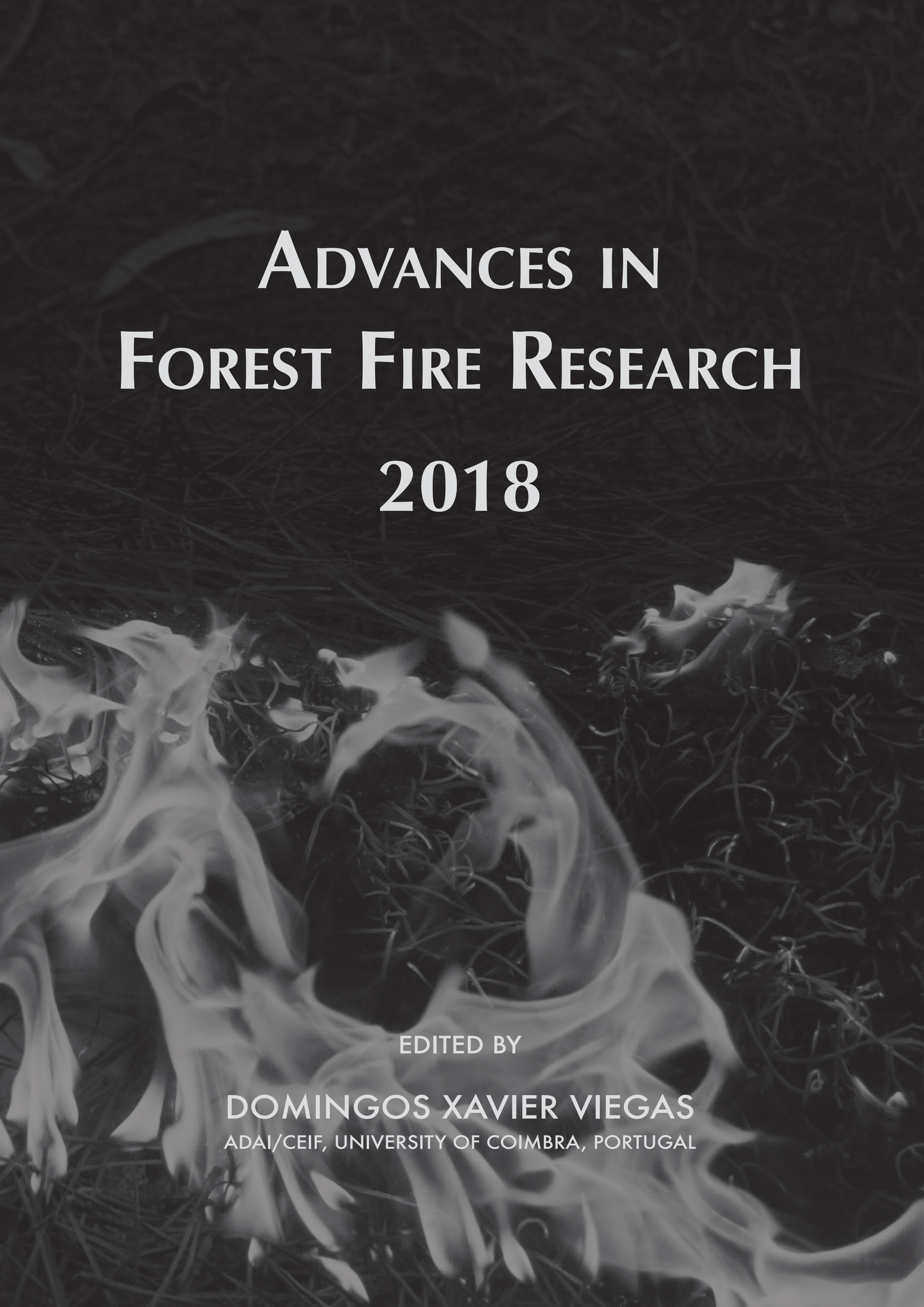


Advances in Forest Fire Research 2018

EDITED BY

DOMINGOS XAVIER VIEGAS
ADAI/CEIF, UNIVERSITY OF COIMBRA, PORTUGAL

https://doi.org/10.14195/978-989-26-16-506_190

Short contribution – Decision Support Systems and Tools

The determinants of crown fire runs during extreme wildfires in broadleaf forests in Australia

Alexander I. Filkov[1,,2]*, Luke Collins[3,4], Anthony Rawlins[1], Thomas J. Duff[1], Brett Cirulis[1], Trent D. Penman[1]

