Improvements in Australia's Bushfire Rate of Spread Models Over Time

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Abstract—We analyzed the predictive accuracy of rate of fire spread models used operationally in Australia in five different fuel types (grasslands, temperate shrublands, semiarid shrublands, dry eucalypt [*Eucalyptus* spp.] forests, and conifer forests). This analysis was undertaken by comparing predictions of older models with those of newer models and noting changes in error statistics based on independent evaluation of datasets composed largely of wildfire observations. We observed the newer models to have improved prediction accuracy in four of the five cases over their previous counterparts; only in the case of the semiarid shrublands was there essentially no difference. Mean absolute errors were reduced between 56 and 70 percent. This study has highlighted the value of continuous improvement in fire behavior modeling.

Keywords: fire behavior, fire environment, fuel type, model evaluation.

INTRODUCTION

Disastrous bushfires that cause loss of human life and property are especially common in southern Australia because of its fire environment (Blanchi et al. 2014), as exemplified, for example, by the 2009 Black Saturday fires in Victoria (Cruz et al. 2012). The accurate prediction of fire propagation across the landscape is thus imperative to informing safe and effective suppression operations and is essential to advising the public with regards to appropriate safety measures and warnings (Neale and May 2018). In keeping with the theme of the Fire Continuum Conference, this presentation is largely based on a recently published study undertaken to assess improvements over time in the models currently used to predict bushfire rates of spread in Australia (Cruz et al. 2018) (for a brief summary see Commonwealth Scientific and Industrial Research Organisation PyroPage Issue #18 at https://research.csiro.au/pyropage/).

A BACKGROUND TRIBUTE

No treatment of Australian bushfire behavior research would be complete without mentioning Alan McArthur (fig. 1A). He was not only an Australian pioneer in fire behavior research, he was one of the world's leading scientists on the subject. In late 1953, McArthur (then 30 years old) accepted a position with the Commonwealth of Australia's Forestry and Timber Bureau as the country's first professional officer engaged full-time in bushfire research. For the next 15 years or so, he devoted most of his time to studying fire behavior in grasslands and native forests.

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Within 5 years, McArthur had developed a model for predicting rate of fire spread in dry eucalypt (*Eucalyptus* spp.) forests (plus flame height and average spotting distance) in the form of a set of tables. He subsequently developed a series of linear and circular slide rules (fig. 1B) reflecting improvements with time based on incremental advances in fire behavior knowledge. A very similar set of developments occurred with respect to grasslands, the most widespread fuel type in the country.

McArthur, as virtually a one-man show, was able to produce more practical fire behavior knowledge over a relatively brief period of time than most in the history of wildland fire behavior research. His two seminal publications on Australian grassland (fig. 1C) and eucalypt fire behavior (McArthur 1966, 1967) are considered classics in the field of wildland fire research. Both of McArthur's fire danger meters were eventually converted to sets of equations by Noble et al. (1980). He died in 1978 at the early age of 55.

