



FROM HECTARES TO TAILOR-MADE SOLUTIONS FOR RISK MITIGATION

**Systems to deliver effective prescribed burning
across Australian ecosystems**

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Cover: Prescribed burn at Bowen Mountain in July 2019. Credit: Hamish Clarke



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EXECUTIVE SUMMARY

We are pleased to present the 2020 Final Report for the Bushfire and Natural Hazards CRC project, *“From hectares to tailor-made solutions for risk mitigation: systems to deliver effective prescribed burning across Australian ecosystems”*.

Prescribed burning is a central feature of contemporary fire management, not just in Australia but in fire-prone countries around the world. Yet we lack a firm quantitative basis for understanding and comparing its effectiveness at mitigating risk across different regions. This project aims to address these gaps and provide critical support to agency decision makers across southern Australia by undertaking a systematic investigation of the drivers of prescribed burning effectiveness across the region. This project will thus support fire managers in transitioning from hectare targets to a set of tailor-made, risk-based approaches.

The project is divided into two phases: fire behaviour accounting and risk accounting. At the heart of the project is predictive modelling of the effect of prescribed burning on subsequent bushfire (wildfire) behaviour. In this project we combine ignition likelihood modelling, fuel type and arrangement from fire management agencies, weather representing all possible local fire weather conditions from Bureau of Meteorology and fire history including wildfire and variable combinations of edge and landscape treatments, applied to agency or model-derived burn blocks. From thousands of simulations, key outputs such as fire size and intensity are used estimate impacts on key management values: house loss, life loss, length of road damaged, length of powerline damaged and area burnt below minimum tolerable fire interval. We use Bayesian decision networks to estimate risk mitigation, including cost, available through different treatments. 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.

The key finding of the project is that the effectiveness of prescribed burning at mitigating area burnt by bushfire and other key values varies considerably across landscapes and values. That is, there is no one-size-fits-all solution to prescribed burning. This has major implications for fire managers, suggesting that tailored prescribed burning solutions are possible, based on the unique risk mitigation profile for any given suite of management values in that region. Further details are included in this report and journal articles listed herein.

While the project now draws to a close, its findings live on in the Prescribed Burning Atlas, a dedicated website for fire managers, researchers and anyone else interested in using our project to support their planning, decision making and communication. The Prescribed Burning Atlas will provide a geographically-based summary of risk for decision makers in an accessible, user friendly format. Our project is unique in placing the design and delivery of this utilisation output at its heart. Active involvement of end-users throughout 2020 and beyond will be crucial in ensuring uptake and translation into outcomes for end-users and the communities they serve. From a research perspective, key outstanding questions include quantification of risk mitigation for new values (smoke effects on human health, biodiversity measures, cultural burning) and expansion of the approach to represent the full richness of planned and unplanned landscape fire over time.



END-USER PROJECT IMPACT STATEMENT

Dr Felipe Aires, *Fire Incident Management Section, National Parks and Wildlife Service, Department of Planning, Industry and Environment, NSW*

It's expected that this project will trigger a significant change in the way fire management agencies deliver their hazard reduction programs and proposed fuel management activities.

The ability to quantify risk and cost to life and property as well as environmental impact and infrastructure damage under a range of different scenarios, will lead land managers to optimised burning strategies for wildfire risk mitigation.

This project will support agencies to make more robust evidence-based decisions and tailor their burning programs to optimise risk reduction and cost-benefits according to their needs. The results emerging from this project will be used by a broad range of stakeholders with multiple objectives.

The Prescribed Burning Atlas will strengthen the narrative that the reduction in risk from prescribed burning varies depending on management values and local variations in landscapes and vegetation communities across south eastern Australia.



PRODUCT USER TESTIMONIALS

Donald McDonald, *Fire Incident Management Section, National Parks and Wildlife Service, Department of Planning, Industry and Environment, NSW*

The Prescribed Burning Atlas neatly packages the wealth of knowledge produced by this project in a visually effective tool. The Atlas is the first tool of its kind to present clear results showing that a given rate of prescribed burning does not deliver the same degree of risk mitigation for all values, and the results differ between landscapes.