[1]*University of Melbourne. Creswick, Victoria Australia 3363, {alexander.filkov@unimelb.edu.au*}*

[2]*Bushfire and Natural Hazards Cooperative Research Centre. Melbourne, Victoria Australia 3002, {office@bnhcrc.com.au}*

[3]*La Trobe University. Bundoora, Victoria, Australia 3086*

[4]*Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria, Australia 3084*

Abstract

Crown fires in forest ecosystems can pose a major threat to life and property due to their high intensities and rapid rates of spread. However, research into the prediction of crown fire dynamics in the Eucalyptus forests of Australia is limited. Previous studies have focused on coarse temporal scales, utilised low resolution weather based predictors, and disregard the spatial nature of crown fires. Our study aimed to use observations from large wildfires in eucalypt forests to develop an empirical model to predict the likelihood of crown fire events using environmental predictors at an hourly scale. Our study was conducted in south-eastern Australia using data from fifteen large wildfires that occurred between 2009 and 2015. Fire severity maps were created for each fire at a 30 m resolution using Landsat imagery from which we calculated the proportion of 30 m pixels experiencing crown fire within a 150 x 150 m window (2.25 ha). Predictor variables were chosen to represent the four key environmental drivers of fire behaviour, namely fuel moisture (i.e. live and dead fuel), fuel load and structure (i.e. surface, elevated and bark fuels, tree height), fire weather (i.e. vapour-pressure deficit, wind speed, relative wind direction) and topography (i.e. slope and ruggedness). Random Forests were used to model the effect of environmental drivers on the proportion of crown fire. Fuel moisture content variables were the best predictors of probability of crown consumption. Topographic variables and fire weather had only an intermediate influence and fuel load and structure had the lowest influence. Crown fire runs largely occurred when thresholds in vapour-pressure deficit (<4 kPa) and dead fuel moisture content (<7%) were exceeded. Predictions from the model showed a high degree of agreement with the raw fire severity maps. The proposed models have the potential to provide guidance on the likelihood of crown fire during fire events.

Keywords: crown fires; risk; prediction; modelling; wildfire

1. Introduction

Extreme fire behaviours are responsible for a disproportionate level of damage (Cruz *et al.* 2012; Peace *et al.* 2016). However, there is limited research regarding their prediction. In part, this is due to the challenges with observing rare complex phenomena and difficulty in measuring behaviours that occur under dangerous conditions. Crown fires are a relatively common type of extreme fire behaviour in forest ecosystems, which are characterised by high fire intensities, rapid rates of spread and high release of radiant heat. Consequently, crown fires reduce the likelihood of successful suppression and can threaten lives of suppression crews (Alexander and Cruz 2011). Crown fires may have negative impacts on some ecosystems services such as biodiversity and water quality (Nyman *et al.* 2011; Smith *et al.* 2011).

The occurrence and nature of crown fires has been extensively studied in conifer systems, with a large number of models having been developed (Cruz and Alexander 2013). Crown fires have been found to be a function of crown fuel properties (such as dead fuel moisture content, bulk density and the gap from the surface fuels to the canopy), surface fuel properties, topography and weather conditions (such as wind speed, temperature). Despite its importance, published research into crown fire dynamics in the broadleaved Eucalyptus forests of Australia is limited.

Remotely sensed maps of fire severity have been used to study environmental drivers of crown fires occurrence. Fire severity is a retrospective measure of the environmental impact of a fire (Keeley 2009). Severity maps can be used to determine the influence of factors including fuels, weather, terrain and disturbance history on fire severity, as a surrogate of crown fire behaviour. Previous studies examining crown fire occurrence in eucalypt forest have used coarse scale measures of fire weather indices, which combine information on fire weather and moisture availability into one value (Price and Bradstock 2012; Taylor *et al.* 2014; Storey *et al.* 2016). These indices do not disentangle the contribution of fire weather and fuel moisture. Furthermore, past studies have considered the likelihood of crown fire at a single point (Price and Bradstock 2012; Collins *et al.* 2014; Storey *et al.* 2016) whereas from a management perspective the prediction of large patches of crown fire, or crown fire runs is desirable as they have larger impacts and are a greater threat to fire suppression activities.

In this study, we aimed to examine the relative importance for drivers of crown fires in Eucalypt forests. We use satellite derived fire severity mapping from 15 large wildfires in south-eastern Australia to develop a model to predict the likelihood and extent of crown fire events using spatially derived environmental predictors and a range of weather measurements.