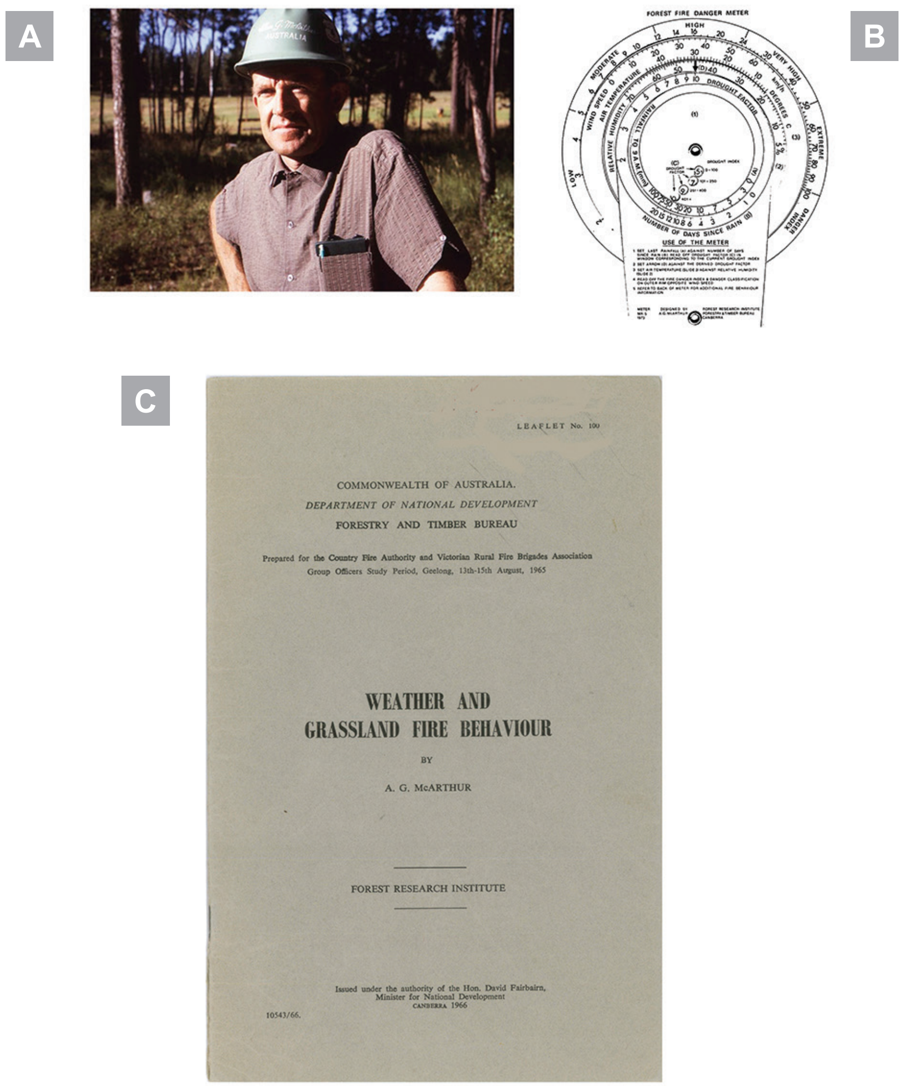

Figure 1—(A) Alan G. McArthur (1923–1978), Australian pioneer bushfire behavior researcher in 1964 (photo courtesy of CSIRO); (B) front of the McArthur Mark 5 Forest Fire Danger Meter; and (C) the front cover of McArthur's (1966) seminal publication on grassland fire behavior.

METHODS

We analyzed the predictive accuracy of five models currently used operationally in Australia to predict rate of fire spread in different fuel types and compared this accuracy with their former, older, model counterparts such as those developed by McArthur and later fire researchers (table 1). Included in these analyses were models developed in Australia for grasslands, temperate shrublands, semiarid shrublands, and dry eucalypt forests (fig. 2A–D), plus a pair of North American models for predicting crown fire spread rates in conifer forests, the most recent of which is used in part for exotic pine (*Pinus* spp.) plantations (fig. 2E) in the country (Cruz et al. 2017).

The primary inputs for all of the models, whether older or newer, are dead fine fuel moisture (or alternatively air temperature and relative humidity) and wind speed. Other inputs include fuel properties such as the degree of curing for grasslands, fuel height for shrublands, understory fuel load for dry eucalypt forests, and canopy bulk density for conifer forests. Both the older and newer rate of fire spread models are described in detail in Cruz et al. (2015).

Table 1–Listing of the older and newer wildfire rate of spread (ROS) models by fuel type and the corresponding evaluation datasets used in the present study.

Fuel type	Older ROS model	Newer ROS model	Independent dataset source
Grasslands	McArthur (1966)	Cheney et al. (1998)	Kilinc et al. (2012)
Temperate shrublands	Catchpole et al. (1998)	Anderson et al. (2015)	Anderson et al. (2015)
Semi-arid shrublands	McCaw (1997)	Cruz et al. (2013)	Cruz et al. (2013)
Dry eucalypt forests	McArthur (1967)	Cheney et al. (2012)	Kilinc et al. (2012)
Conifer forests	Rothermel (1991)	Cruz et al. (2005)	Alexander and Cruz (2006)