The tool allows end-users to explore inter-regional differences in risk mitigation from prescribed burning across multiple management values as well as different scenarios of hazard reduction (landscape against edge treatment) and their impact on those values for a pre-determined location. The ability to rapidly access the impacts of different mitigation scenarios will improve fire management agencies capacity to tailor their burning programs and optimise the risks in relation to costs.

This tool provides evidence-based messaging regarding the functional role of hazard reduction treatments in bush fire risk reduction and the expectation is that a broad range of end-users will utilise it with multiple objectives.

Over the next few months we will be working to help disseminating this tool through the end-user network and learning how each agency can harness this knowledge to improve risk reduction of prescribed fires.

Dr Adam Leavesley, *Research Utilisation Manager, ACT Parks and Conservation Service, Parks and Territory Services Division, Territory and Municipal Services*

The project contributed valuable data to the five-yearly ACT Government Regional Fire Management Plan 2019-2024 which details the ACT prescribed burning program. Particularly useful in that process was a commissioned extension of the main project work, in which the cost effectiveness of the various fire management options was simultaneously compared with the bushfire risk outcomes. Another really valuable product of the project was in understanding how the bushfire risk within different landscapes varies. This work identified landscape-level generalisations which can be used to decide how to approach prescribed burning across regions not specifically studied.



INTRODUCTION

The Bushfire and Natural Hazards CRC project, “*From hectares to tailor-made solutions for risk mitigation: systems to deliver effective prescribed burning across Australian ecosystems*”, aimed to systematically investigate drivers of prescribed burning effectiveness across southern Australia to provide critical support to decision makers in agencies across the region.

To deliver on this overarching goal, the project:

- compared the performance of different prescribed burning strategies in reducing risk to multiple values;
- derived fire regime characteristics and risk solutions for individual bioregions;
- provided results for current conditions and climate change scenarios, and
- organised results in an accessible interface, tailored for agency needs and amenable to updates.

A number of complementary project streams have been designed to meet these project objectives:

1. Fire spread simulations in case study landscapes, designed to sample variation in climate, population and land-use across southern Australia (Years 1-2);
2. Empirical analyses of prescribed burning effects on area burned, severity and other direct impacts of fire (Years 1-2);
3. Risk estimation for case study landscapes (Years 2-3);
4. Multi-criteria decision analysis to investigate trade-offs between key values and cost-benefit (Years 2-3);
5. Modelling of the effects of climate change on ignitions, fuel, fire regimes and risk (Years 2-4);
6. Data, models, software, testing and launch of the Prescribed Burning Atlas (Years 3-5).

In the 2019-2020 financial year, the project focus was on analyses including climate change and cost effectiveness, and development, testing and the launch of the Prescribed Burning Atlas. This report presents methodology and results across all project areas and years. Some material in this report is reproduced from previous annual reports, and two manuscripts:

Clarke et al. (2019) A new decision support tool for prescribed burning risk assessment, Australian Journal of Emergency Management, Monograph No. 4

Penman et al. (2020) Cost-effective prescribed burning solutions vary between landscapes in eastern Australia, Frontiers in Forests and Global Change.



BACKGROUND

Prescribed burning in Australia, currently stands at a crossroads. The 2009 Victorian Bushfires Royal Commission (BFRC) recommended an annual treatment target of 5% of public land in Victoria. Subsequently, concerns have been formally raised (e.g. BFRC Implementation Monitor 2013 Annual Report) that such an area-based target may not deliver the most effective levels of risk reduction for people and property in Victoria. Concurrently, some other states have adopted such a prescribed burning target, but formal attempts to evaluate its effects on risk to people, property and environmental values across different jurisdictions are lacking. Extrapolation of the 2009 BFRC recommendation pre-supposes that there is a 'one-size fits all' solution to the problem. While many agencies are moving toward planning systems supposedly based on risk assessment, knowledge of the best way to use prescribed fire to reduce risk to key values is generally lacking.

General principles 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 essence, the use of prescribed fire for risk mitigation involves understanding how risk to any particular management value will respond to variations in the spatial location and rates of treatment. Managers and policy-makers need to know how these fundamental elements of prescribed burning can be tailor-made to suit the environmental and human context of their local jurisdictions. A variety of fundamental problems need to be overcome to deliver suitable and effective prescribed burning solutions across different Australian environments.

