel moisture content such as those considered by Pook and Gill (1993). In particular we considered the Fuel Moisture Index, defined as:

$$FMI = 10 - 0.25 \times (T - H)$$

where T and H are temperature (°C) and relative humidity (%), respectively. *FMI* is a dimensionless index and should not be considered as giving a direct estimate of fuel moisture content, as such. However, the question of principle interest was how *FMI* compared to the output of more complicated fuel moisture models. This question was answered in Sharples et al. (2009a) where it was shown that *FMI* compared remarkably well to the output of existing models, especially the model for the moisture content of eucalypt litter mentioned above.

Given the success of *FMI* in describing the moisture content of fine, dead fuels, the researchers then combined it with measures of wind speed and drought effects into a simple fire danger index, defined as

$$F_D = D \times U \div FMI$$

where D is the drought factor and U is the wind speed, and where wind speed is

END USER STATEMENT

"All fire fighters are trained to predict, with some appropriate level of skill, the behaviour of fire, using weather, terrain and fuel. They are provided with the tools to allow them to calculate the key locally used indices, whether those tools are look-up tables, circular slide rules or computer programs.

"This research demonstrates how it is possible to provide better, more intuitive tools for this task. The work makes it possible to observe changes in conditions in the field and then understand how those changes may alter fire danger and fire behaviour. The expected improvement in ability, in the demanding environment of the fire ground, should provide real dividends in terms of fire fighter and community safety.

"The simplicity of the work will greatly improve understanding of other phenomena studied by this research project (especially foehn winds, subsidence inversions, mountain wind waves and low level jets) and other projects within the CRC, notably the work on abrupt surface drying events."

– Andrew Stark MoM, University of Wollongong
Chief Officer, ACT Rural Fire Service, ACT Emergency Services Agency

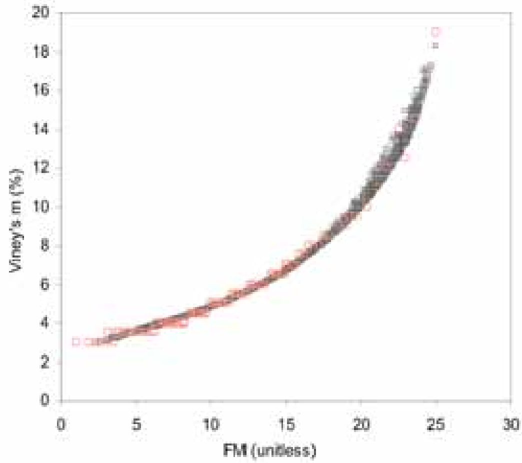

Figure 1: Black circles show predictions arising from the model of Viney (1991) plotted against *FMI* values. Red circles show fuel moisture values from McArthur (1967) plotted against *FMI* values.