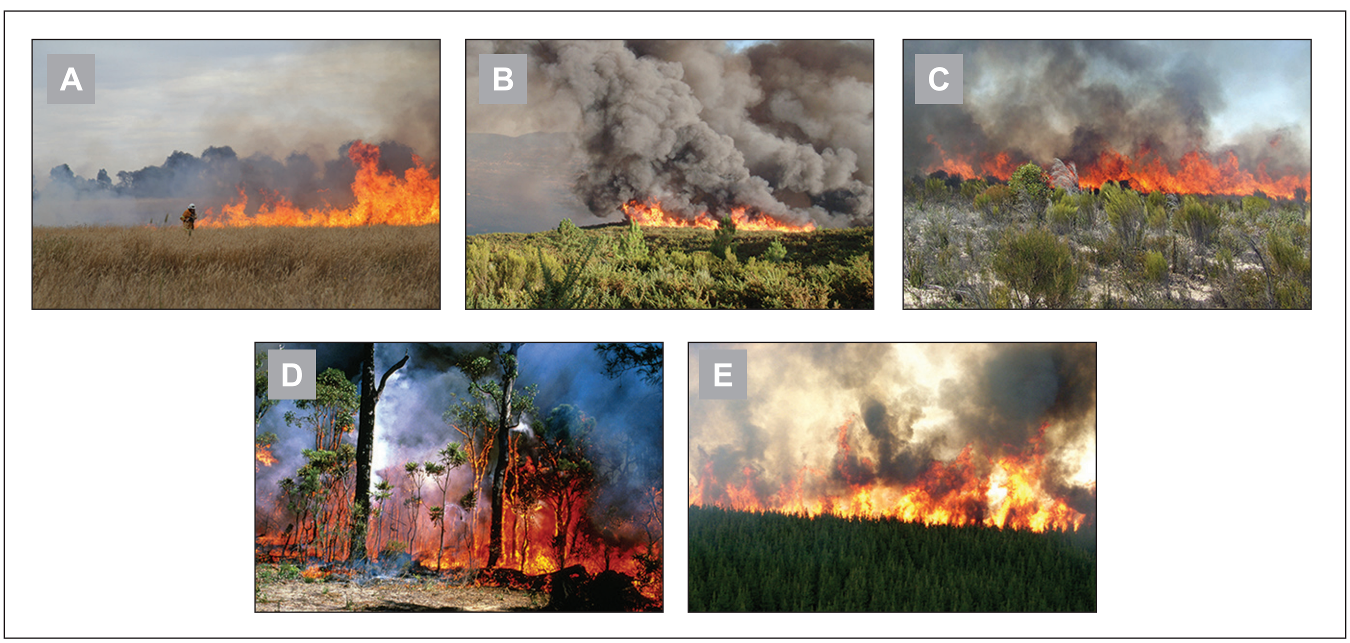

Figure 2—Representative photos of free-burning fires in five distinct fuel types: (A) grassland (photo courtesy of CSIRO), (B) temperate shrubland (photo by P. Palheiro), (C) semiarid shrubland (photo courtesy of CSIRO), (D) dry eucalypt forest (photo courtesy of CSIRO), and (E) conifer forest (photo by S. Cathcart).

Scatterplots of model predictions against observed rates of fire spread were prepared by plotting the predicted values on the x-axis for both the older and newer models against the observed values on the y-axis (Piñeiro et al. 2008) using independent datasets (table 1) composed primarily of field observations of wildfires (*n* = 463) and to a much lesser extent, prescribed fires (*n* = 7) in the case of semiarid shrublands. Linear trends were then determined for comparison with the line of perfect agreement.

Error statistics were calculated following Willmott (1982). Finally, we compared the error metrics calculated for older and newer models to assess changes in the error statistics.

RESULTS AND DISCUSSION

Model evaluation results show the current models to have improved prediction accuracy over their previous counterparts (fig. 3). The observable scatter in these plots is characteristic of wildfire data, reflecting both the temporal and spatial variability in the fire's behavior and the environmental conditions.