The Bushfire and Natural Hazards CRC project "*From hectares to tailor-made solutions: systems to deliver effective prescribed burning across Australian ecosystems*" is designed to address these challenges.



RESEARCH APPROACH

This project has been informed by several fundamental questions. How does the efficacy of prescribed burning for altering fire regimes vary across differing environments? How can the demands of competing values be effectively resolved? How can prescribed burning address variation in human and natural values across landscapes and regions? How can fire behaviour modelling be applied to these questions in a way that harnesses its capacity while recognising its constraints?

The express purpose of our research was 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. In order to systematically explore how risk responds to treatment, 13 study areas representing as much of the diversity of southern Australia as possible were selected. This includes human and biophysical attributes such as population density, land use, vegetation type and climate (Figure 1, Table 1). The project is divided into two phases: fire behaviour accounting and risk accounting.

FIRE BEHAVIOUR ACCOUNTING

Central to the project is predictive modelling of the prescribed burning effects on the behaviour and incidence of unplanned fires (i.e. bushfires). Simulation modelling involves the coding and scaling up of fire behaviour models to predict spatial patterns of fire spread and extent at the landscape scale. These simulators are provided with certain inputs (e.g. the terrain, vegetation type and weather conditions in a case study landscape) to produce estimates of properties of a fire such as rate of spread, flame height and intensity. Simulation modelling has played a key role in advancing risk techniques in Australia and elsewhere. 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.

Choice and experimental design of fire behaviour simulator

Simulation models are widely used in fire management in Australia. For example, in South Australia and the eastern states the primary tool is the PHOENIX RapidFire model (Tolhurst et al. 2008; hereafter referred to as PHOENIX). PHOENIX is used by fire agencies in these states for incident prediction, risk assessment and strategic planning. We therefore decided in conjunction with end-users to make PHOENIX the simulation model in our project, although our approach is compatible with other fire simulators and simulation frameworks. PHOENIX and other similar simulators incorporate features of the landscape 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. no



ographic effects on temperature and relative humidity). Here we provide 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 data from the Bureau of Meteorology 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 (i.e. temperature, wind, wind change).
- Fire history includes bushfire as well as variable combinations of planned 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, with key outputs being 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. Initially we used a core set of values including house loss, life loss, length of road damaged, length of powerline damaged and area burnt below minimum tolerable fire interval (TFI). TFI is used as an indicator of ecosystem resilience at a landscape level, reflecting our scientific understanding of the amount of time required between fires to maintain vegetation diversity for specific vegetation types. These values were identified as priorities for end-users, and we are currently working with agencies to incorporate additional values and associated vulnerability models. In terms of previous simulation modelling studies, key improvements in this project 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.

