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Evaluating models to predict daily fine fuel moisture content in eucalypt forest

A. Slijepcevic [a], W.R. Anderson [b], S. Matthews [c,d,*], D.H. Anderson [e]

[a] Fire and Emergency Management, Country Fire Authority, 8 Lakeside Drive, Burwood East, VIC 3151, Australia
[b] School of Physical, Environmental and Mathematical Sciences, UNSW, Canberra, ACT 2600, Australia
[c] CSIRO Ecosystem Sciences and CSIRO Digital Productivity and Services Flagship, Eveleigh, NSW 2015, Australia
[d] Faculty of Agriculture and Environment, University of Sydney, Eveleigh, Sydney, Australia
[e] 45 Tantawangalo Mountain Rd., Candelo, NSW 2500, Australia

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ABSTRACT

Two models were evaluated for predicting dead fine fuel moisture content on sites in dry and damp eucalypt forests in Tasmania on a daily basis. Models were based on modifications of the Canadian Fine Fuel Moisture Code, and the process-based model of (Matthews, 2006) with and without modifications to better fit the data. All three models predicted well on the dry site, with little to choose between the two modified models. The process-based model performed better on the damp site. Site differences in moisture content could be explained by differences in vegetation and canopy cover. The ability of the models to predict conditions suitable for prescribed burning was tested. The modified Canadian model resulted in more correct predictions of optimal burning conditions than the process-based models. The modified process-based model gave the most predictions that would falsely indicate conditions were suitable for prescribed burning.

1. Introduction

The moisture content of dead fine fuels has an important role in fire behaviour through controlling fuel flammability, rate of spread, fuel availability, and fire intensity. Predicting fuel moisture content is very important to fire and land managers, as it enables better prediction of current and potential fire behaviour which is required for bushfire response readiness and for conducting planned burning.

Fuel moisture content is the percentage by weight of free and absorbed water in the fuel, and is normally expressed as the percentage of water per oven dry weight of fuel (Viney, 1991). In the absence of precipitation, dead fine fuels (i.e. plant material less than 6 millimetres in diameter) have moisture contents between 3% and 35% (Berry and Roderick, 2005). This upper limit is known as the fibre saturation point and is the moisture content reached at 100% relative humidity. When exposed to precipitation water will also be stored in the cell cavities and on the surfaces of the fuel. In this case fuel moisture may reach values as high as 300% (see, for example, the data range for karri profile litter in Matthews et al., 2007).

Under drying conditions dead fuels undergo desorption and release moisture to the surrounding environment through evaporation until the vapour pressure in the fuel reaches that of the surrounding air. Once this has occurred the fuel is considered to be at its equilibrium moisture content (EMC) (Merrill and Alexander, 1987). Similarly, when the fuel moisture content is below EMC the fuel adsorbs moisture from the air. The drying or wetting rate of a dead fuel particle can be summarised by its response time, which is the time required for it to lose or gain about two-thirds (63%) of the difference between its initial moisture content and its equilibrium moisture content (Merrill and Alexander, 1987). Rates of wetting and drying are determined by the chemical and physical characteristics of the fuel and by weather conditions (Viney, 1991; Matthews, 2013; Slijepcevic et al., 2013). Currently there is a good understanding of the processes that drive FMC but no model has been identified as suitable for resolving spatial variation due to topography or forest structure (Matthews, 2013).

The primary aim of this paper is to test and develop models for predicting dead fuel moisture content for operational fire management in Eastern Australian dry and damp eucalypt forests. Models for predicting dead fine fuel moisture content (FMC) in dry conditions were tested and calibrated in Slijepcevic et al. (2013). This

* Corresponding author at: CSIRO Ecosystem Sciences and CSIRO Digital Productivity and Services Flagship, Eveleigh, NSW 2015, Australia. Tel.: + 61 2 8627 1034; fax: +61 2 8627 1099.

E-mail addresses: a.slijepcevic@cfa.vic.gov.au (A. Slijepcevic), w.anderson@adfa.edu.au (W.R. Anderson), Stuart.Matthews@csiro.au (S. Matthews).

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paper considers models for predicting FMC in both dry conditions and after rain, and determines how well these models can predict conditions for prescribed burning. Two models were selected to represent the process-based (Matthews, 2006) and empirical (Van Wagner and Pickett, 1985) approaches to modelling FMC.

2. Methods

2.1. Data collection, site location and vegetation community description

Two sites on the lower foothills of Mt Wellington in Tasmania (42°53′28″S, 147°16′28″E), located within 750 m of each other, but one in damp and one in dry sclerophyll forest, were used in the study. Two flat areas on these sites were used to make the daily observations used in this analysis. The lower slopes of Mount Wellington are mostly dominated by *Eucalyptus obliqua* or *Eucalyptus tenuiramis*, or an association between these species. Although the underlying rock is predominantly Permian mudstone, dolerite talus and Triassic sandstone sites are also present (Johnson, 1994).