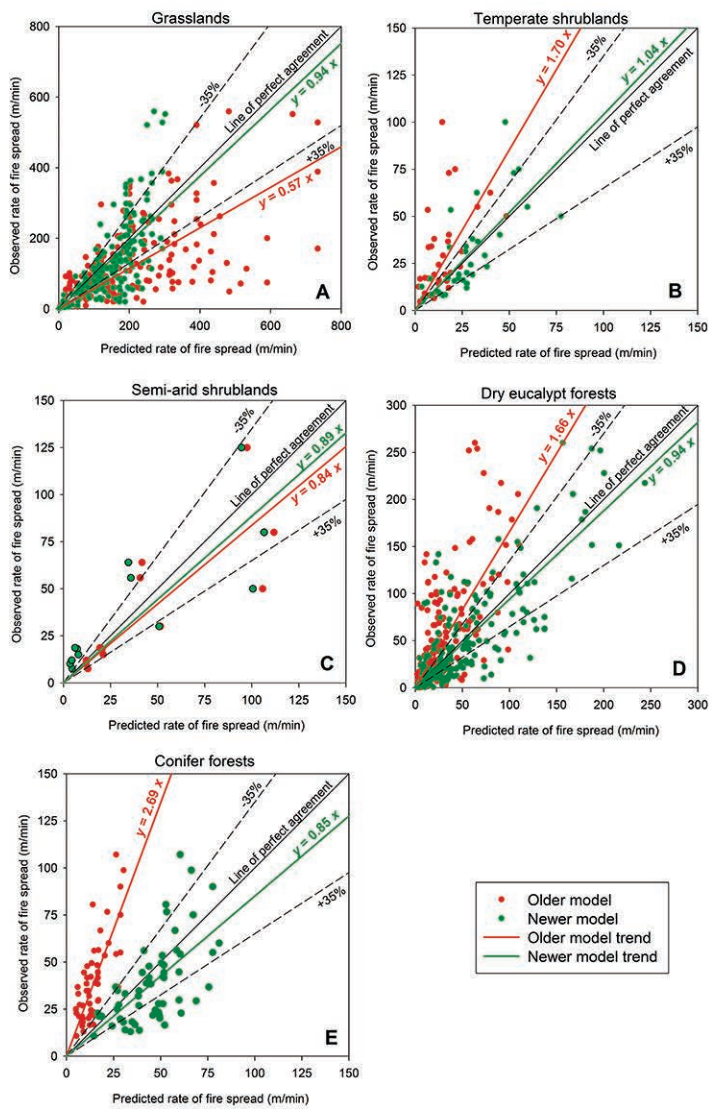

Figure 3—Scatterplots of observed rates of fire spread versus predictions from the older (red dots) and newer (green dots) models and resultant linear trends for (A) grasslands, (B) temperate shrublands, (C) semiarid shrublands, (D) dry eucalypt forests, and (E) conifer crown fires. The dashed lines around the line of perfect agreement indicate the ±35-percent error interval as per Cruz and Alexander (2013).

The mean absolute error (MAE), which is expressed in the same units as the original data (i.e., m minute^{-1} in this case), is a quantity used to express how close predictions are to the observed value. As the name suggests, the MAE is an average of the absolute error. These values were reduced by 68 percent for grasslands, 56 percent for temperate shrublands, 52 percent for dry eucalypt forests, and 70 percent for crown fires in conifer forests (fig. 4A). A minor increase in the MAE of 3 percent was noted in the semiarid shrublands. This outcome may be due in part to the small sample size of the independent dataset (n = 13).

The most significant improvement observed was the reversal or reduction of underprediction and overprediction biases achieved with four of the five newer models (fig. 4B).