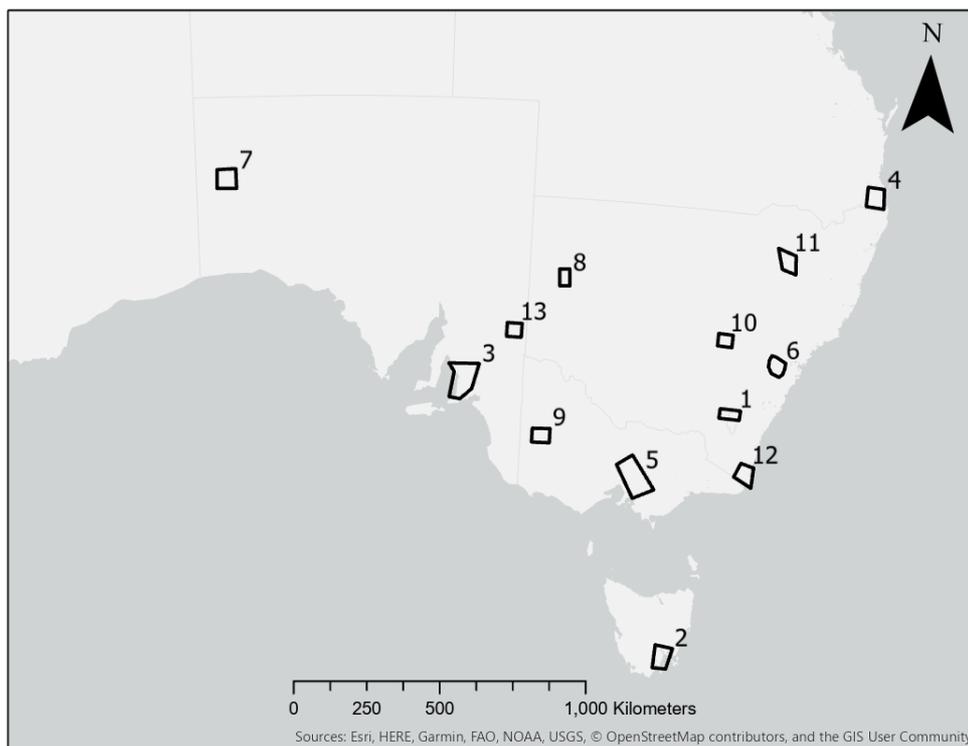


FIGURE 1: CASE STUDY LOCATIONS IN SOUTH-EASTERN AUSTRALIA. 1 = ACT CANBERRA, 2 = TAS HOBART, 3 = SA ADELAIDE HILLS, 4 = SOUTH-EASTERN QUEENSLAND, 5 = VIC CENTRAL HIGHLANDS, 6 = NSW BLUE MOUNTAINS, 7= SAS MAMUNGARI, 8 = NSW BROKEN HILL, 9 = VIC LITTLE DESERT, 10= NSW SW SLOPES, 11 = NSW NANDEWAR, 12 = NSW SOUTH-EAST CORNER, 13 = SA MURRAY DARLING BASIN.

Terrestrial Ecoregion	Bioregion/case study landscape	Notes
Temperate Broadleaf and Mixed Forest	South-eastern Queensland (Site 4)	These areas form a gradient of mainly forested landscapes along the east coast, ranges and slopes, encompassing wide variations in population and land uses. They complement existing risk modelling exercises done in the Sydney region and Otways
	Victoria Midlands (5)	
	South East Corner (12)	
	South Eastern Highlands (1)	
	Tasmanian Southern Ranges (2)	
	Sydney Basin (6)	
Mediterranean Forests, Woodlands and Scrub	Murray Darling Depression (13)	These areas form a mixed gradient of dry vegetation from western Victoria to South Australia
	Flinders Lofty Block (3)	
Temperate Grasslands, Savannas and Shrublands	Murray Darling Depression (9)	Case studies in these bioregions represent the spectrum of mixed agriculture and remnant vegetation that typifies moderately populated inland regions in Victoria and NSW
	Nandewar (11)	
	NSW South Western Slopes (10)	
Deserts and Xeric Shrublands	Great Victoria Desert (7)	Theses case studies situated in SA and NSW explore effects in sparsely populated rangelands and conservation reserves
	Broken Hill Complex (8)	

TABLE 1 ENVIRONMENTAL FEATURES OF CASE STUDY LANDSCAPES. SITE NUMBERS ARE PROVIDED IN FIGURE 1. ECOREGIONS SOURCED FROM AUSTRALIA'S NATIVE VEGETATION: A SUMMARY OF AUSTRALIA'S MAJOR VEGETATION GROUPS (2007) COMMONWEALTH OF AUSTRALIA



Simulation Information

PHOENIX (Tolhurst et al. 2008) was used to examine the interactive effects of fuel treatment and location under various weather scenarios. PHOENIX is a dynamic fire spread model which is used to predict the spread of fire from ignition points using inputs of weather, fuel load and terrain. This model simulates two dimensional fire growth over complex variable landscapes using Huygen's propagation principle of fire edge (Knight and Coleman 1993). Surface fire behaviour is based on adapted versions of the CSIRO Southern Grassland Fire Spread model (Cheney et al. 1998) and McArthur Mk5 Forest Fire Behaviour model (McArthur 1967; Noble et al. 1980). PHOENIX also includes a sub-model for spot fire propagation which incorporates ember production, distribution and ignition. The model outputs are fire behaviour metrics that are of value for subsequent risk analysis, namely intensity, rate of spread, flame height, ember density and convection.