The damp site has a vegetation community consisting of *E. obliqua* open-forest /tall open-forest over narrow-leaved shrubs (type Eo/S from Johnson, 1994). This *E. obliqua* community occurs on two types of sites, the first on dry or exposed slopes at the upper (altitudinal) range of *E. obliqua* and the second on lower more sheltered or moist sites, such as the site used in this study. Sedges or bracken (*Pteridium eculentum*) commonly dominate the ground layer. This community represents a transition zone between dry and wet sclerophyll forest and can be described either as a shrubby *E. obliqua* forest (Duncan and Brown, 1985) or an *E. obliqua–Olearia lirata–Pultenaea juniperina* wet sclerophyll forest (OB010) (Kirkpatrick et al., 1988).

The dry site has a vegetation community consisting of *E. obliqua–E. tenuiramis* open-forest over shrubs-heath (type Eo-Et/S-H from Johnson, 1994). This community represents a transition from *E. tenuiramis* forest over heath (type Et/H from Johnson, 1994) to an *E. obliqua* forest over heath (type Eo/H from Johnson, 1994). In this community, *Pteridium esculentum* often dominates the ground layer, however many sites are bare, such as the one in this study. It is best described as a shrubby *E. obliqua (E. obliqua–E. tenuiramis)* forest (Duncan and Brown, 1985).

Daily data was collected in the summers of two years, 2002/2003 and 2003/2004. In the first year, the sampling started on 18/12/2002 and concluded on 29/04/2003, while in the second year sampling commenced on 4/11/2003 and concluded on 8/03/2004. This paper uses data from a subset of days (5/01/2004 to 10/02/2004) when solar radiation measurements were made on site.

2.2. Field measurements

2.2.1. Weather measurements

WeatherMaster 2000 (Environdata, QLD, Australia) portable weather stations measuring temperature, humidity, and wind speed were installed on the sampling sites. Solar radiation was measured using Li-200 silicon pyranometers (LiCor, NE, USA). Half-hourly readings of temperature, relative humidity, wind speed and radiation were available for the sampling period. Data were missing on the damp site for a period of about 7 days when the site meteorological station failed. Regression models with autoregressive-moving average error terms were fitted using the relevant dry site variable as the independent variable, and the missing wet site data were predicted from these models (see Makridakis et al., 1998 for details). Estimation of missing data for the damp site had little effect on results as the relevant period (27/01/04 to 4/02/04) was during a very wet period when very few measurement of fuel moisture content were able to be made. Rainfall could be assumed to be reasonably similar on both sides during that period as the sites were only a few hundred metres apart.

2.2.2. Moisture content sampling

Dead fuel moisture content was collected on each of the sites once daily between 12:00 and 14:00. In all there were 27 days of moisture content data, as samples were not collected in the rain. Samples were collected from dispersed locations within these sites.

Dead-fuel moisture samples were taken from bark and litter. Near-surface samples were only collected on the damp site, as there was negligible near-surface fuel on the dry site. (Near-surface fuel is a loose mixture of bark, dead leaves and grass above the litter which is described in McCaw et al., 2012.) The litter samples were collected as two separate samples: one being from the whole profile and the other from the top centimetre of the litter. Elevated bark fuel moisture was sampled at a height of about 1.5 m. Each dead-fuel moisture sample was made up from three to five sub-samples of the bark (*E. Obliqua*) and top litter and three sub-samples of the profile, each of which had a field weight of about 10–15 g. This material was sealed in metal tins for transport back to the laboratory. The field weight of samples was determined as soon as practicable following collection. Oven-dry weights were obtained after drying samples to constant weight at 105 °C (Matthews, 2010).

2.2.3. Fuel characteristics

Fuel hazard scores in the range (0,4) which describe the amount and arrangement of fuel present on the basis of visual assessment (Gould et al., 2011) were estimated on the sites for each fuel stratum based on the methods given in Marsden-Smedley and Anderson (2011). Fuel loading was estimated from these scores using interpolation of Tables 9.2 and 9.3 in Hines et al. (2010).

2.3. FMC models

2.3.1. The Canadian Fine Fuel Moisture Code

The Canadian Forest Fire Weather Index System (Van Wagner, 1987) predicts the moisture content of three main layers of dead forest floor fuels and combines these with the influence of wind speed to estimate fire behaviour potential. The system uses Canadian mature jack (*Pinus banksiana*) and lodgepole (*Pinus contorta*) pine stands on level terrain as its reference fuel type. It comprises six numerical ratings – three fuel moisture codes and three fire behaviour indices. For each of the codes, moisture is added after rain and reduced after each day's drying. Higher values of codes correspond to lower moisture contents. All codes have built-in time lags and rainfall thresholds (below which precipitation will not lower the value). The system uses standard, daily weather inputs of noon temperature, relative humidity, wind speed and rainfall accumulation.

The Canadian Fine Fuel Moisture Code (FFMC) represents the moisture content of fine surface litter and other fine fuels on the forest floor, and indicates ignition potential. It is based on the value of the previous time step's moisture content, the current EMC, the response time and the rainfall in the timestep. The FWI System calculates outputs daily at 12:00 local standard time (LST), to represent conditions during the peak afternoon burning period of around 16:00 LST (Van Wagner and Pickett, 1985). There are also methods in place to compute outputs on an hourly basis that provide more current estimates of fire potential (Van Wagner, 1977; Alexander et al., 1984; Lawson et al., 1996). A complete description of the FFMC is contained in Van Wagner (1987).

The hourly FFMC is calculated by determining the EMC under drying (E_d) and wetting (E_w) conditions. Drying (k_d) and wetting