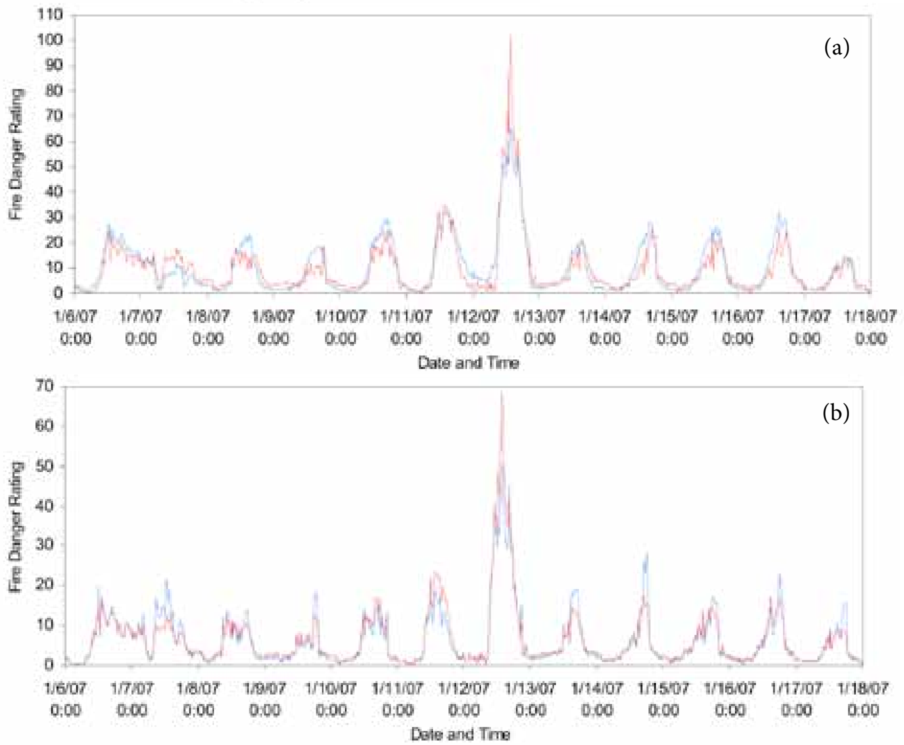

Figure 2: (a) Time series of *FFDI* (blue) and F_D (red), (b) Time series of *GFDI* (blue) and F_D (red).

assumed to have a minimum value of 1 km h^{-1}. Sharples et al. (2009b) showed that, under the assumption of maximum fuel availability, F_D compared reasonably well with existing fire danger indices, such as *FFDI* and *GFDI*. Sharples et al. (2009c) then presented similar results for variable fuel availability.

The researchers also considered the structure of existing fire danger rating systems in terms of the *FMI*. These considerations resulted in the discovery that *FMI* could be used to easily calculate *FFDI* and *GFDI* with near exactitude.

RESEARCH OUTCOMES

Fig. 1 shows the relationship between *FMI* and the fuel moisture content of eucalypt litter *m* as modelled by Viney (1991) and McArthur (1967). The relationship is clearly a very tight one, with a nonlinear correlation of 0.9989. The nature of the relationship apparent in Fig. 1 implies that *FMI* provides an equivalent measure of the fuel moisture content of eucalypt litter.

Fig. 2a shows time series plots of F_D and *FFDI*, while Fig. 2b shows F_D and *GFDI*. Curing values used in the calculation of *GFDI* were converted to equivalent drought factor values to calculate the corresponding F_D values. Fig. 3 illustrates how curing was converted to drought factor, or vice versa – the function was adapted from Fig. 4.9 of Cheney and Sullivan (1997). Fire weather data recorded by the Bureau of Meteorology at Canberra Airport between November 2006 and March 2007 were used to facilitate the comparison. The F_D time series in Fig. 2a and 2b have been multiplied by a constant calibration factor so that their mean values match the mean values of *FFDI* and *GFDI*, respectively.

Analytical consideration of the structure of *FFDI* and *GFDI* revealed that *FMI* could be used to calculate the McArthur indices with near exactitude. In particular, Fig. 4 illustrates the structure of *FFDI* and *GFDI* in terms of *FMI* and wind speed *U*. In both cases it is apparent that the McArthur index can be conceptualised in terms of straight lines in the (*FMI*, *U*)-plane.

Overall, the main conclusion to be drawn from the research is that the existing models for calculating *FFDI* and *GFDI* are needlessly complicated. In fact the research indicates that the whole concept of fire danger rating could be simplified considerably and presented in a much more intuitive way.

BLACK SATURDAY AND THE FMI

The Fuel Moisture Index (*FMI*) was designed to be a positive index. *FMI* will only take negative values if the difference between temperature and relative humidity exceeds 40. While it is possible that this difference could exceed 40, the researchers have never encountered such an instance in forest fire weather observations. In fact, the smallest value of *FMI* ever encountered by the researchers was on Black Saturday (7 February 2009), when it reached a minimum of 0.5 at Mangalore in central Victoria.

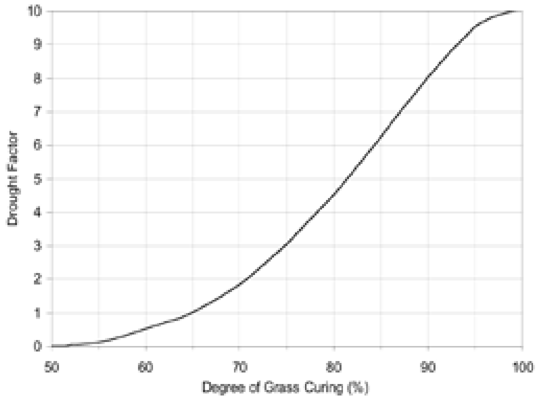

Figure 3: Function used to convert degree of grass curing to an equivalent drought factor.