All simulations were run in PHOENIX 4.0.0.7; the latest operational release and the version currently used by the Department of Environment, Land, Water and Planning (DELWP). Input data layers were provided by relevant agencies in each state and territory. Simulations were run at 180 m resolution to optimise model performance based on recommendations of Tolhurst et al. (2008) and consistent with current risk analysis undertaken by DELWP.

Weather

Fires were modelled using a series of fire weather scenarios based on the McArthur Forest Fire Danger Index (FFDI). This study used a selection of automatic weather station (AWS) weather streams based on the 3:00 pm FFDI. Where available, for each FFDI category (low, high, very high, severe, extreme, catastrophic), three weather types were selected based on the predominant drivers of FFDI; wind, windy with a change and temperature. Within each of these driver categories up to three replicates weather streams were chosen. The result of this process created up to 54 weather streams (6 FFDI x 3 drivers x 3 replicates).

Ignitions

One thousand ignition points were used per case study landscape. To achieve this, a set of 10,000 random points were generated from a uniform distribution across the study area. For each of these points, an ignition probability was calculated using a Bayesian network (BN) developed for ignitions in Victoria (Penman et al. 2014a) and subsequently tested in South Australia and Tasmania (Clarke et al. 2019). This BN has been found to be robust for NSW (unpublished data). The 1,000 points with the highest ignition probability were selected as ignition points for each case study landscape. This approach provided a realistic distribution of ignition likelihood compared with commonly used 'regular' ignition grids which space ignitions evenly throughout the landscape.



Fuel Treatment Options

To represent fuel management in the case study landscape, simulated spatial layers for bushfire history and prescribed fire treatment history were created. These fires histories were combined to create a series of fire history datasets.

Bushfires were modelled for a period of 30 years. For each year, bushfires were randomly selected from the bushfire history database until the threshold value was crossed. The threshold was the average area burnt which was calculated over the bushfire history layer that was created. Five unique fire histories were created for use in each case study landscape.

To create a prescribed burning history, landscapes were first divided into treatment blocks supplied by agencies or calculated based on a series of selection criteria: agency rankings of treatability (i.e. suitability for being treated with prescribed fire), extent of native vegetation, bushfire management zone and land tenure. Two burn-block datasets were then created: one for public land and one for both public and private land (see examples in Figures 2 and 3).

Six levels of prescribed burning effort (% per annum) were used: 1, 2, 3, 5, 10 and 15. A zero case (no prescribed burning) was also used. Five replicate treatment history layers were generated for each treatment level for a 20-year period (to allow treatment effects to be realised) by constrained random selection until the treatment level was within 0.05% of the target burn level.

Prescribed fire and bushfire histories were then merged to develop 30 fire history layers (6 prescribed burning levels x 5 replicates). Fire history layers were visually checked individually to ensure they represented realistic scenarios, both temporally and spatially.

To explore spatial effects, results were partitioned into edge (i.e. wildland-urban interface) and landscape (i.e. more remote) burns. This allowed a 7 x 7 matrix to be constructed with the six prescribed burning levels and the zero case for both edge and landscape burns (See Figure 11).