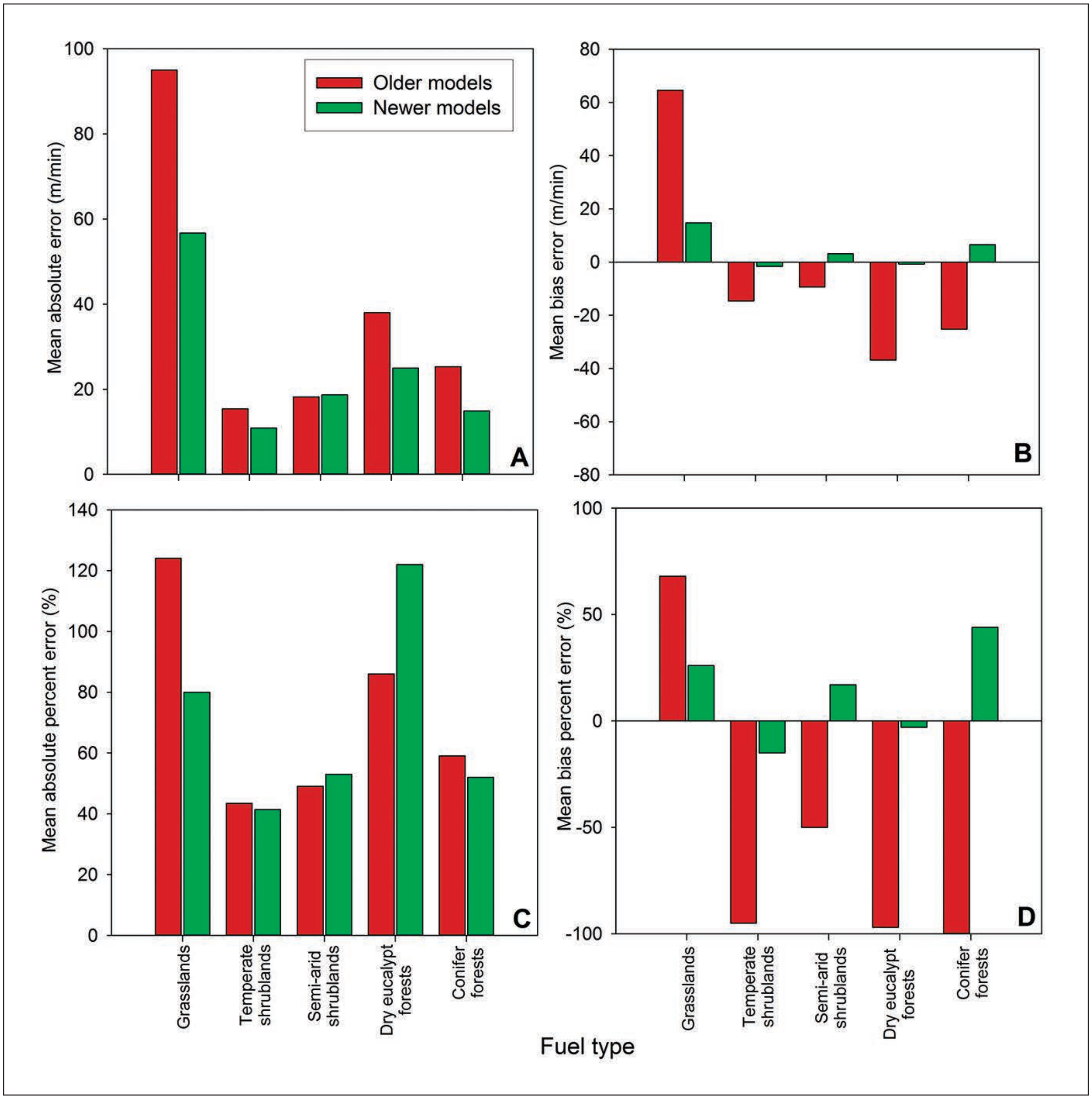

Figure 4—Change in error statistics achieved between older (red) and newer (green) rate of fire spread models.

CONCLUDING THOUGHTS

This study has highlighted the value of continuous improvement in operational wildland fire spread models, a fact that should be borne in mind when it comes to long-term planning by both senior research administrators and fire researchers. This outcome is in keeping with the tradition established by Alan McArthur before his death of carrying out revisions every 2 to 5 years; for example, between 1958 and 1977 he undertook the completion of five different editions of his grassland and eucalypt fire behavior models (Cruz et al. 2015). It also represents a good example of a wildland fire science continuum.

REFERENCES

Alexander, Martin E.; Cruz, Miguel G. 2006. Evaluating a model for predicting active crown fire rate of spread using wildfire observations. Canadian Journal of Forest Research. 36: 3015–3028.

Anderson, W.R.; Cruz, M.G.; Fernandes, P.M.; [et al.]. 2015. A generic, empirical-based model for predicting rate of fire spread in shrublands. International Journal of Wildland Fire. 24: 443–460.

Blanchi, Raphaele; Leonard, Justin; Haynes, Katharine; [et al.]. 2014. Environmental circumstances surrounding bushfire fatalities in Australia 1901–2011. Environmental Science & Policy. 37: 192–203.

