Peer-reviewed article

ABSTRACT

In most Australian jurisdictions, the use of prescribed fire is promoted on the basis of its efficacy in mitigation of risk. Despite this, formal attempts to evaluate effects on risk to people, property and environmental values across different jurisdictions are generally lacking. In particular, there is no basis for assessing the generality of attempts to predict risk in response to any particular strategy for use of prescribed fire (e.g. the 5 per cent target recommended by the 2009 Victorian Bushfires Royal Commission). General principles therefore need to be developed about how to apply a risk-based approach across widely varying environments, human communities and combinations of key management values.

In this Bushfire and Natural Hazards Cooperative Research Centre project, researchers from the University of Wollongong, Western Sydney University and the University of Melbourne have come together with end users across southern Australia to design a project to systematically investigate how risk to any particular management value will respond to variations in the spatial location and rates of treatment. Project outputs are currently being moulded for utilisation by end users in a dedicated tool, the Prescribed Fire Atlas, which will guide the implementation of 'tailor-made' prescribed burning strategies to suit the biophysical, climatic and human context of all bioregions across southern Australia.

A new decision support tool for prescribed burning risk assessment

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Introduction

Fire managers and scientists are working together to develop new ways to assess the risks associated with wildfire. In Victoria there has been a transition to a risk reduction target, which uses modelling and analysis to compare the different management scenarios with a maximum risk baseline (Victorian Government 2015a). The approach explicitly refers to residual risk, the percentage of maximum bushfire risk that remains in the landscape following a particular fire management scenario. Similar risk assessment methods have been employed in Tasmania (State Fire Management Council 2014). Cost trade-offs have been analysed for future fire management approaches in the Australian Capital Territory, to determine which are most cost-effective and provide the greatest reduction in risk (Penman and Cirulis 2019). There are many other examples in Australia and abroad of risk assessment for fire management, both at an integrated level (e.g. Alcasena et al. 2019, Finney et al. 2011) as well as for particular issues such as forestry (Ager et al. 2019), biodiversity conservation (Bentley and Penman 2017) and suppression (Penman et al. 2011).

Prescribed burning is the main fire risk reduction tool currently available and is therefore a major focus for risk assessment. The clarity of its rationale – to reduce the risks from wildfire by modifying fuel properties through the application of fire under moderate weather conditions – stands in stark contrast to the complexity of its application. Although it is not yet required of most fire managers, the aforementioned risk assessments suggest the possibility of eventually providing a comprehensive, quantitative accounts of all the costs and benefits of prescribed burning, as well as the trade-offs between multiple management objectives. These analyses could include the influence of prescribed burning on the risks posed by wildfires (e.g. to human settlements and environmental values) as well the risks of planned burns themselves (e.g. smoke impacts on human health and amenity, environmental values).

In this context, there is a need for standardised approaches for comparing and contrasting risk across multiple assets that can be readily communicated within agencies and to the community. Such tools are best developed in collaborative projects of researchers and end users, such as in our project supported by the Bushfire and Natural Hazards Cooperative Research Centre (BNHCRC). The express purpose of our research is to support the delivery of effective, 'tailor-made' prescribed burning solutions across southern Australian ecosystems by providing a quantitative trajectory of risk reduction for multiple values in response to differing prescribed burning strategies. The project is divided into two phases: fire behaviour accounting and risk accounting.

Fire behaviour accounting

At the heart of the project is predictive modelling of the effect of prescribed burning on the incidence and behaviour of unplanned fires. Simulation modelling involves the coding and scaling up of fire behaviour models to predict spatial patterns of fire spread and extent at landscape scales. These simulators are provided with certain inputs (e.g. the terrain, vegetation type and weather conditions in a case study landscape), in order to produce estimates of wildfire properties such as rate of spread, flame height and intensity. Simulation modelling has played a key role in advancing risk techniques (for recent examples see Connell et al. 2019, Guillaume et al. 2019 and Furlaud et al. 2018). The key advantage of simulation modelling is the ability to run large numbers of experiments representing scenarios of spatial scale, treatment rate, patterns, asset configurations and weather conditions that would be impossible to explore in empirical field experiments. While simulators have a range of limitations, such as their computational expense and inaccuracies in the representation of key processes and elements (or their omission altogether), it is reasonable to expect performance to improve as existing models are validated, improved and new models are developed (Sa et al. 17, Faggian et al. 17, Duff et al. 18).