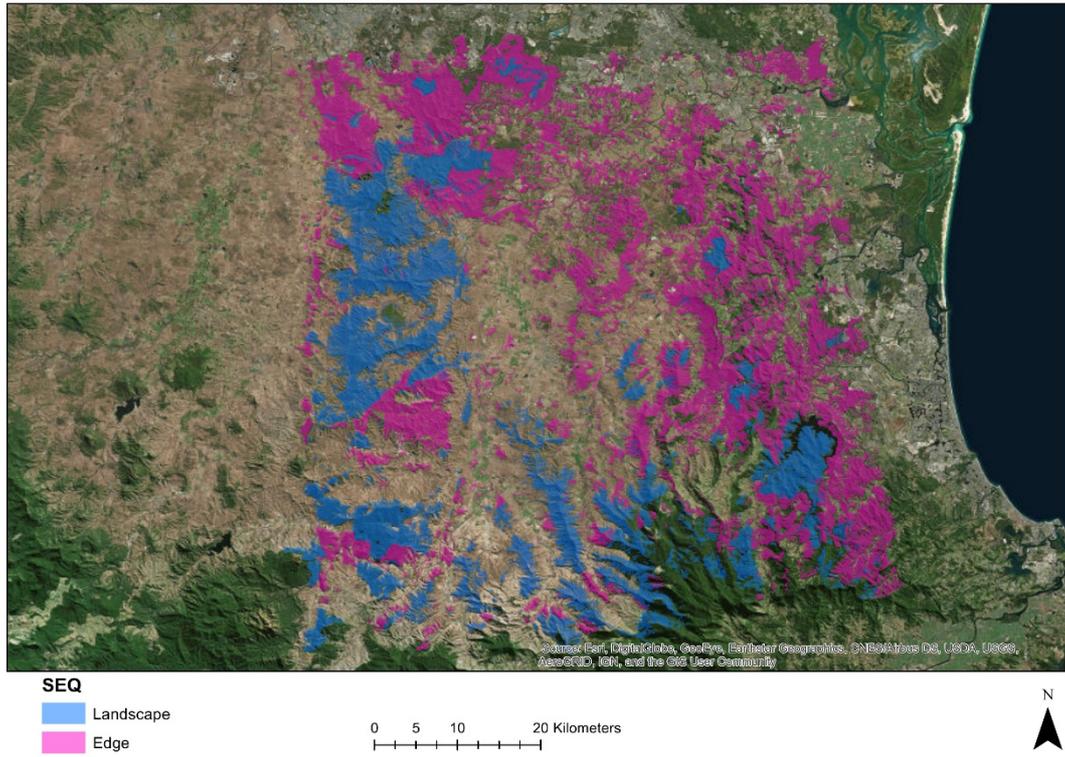


FIGURE 2 LOCATION OF EDGE AND LANDSCAPE BURN BLOCKS, SOUTH-EASTERN QUEENSLAND (SITE 4 IN TABLE 1)

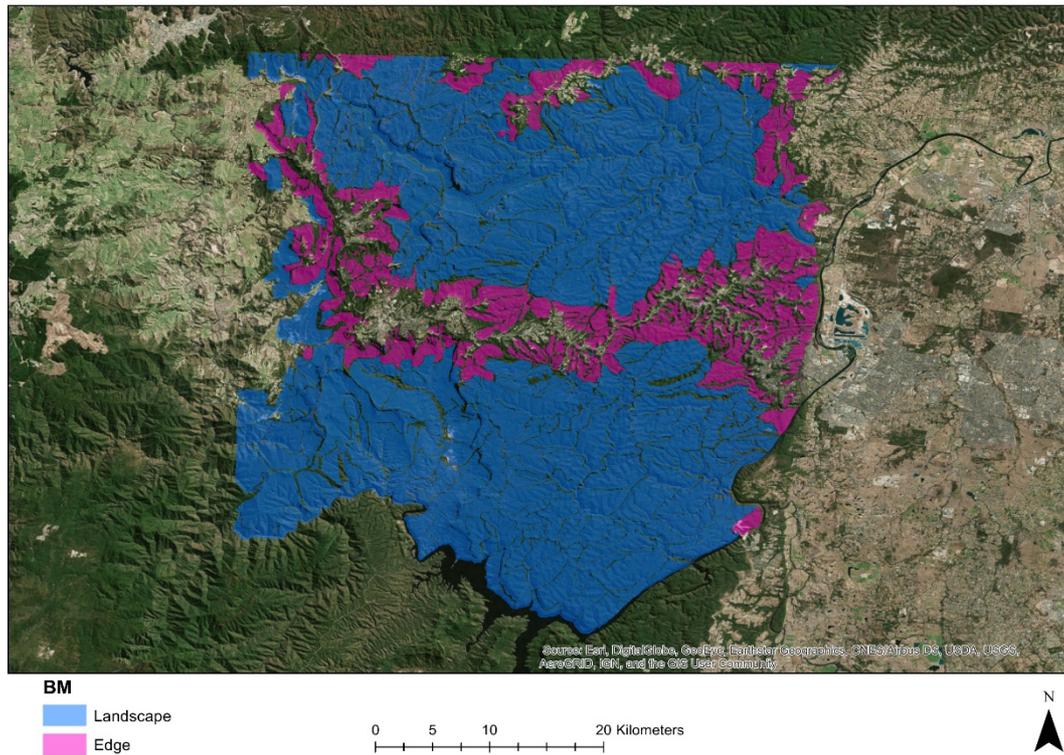


FIGURE 3 LOCATION OF EDGE AND LANDSCAPE BURN BLOCKS, BLUE MOUNTAINS (SITE 6 IN TABLE 1)