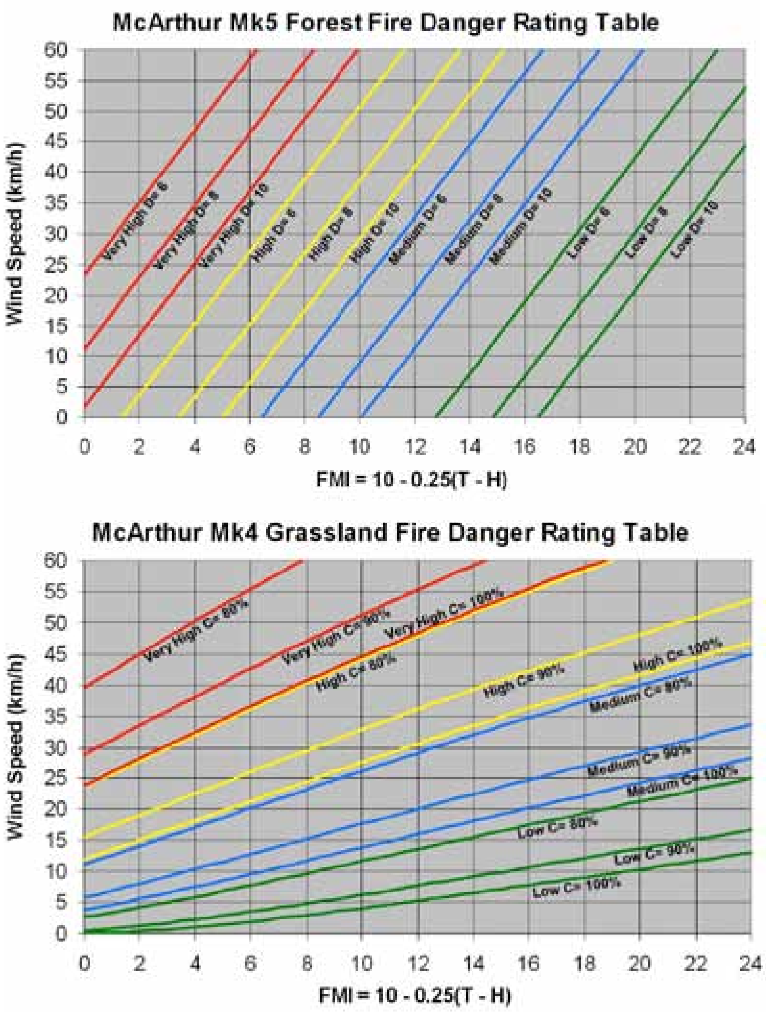

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Figure 4: Forest and grassland fire danger rating characterised in terms of *FMI* and *U* for various drought factors and degrees of grass curing.

HOW IS THE RESEARCH BEING USED or HOW COULD IT BE USED?

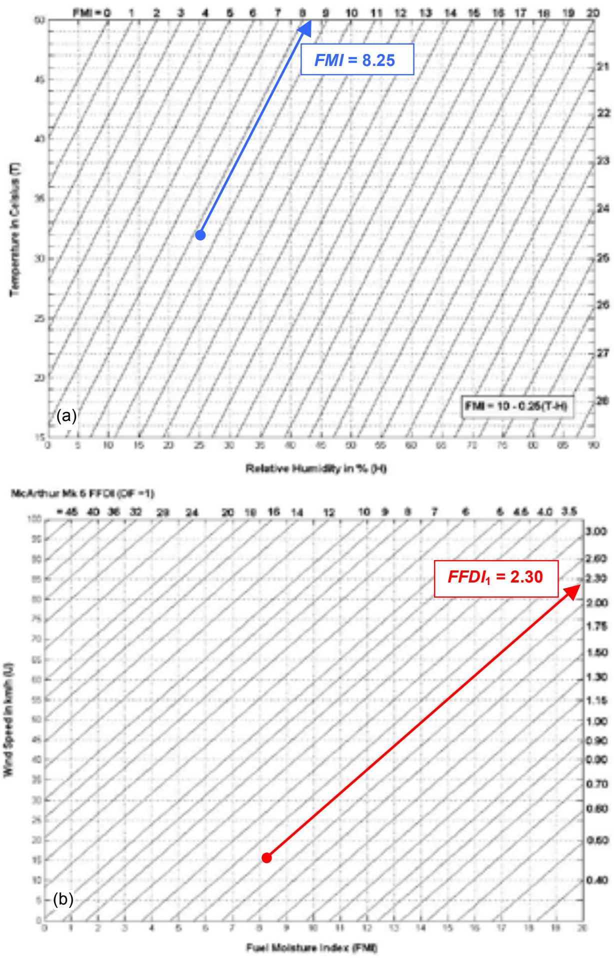
The simple indices developed by the HighFire Risk project research team are currently being used by other researchers in the Bushfire CRC and elsewhere in Australia. The research team have also been contacted by international researchers, whom are interested in the simple and intuitive nature of the indices.