2. Methods

A key objective of our study was to model crown fire occurence in eucalypt forests using fine temporal scale (i.e. sub daily) fire weather data. Therefore, in our study we only considered fires that had reconstructed perimeter isochrones of progression and linescans at a sub-daily resolution[1] and burnt predominantly within eucalypt forests. Fifteen case study fires between 2009 and 2015 met the criteria to be suitable for analysis. These fires all have several progression isochrones each day with an average interval of 4 hours.

Fire severity maps were created for the study fires using Landsat imagery (30 m resolution) and a Random Forest (RF) classifier, following the approach outlined in Collins et al. (Collins *et al.* 2018). Fire severity maps were generated using the Google Earth Engine platform (Gorelick *et al.* 2017). The mapping approach used numerous spectral indices derived from pre- and post-fire Landsat imagery as predictor variables for a RF classifier. Five fire severity classes were classified in the mapping - unburnt, crown unburnt, partial crown scorch, crown scorch and crown consumption. We reclassified each pixel as either experiencing crown fire (i.e. crown consumption) or not. In our study we quantified crown fire runs by calculating the proportion of pixels experiencing crown fire within a 5 x 5 pixel moving window (150 m x 150 m).

Predictor variables were selected to represent the four key drivers of fire severity included in existing crown fire models and fire severity studies – fuel moisture, fuel load, fire weather and topography. Eleven predictor variables were used in the analysis, each representing different aspects of the four drivers: i) Live and dead fuel moisture content (fuel moisture); ii) Surface, elevated and bark fuels and tree height (fuel load); iii) Vapour-pressure deficit, wind speed and relative wind

[1] Linescans are images from high altitude aircraft mounted Infrared linescan systems

direction (fire weather); and iv) Slope and topographic ruggedness (topography). We used Random Forests[1] to model the effect of these environmental drivers on (i) crown fire occurrence and (ii) the proportion of pixels experiencing crown fire.

3. Results and discussion

Assessment of the importance of predictor variables, based the Gini scores[2], indicates that variables reflecting air and fuel moisture were most influential in determining crown fire runs, with fire weather and topography having intermediate influence and fuel load and structure having the lowest influence (Fig. 1).

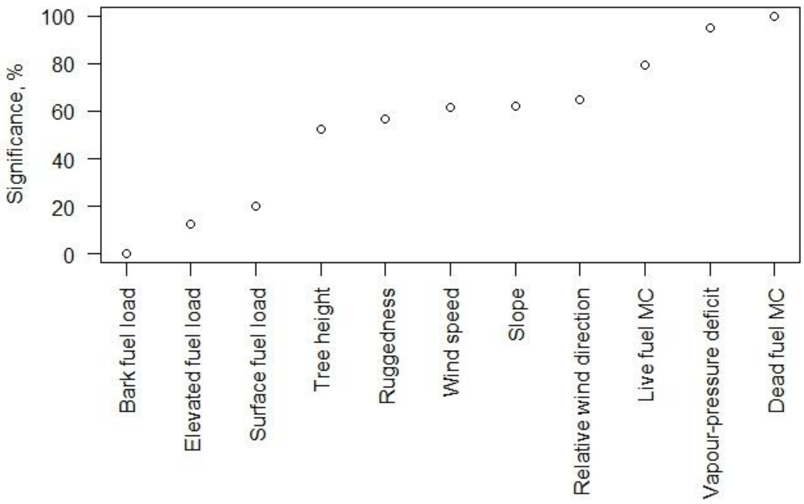


Figure 1 - Importance of predictor variables for the prediction of crown fire runs. Relative significance of variable is dimentionless value changing from 0 to 100 %.

Dead fuel moisture content and vapour-pressure deficit. had clearly identified thresholds, below which crown fires rarely occurred. These threshold values for vapour-pressure deficit and dead fuel moisture content were 4 kPa and 6.9 % respectively. A decrease of dead fuel moisture content less of one percent (below 6.9%) and an increase of vapour-pressure deficit from 4 kPa to 7 kPa led to growth of the proportion of pixels where crown fires occurred by 3 times (Fig. 2). These findings highlight the fact, that moisture plays an important role in the ignition and combustion process (Zhou *et al.* 2005; Weise *et al.* 2016). Even low changes of it can vital increase the crown fire likelihood.