Replication

Up to 882,000 fires were simulated in each case study landscape. This was based on 1,000 ignition points, six FFDI categories, three FFDI drivers and 49 spatial treatment options. Due to regional differences in vegetation, population density and fire weather, not all levels of all of treatment conditions were possible in every case study landscape.

Ignition locations are shown in Figures 4 and 5 for two sample study landscapes.

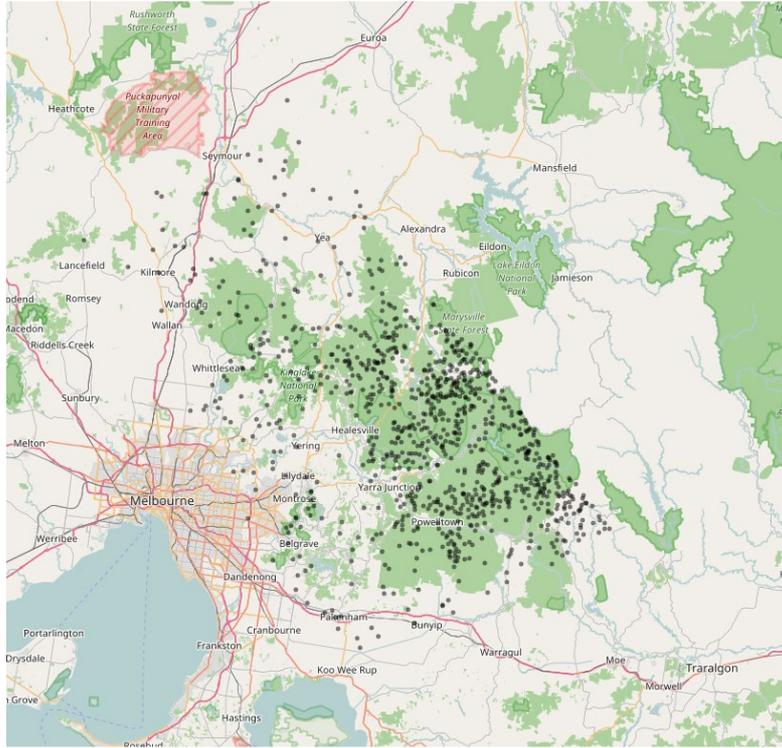


FIGURE 4 LOCATION OF IGNITION POINTS, EAST CENTRAL VICTORIA (SITE 5 IN FIGURE 1)