Choice and experimental design of fire behaviour simulator

Simulation models are widely used in Australian fire management, and in South Australia and the eastern states the primary tool is PHOENIX RapidFire (Tolhurst et al. 2008). PHOENIX is used by fire agencies in these states for incident prediction, risk assessment and strategic planning. For example, it was used in the development of statewide and regional risk profiles in Victoria (Victorian Government 2015b). We therefore decided in conjunction with end users to make PHOENIX the simulation model in our project, although our approach is compatible with other simulators (e.g. Johnston et al. 2008, Tymstra et al. 2010) and simulation frameworks (e.g. Hilton et al. 2015). PHOENIX and other similar simulators are spatially explicit and hence have many inputs that are spatially explicit, such as fuel mapping, asset locations and fire history. With the exception of wind, weather is assumed to be spatially uniform i.e. orographic effects on temperature and relative humidity. Here we sketch the key aspects of our experimental design; for full details see Cirulis et al. (2019).

There are several key inputs to the simulation process.

- Ignition locations are selected using a spatial likelihood model (Clarke et al. 2019).
- Fuel type and arrangement is based on data and advice from fire management agencies.
- Weather is drawn from Bureau of Meteorology data and samples from the full range of possible conditions at each case study location, including fire danger index classes and different drivers of high fire danger (temperature-driven, wind-driven, wind change-driven).
- Fire history includes wildfire as well as variable combinations of edge and landscape treatments, applied to burn blocks derived from agency data or generated using an algorithm.

The above combination of inputs results in thousands of simulations, whose key outputs are predictions of fire size, fire intensity, flame height and the presence of embers for given weather conditions, treatment rates and treatment locations. Vulnerability models are used to relate fire properties to impacts on individual assets or management values, based on peer reviewed literature. We have initially used a core set of house loss, life loss, length of road damaged, length of powerline damaged and area burnt below minimum tolerable fire interval. These values were identified as priorities for end users and we are currently working with them to develop further values and associated vulnerability models. Key improvements to existing simulation modelling studies are the use of ignition likelihood and a representative distribution of local weather, the consideration of an increased number of assets and the exploration of a greater diversity of potential treatment futures supported by improved computing power.

Risk accounting

We use Bayesian decision networks to estimate the level of risk mitigation available through different prescribed burning treatments (Marcot et al. 2006). Bayesian decision networks are mathematical models presented graphically, allowing for the interaction and influence of many factors on an outcome of interest. They are able to propagate the probability distributions (and associated uncertainty) of multiple variables, as well as selections from a range of candidate options for one or more decisions, through to an overall likelihood. These features make them ideal tools for wildfire risk assessment (Penman et al. 2011):

- Their graphical nature makes them easy to understand
- Their ability to integrate multiple factors makes them suitable for holistic analyses that support decisions around one or more management options
- Their ability to handle probability distributions means they are able to provide true estimates of risk, while making transparent key sources of uncertainty in overall outcomes.

In our approach, the model learns probability distributions of fire weather conditions and wildfire incidence for combinations of discrete rates of prescribed burning in edge and landscape blocks, and generates estimates of residual risk at each treatment level. The use of data from fire behaviour simulations (e.g. probability distributions of area burnt) is an integral part of the process. By incorporating the entire range and probability of local conditions, this process produces 'full' estimates of risk that can be compared between case study landscapes. It is thus possible to not only investigate the trajectory of risk reduction for different values in a given region, but also ask how such trajectories differ between regions, both in absolute as well as relative terms (e.g. compared to zero treatment). These trajectories can also be used as input into trade-off analyses (e.g. Driscoll et al. 2010), highlighting the ramifications of optimising for particular values or sets of values. Identifying effective risk reduction options is a key objective for fire managers that will use this tool.