Since the Victorian Black Saturday fires of February 2009 there has been considerable interest in the development of new fire danger rating systems, especially for cases when *FFDI* is over 50. In these conditions, the ratio of F_D to *FFDI* will be high if strong winds are the principle driver, and may be extremely high if *FMI* approaches zero. Both of these circumstances have been found to be common contributors to dangerous fires. Users of any fire danger rating system are advised that under these conditions there has been little, if any, experimental validation.

The extremely simple formulation of the *FMI* means that it can be quickly and easily implemented in the field, either by employing mental arithmetic or using a simple graphical tool. Using the *FMI* in such a way would provide personnel on a fire-ground with a way to quickly assess flammability potential. This would be of use when undertaking prescribed burning, where fire behaviour within certain thresholds is desired. *FMI* could be used more generally in wildfire control and suppression, especially to provide information on when fuel moisture becomes critically low. For example, a drop in the *FMI* below about 5 could herald an increase in fire intensity and the potential for spot fires to form away from the main fire line.

The intuitive nature of the indices *FMI* and F_D means that when considering processes that can result in extreme dewpoint depression events, for example, it is easier to appreciate and understand their impacts. These types of processes are the subject of other research in the HighFire Risk Project, and can have profound influences on major wildfires that may not be immediately evident from a circular slide-rule or a complicated mathematical formula. The fire danger index F_D has an additional benefit in that it can be used to compare estimated and measured fuel moisture content in the field, thereby providing a field estimate of drought factor – something which has hitherto not been available.

The research could also be used to construct simple graphical tools for calculating *FFDI* and *GFDI*. For example, Fig. 5 shows two panels that can be used to easily calculate *FMI* and *FFDI*. These panels could be incorporated into operations handbooks carried by fire-ground personnel, thus allowing quick implementation of the method. The breakout box provides an example of how this is achieved. Similar graphical tools also exist for *GFDI*.



The novel conceptualisation of fire danger rating implied by the research findings could be used in training materials to simplify the way the subject is taught and to provide fire-ground personnel with a more intuitive notion of fire danger rating. Remarkably, this useful simplification can be made without significantly affecting the derived information and its implications.

FUTURE DIRECTIONS

Although *FMI* and F_D have been shown to accord well with the predictions of several fuel moisture content and fire danger rating models, caution should be exercised when applying the method in the field. The methods employed in the research were largely theoretical and need to be supplemented by an empirical analysis involving actual fuel moisture data for a number of different fuel types and fuel size classes. The researchers are eager to pursue this in further collaborative work with interested end-users.

However, regardless of what empirical data might reveal, the facts remain that *FMI* will always provide a measure of fuel moisture content practically equivalent to that predicted by the McArthur/Viney model, and F_D will always provide a measure of fire danger roughly equivalent to that predicted by *FFDI* and *GFDI*.

Figure 5: (a) Graph for determining FMI from relative humidity in % and temperature in °C, (b) Graph for determining FFDI from FMI and U (km/h).

USING FMI TO CALCULATE FFDI: AN EXAMPLE

Suppose you have the following fire weather information:

- Temperature is 32°C
- Relative Humidity is 25%
- Wind Speed is 16 km h^{-1}
- Drought Factor is 7.

FFDI can be calculated using the panels shown in Fig. 5 as follows:

1. Use panel 1 (Fig. 5a) to calculate the *FMI* (or just use mental arithmetic if you can). Find the point corresponding to (32°C, 25%) and follow the line up to read off the *FMI* value, as indicated by the blue dot and arrow.

   $$FMI = 8.25$$

2. Use panel 2 (Fig. 5b) to calculate the *FFDI* corresponding to a drought factor D = 1. Find the point corresponding to *FMI* = 8.25 and U = 16 km h^{-1} and follow the line up to read off $FFDI_1$, as indicated by the red dot and arrow.

   $$FFDI_1 = 2.30$$

3. Multiply the number obtained in step 2 by the drought factor to obtain the McArthur Mark 5 Forest Fire Danger Index.

   $$FFDI = 2.3 \times 7 = 16.1$$

This value compares favourably with the value of 15.2 obtained using a circular slide-rule and with the value of 15.6 obtained using the formula derived by Noble et al. (1980).

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