For the predictor variables; tree height, surface fuel load, wind speed and relative wind direction, the number of pixels where crown fires occurred doubled. This occured at threshold values of: >35 m tree height, <18 t/ha load, >40 km/h speed, 45°-90° and 135°-180° wind direction. The rest of predictor variables changed within 10 % of pixels without showing any consistent patterns.

---

[1] Random forests or random decision forests are an ensemble learning method for classification, regression and other tasks, that operate by constructing a multitude of decision trees at training time and outputting the class that is the mode of the classes (classification) or mean prediction (regression) of the individual trees.

[2] The Gini coefficient measures the inequality among values of a frequency distribution.

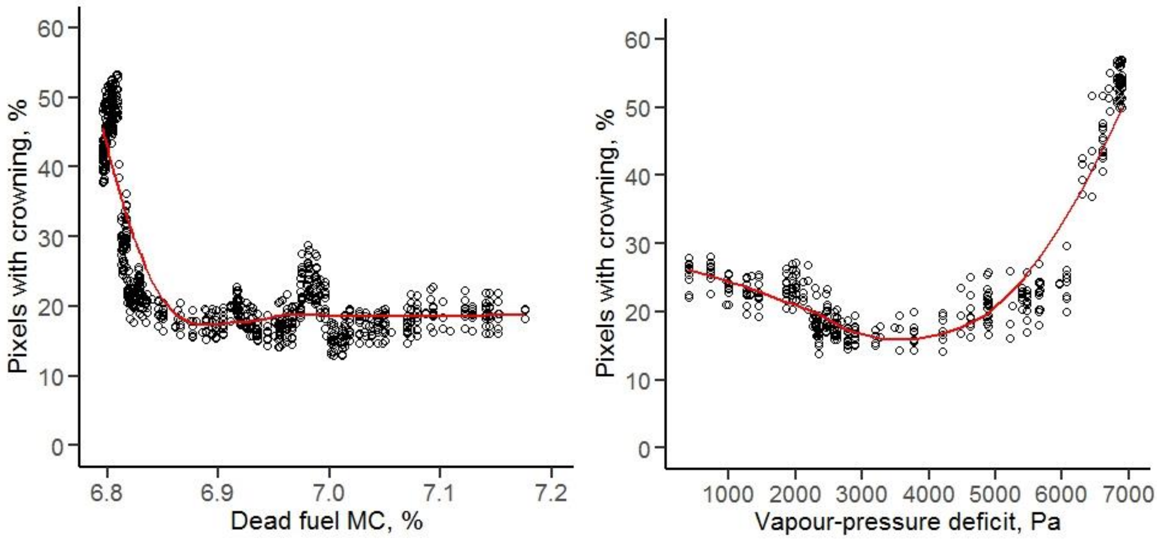
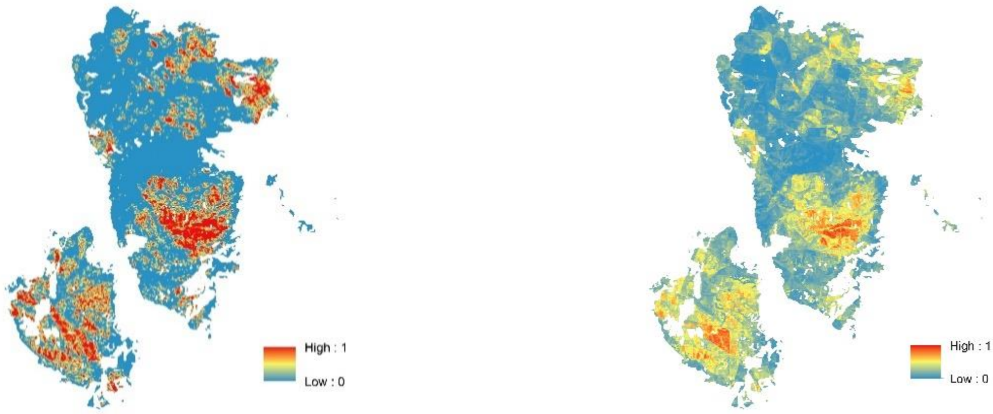


Figure 2 - Influence of dead fuel moisture content and vapour-pressure deficit on the percent of pixels effected by crown fire. Proportion is changing from 0 to 100 %, which is corresponding to total amount of pixels.

Mapped predictions from the Random Forest model show a high degree of agreement with the mapped fire severity observations suggesting it could be useful tool for decision support (Fig. 3).