Catchpole, Wendy; Bradstock, Ross; Choate, J.; [et al.]. 1998. Cooperative development of equations for heathland fire behaviour. In: Viegas, Domingos X., ed. Proceedings of the III international conference on forest fire research/14th fire and forest meteorology conference; 16–20 November 1998; Luso, Portugal. Coimbra, Portugal: Associação para o Desenvolvimento da Aerodinâmica Industrial and University of Coimbra: 631–645.

Cheney, N.P.; Gould, J.S.; Catchpole, W.R. 1998. Prediction of fire spread in grasslands. International Journal of Wildland Fire. 8: 1–13.

Cheney, N. Phillip; Gould, James S.; McCaw, W. Lachlan; Anderson, Wendy R. 2012. Predicting fire behaviour in dry eucalypt forest in southern Australia. Forest Ecology and Management. 280: 120–131.

Cruz, M.G.; Alexander, M.E.; Plucinski, M.P. 2017. The effect of silvicultural treatments on fire behaviour potential in radiata pine plantations of South Australia. Forest Ecology and Management. 397: 27–38.

Cruz, M.G.; McCaw, W.L.; Anderson, W.R.; Gould, J.S. 2013. Fire behaviour modelling in semi-arid mallee-heath shrublands of southern Australia. Environmental Modelling & Software. 40: 21–34.

Cruz, M.G.; Sullivan, A.L.; Gould, J.S.; [et al.]. 2012. Anatomy of a catastrophic wildfire: The Black Saturday Kilmore East fire in Victoria, Australia. Forest Ecology and Management. 284: 269–285.

Cruz, Miguel G.; Alexander, Martin E. 2013. Uncertainty associated with model predictions of surface and crown fire rates of spread. Environmental Modelling & Software. 47: 16–28.

Cruz, Miguel G.; Alexander, Martin E.; Sullivan, Andrew L.; [et al.]. 2018. Assessing improvements in models used to operationally predict wildland fire rate of spread. Environmental Modelling & Software. 105: 54–63.

Cruz, Miguel G.; Alexander, Martin E.; Wakimoto, Ronald H. 2005. Development and testing of models for predicting crown fire rate of spread in conifer forest stands. Canadian Journal of Forest Research. 35: 1626–1639.

Cruz, Miguel G.; Gould, James S.; Alexander, Martin E.; [et al.]. 2015. A guide to rate of fire spread models for Australian vegetation. Canberra, Australian Capital Territory and Melbourne, Victoria, Australia: CSIRO Land and Water Flagship and AFAC. 125 p.

Kilinc, Musa; Anderson, Wendy; Price, Ben. 2012. The applicability of bushfire behaviour models in Australia. DSE Schedule 5: Fire Severity Rating Project Technical Report 1. Melbourne, Victoria, Australia: Department of Sustainability and Environment. 60 p.

McArthur, A.G. 1966. Weather and grassland fire behaviour. Leaflet 100. Canberra, Australian Capital Territory, Australia: Commonwealth of Australia, Forestry and Timber Bureau. 23 p.

McArthur, A.G. 1967. Fire behaviour in eucalypt forests. Leaflet 107. Canberra, Australian Capital Territory, Australia: Commonwealth of Australia, Forestry and Timber Bureau. 36 p.

McCaw, William Lachlan. 1997. Predicting fire spread in Western Australian mallee-heath shrubland. Sydney, New South Wales, Australia: University of New South Wales. 240 p. Ph.D. thesis.

Neale, Timothy; May, Daniel. 2018. Bushfire simulators and analysis in Australia: Insights into an emerging sociotechnical practice. Environmental Hazards. 17: 200–218.

Noble, I.R.; Bary, G.A.V.; Gill, A.M. 1980. McArthur's fire danger meters expressed as equations. Austral Ecology. 5: 201–203.

Piñeiro, Gervasio; Perelman, Susana; Guerschman, Juan P.; Paruelo, José M. 2008. How to evaluate models: Observed vs. predicted or predicted vs. observed? Ecological Modelling. 216: 316–322.

Rothermel, Richard C. 1991. Predicting behavior and size of crown fires in the northern Rocky Mountains. Res. Pap. INT-RP-438. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 46 p.

Willmott, Cort J. 1982. Some comments on the evaluation of model performance. Bulletin of the American Meteorological Society. 63: 1309–1313.