At the request of end users we incorporated cost into the Bayesian decision network. The impacts of wildfire can be wide-ranging, including to livelihoods, human health, infrastructure, primary production and ecosystem services (Bowman and Johnston 2014; Stephenson et al. 2013). Estimates of the cost of wildfire are therefore substantial, although they vary considerably depending on scope and method e.g. at least $4b for the 2009 Black Saturday fires (Teague et al. 2010) and average annual costs for 2007-2016 of $1.1b (ABR DRSC 2017). In the U.S., the 2017 fire season was the most expensive ever, with costs exceeding $US 2.4b (US Forest Service, 2019). We have initially included two classes of cost: treatment costs (separate cost for edge and landscape) and impact costs (e.g. cost of house loss, powerline damage). The local trajectories of cost for given treatment rates and locations can then be tracked and compared between regions, allowing identification of the most cost-effective prescribed burning strategies, either overall or for a given management value.

Using project outputs

The research team has worked with end users to develop an interface for exploring and interrogating the multifaceted outputs from the project. This interface, called the Prescribed Fire Atlas, is a decision support tool, not a decision making tool. The aim is to present outputs clearly, engagingly and with appropriate guidance material, to enable end users to make their own decisions. Feedback from end users has so far identified a number of issues and priorities for inclusion in the Atlas:

- There is value in both relative and absolute measures. This enables end users to not only identify individual and aggregate risks/costs, but also compare them with alternatives such as business as usual scenarios, solutions in other jurisdictions and risk reduction targets.
- There is value in bottom up and top down approaches to interrogation of outputs i.e. entering current or potential strategies in order to determine their risk and cost, and specifying desired risk levels or available budgets in order to assess available options within these constraints.
- Given that the Atlas joins a long list of decision support tools and web interfaces available to fire managers, there is a need to ensure its design maximises complementarity and compatibility with these other tools.
- The Atlas may have value as a tool to support internal and external communications and education, aside from its core role in strategic planning and risk assessment. Project outputs could be used to educate stakeholders and overcome misunderstandings about the relationships between biophysical drivers, planned and unplanned fire.

Conclusion and future challenges

We have described here a tool for systematically comparing prescribed burning effects on risk mitigation across multiple landscapes and management values. The tool has been designed to provide a credible means by which fire agencies can respond to demands for transparent accounting of the costs and benefits of their activities. It does this by combining methodologies for assessing the effects of prescribed burning on fire behaviour and risk to management values including costs. While the project represents an important step forward in wildfire risk management research, a number of challenges remain to maximise its value. The treatment of values is essentially modular, meaning that the addition of new values (e.g. agricultural impacts, human health impacts from smoke) or modifications of existing ones is not just desirable, but possible. The project can equally easily incorporate new costs associated with prescribed burning, suppression and wildfire impacts as they are made available. It will also be important to test the sensitivity of results to choice of simulator and fire behaviour model (e.g. Zylstra et al. 2016). Hosting, maintenance, evaluation and monitoring of the Prescribed Fire Atlas are important issues, particularly in light of funding for the BNHCRC ending in 2021. Finally, as our understanding of wildfire risk and the effects of wildfire management improves, it may be possible to transition from cost effectiveness analyses to a cost benefit analysis, moving from an appraisal of costs of different management options to an assessment of their net benefit to society (NSW Treasury 2017).

Acknowledgements

This work was supported by the Bushfire and Natural Hazards Cooperative Research Centre. We acknowledge and thank staff in the NSW Rural Fire Service, NSW National Parks and Wildlife Service, ACT Parks and Conservation Service, Tasmanian Fire Service, Victorian Department of Environment, Land, Water and Planning, South Australian Department of Environment, and Queensland Fire and Emergency Services.

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