Deddick, Vic

Observation Prediction

Figure 3 - Comparison of observed proportion of pixels with crowning vs predicted. Proportion of pixels with crowning is changing from 0 (no crowning) to 1 (all pixels with crowning).

As the weather variables can be forecast into the future, Random Forest predictions could be used to forecast the likelihood of crown fire runs while fires are occurring. In the study area, potential fire runs could be forecast at an hourly temporal resolution for up to 7 days into the future. This could provide managers with a rapid means of assessing the likely fire impacts and risks to personnel. Such information would be invaluable for fire managers in terms of allocating fire suppression resources and issuing public warnings

4. Acknowledgements

This study was funded by the Bushfire and Natural Hazards Cooperative Research Centre '*Determining threshold conditions for extreme fire behaviour'* project.

5. References

Alexander M, Cruz M (2011) What are the safety implications of crown fires? InFox R (ed) 'Proceedings of 11th International Wildland Fire Safety Summit', Missoula. 1–16. (International Association of Wildland Fire: Missoula) https://publications.csiro.au/rpr/download?pid=csiro:EP114880&dsid=DS2.

Collins L, Bradstock RA, Penman TD (2014) Can precipitation influence landscape controls on wildfire severity? A case study within temperate eucalypt forests of south-eastern Australia. *International Journal of Wildland Fire* **23**, 9–20. doi:10.1071/WF12184.

Collins L, Griffioen P, Newell G, Mellor A (2018) The utility of Random Forests for wildfire severity mapping. (in Review).

Cruz MG, Alexander ME (2013) Uncertainty associated with model predictions of surface and crown fire rates of spread. *Environmental Modelling and Software* **47**, 16–28. doi:10.1016/j.envsoft.2013.04.004.

Cruz MG, Sullivan AL, Gould JS, Sims NC, Bannister AJ, Hollis JJ, Hurley RJ (2012) Anatomy of a catastrophic wildfire: The Black Saturday Kilmore East fire in Victoria, Australia. *Forest Ecology and Management* **284**, 269–285. doi:10.1016/j.foreco.2012.02.035.

Gorelick N, Hancher M, Dixon M, Ilyushchenko S, Thau D, Moore R (2017) Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sensing of Environment* **202**, 18–27. doi:10.1016/j.rse.2017.06.031.

Keeley JE (2009) Fire intensity, fire severity and burn severity: A brief review and suggested usage. *International Journal of Wildland Fire* **18**, 116–126. doi:10.1071/WF07049.

Nyman P, Sheridan GJ, Smith HG, Lane PNJ (2011) Evidence of debris flow occurrence after wildfire in upland catchments of south-east Australia. *Geomorphology* **125**, 383–401. doi:10.1016/j.geomorph.2010.10.016.

Peace M, Mattner T, Mills G, Kepert J, McCaw L (2016) Coupled fire-atmosphere simulations of the Rocky River fire using WRF-SFIRE. *Journal of Applied Meteorology and Climatology* **55**, 1151–1168. doi:10.1175/JAMC-D-15-0157.1.

Price OF, Bradstock RA (2012) The efficacy of fuel treatment in mitigating property loss during wildfires: Insights from analysis of the severity of the catastrophic fires in 2009 in Victoria, Australia. *Journal of Environmental Management* **113**, 146–157. doi:10.1016/j.jenvman.2012.08.041.

Smith HG, Sheridan GJ, Lane PNJ, Nyman P, Haydon S (2011) Wildfire effects on water quality in forest catchments: A review with implications for water supply. *Journal of Hydrology* **396**, 170–192. doi:10.1016/j.jhydrol.2010.10.043.

Storey M, Price O, Tasker E (2016) The role of weather, past fire and topography in crown fire occurrence in eastern Australia. *International Journal of Wildland Fire* **25**, 1048–1060. doi:10.1071/WF15171.

Taylor C, Mccarthy MA, Lindenmayer DB (2014) Nonlinear Effects of Stand Age on Fire Severity. *Conservation Letters* **7**, 355–370. doi:10.1111/conl.12122.

Weise DR, Koo E, Zhou X, Mahalingam S, Morandini F, Balbi JH (2016) Fire spread in chaparral - A comparison of laboratory data and model predictions in burning live fuels. *International Journal of Wildland Fire* **25**, 980–994. doi:10.1071/WF15177.

Zhou X, Mahalingam S, Weise D (2005) Modeling of marginal burning state of fire spread in live chaparral shrub fuel bed. *Combustion and Flame* **143**, 183–198. doi:10.1016/j.combustflame.2005.05.013.