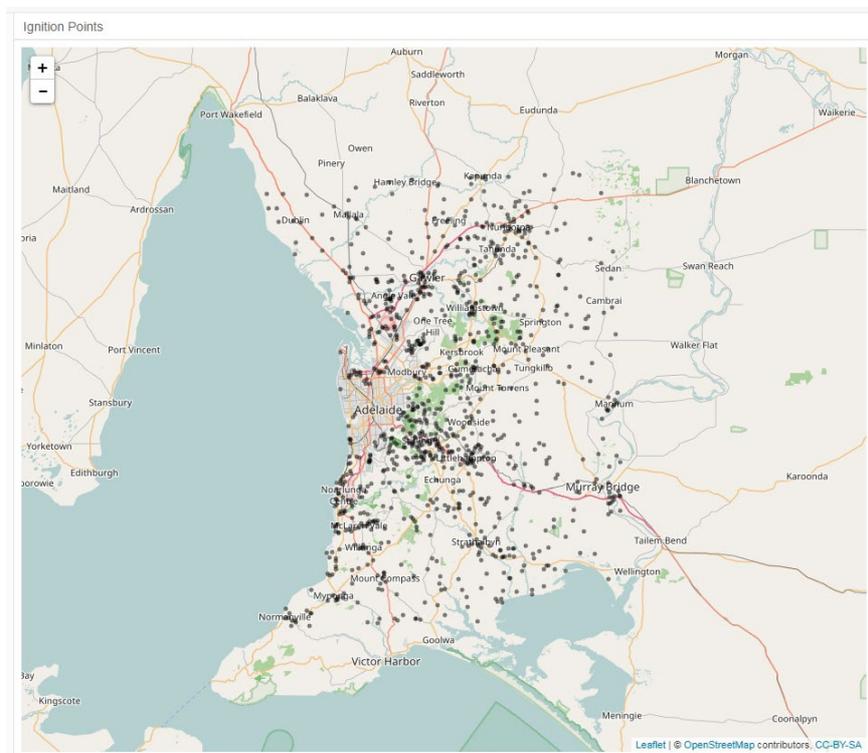


FIGURE 5 LOCATION OF IGNITION POINTS, ADELAIDE (SITE 3 IN FIGURE 1)



Key Outputs and Risk Estimation

Area Burnt

Output value: The area burnt per fire (ha).

Method of calculation: Direct PHOENIX output. All cells affected by fire.

House Loss

Output value: The number of houses lost per fire.

Inputs: PHOENIX prediction of convection, flame length and embers combined with address point layer.

Method of calculation: House loss was calculated in coordination with DELWP. For all cells affected by fire (flames, embers and/or convection), house loss probability was calculated based on the equations presented in Tolhurst and Chong (2011). Probability of house loss was then multiplied by the number of houses in that cell based on the address point layer. This gave a house loss per cell, which was then summed across the fire to provide a total number of houses predicted to have been lost in that fire.

Limitations: The equations of Tolhurst and Chong (2011) are based on a small set of fires in which house loss events occurred. These equations have not been tested on an independent data set due to the infrequent nature of such events.

Reliability: On a relative scale, this metric is considered reliable as it was developed based on PHOENIX output for real fires. As noted above, the metric was derived from a small subset of fires and the absolute values of these outputs are less reliable. It should be noted that actions of fire agencies or residents at individual properties and house construction standards were not explicitly considered in this metric.

Life Loss: Harris Method

Output value: The number of lives lost per fire.

Inputs: PHOENIX-based prediction of houses exposed to fire using the address point layer and population density.

Method of calculation: The number of houses exposed, and people exposed to fire (flames embers or convection) per cell was calculated. The people and houses exposed were then used to calculate expected fatalities using the formulas from Harris et al. (2012).

Limitations: There are several limitations to the method. Firstly, the equations have been developed from empirical data for a limited set of fires. These fires have not been run in PHOENIX for comparison. Secondly, the equations have a relatively poor fit. Finally, the population density layer has been derived from the mesh-block dataset obtained from the Australian Bureau of Statistics. Individual mesh-blocks are not consistent in size or shape and the underlying data on



population and house density is based on the 2011-2012 census. As a result, there are unavoidable spatial inaccuracies in this data set.

Reliability: As a relative measure, the metric is considered reasonably robust and more reliable than the ratio method (see above) as it considers the houses and population exposed. However, it has the unavoidable limitation of not considering the actions of agencies or people in response to fires.

Roads

Output value: The length of road damaged per fire (m).

Inputs: Total length of road per cell, obtained from agencies, and PHOENIX output for fire intensity (kW/m).

Method of calculation: To calculate loss, a threshold-based calculation was used where roads and powerlines were considered destroyed if they were exposed to a fire with intensity greater than 10,000 kW/m (Deloitte 2015).

Limitations: The output of this calculation is binary; the infrastructure is either destroyed or not-destroyed. No consideration was given to the level of destruction, which will obviously influence the repair cost. Additionally, road construction is not the same across all assets and their durability will be different. Furthermore, the length of loss is not necessarily equal to the impact. For example, 100 m of loss could be one road for 100 m or 50 m for two separate roads. The consequences of these two scenarios are potentially very different.

Reliability: The locations from the infrastructure data are considered to be reliable and the thresholds used are based on observations and expertise from real fires. However, not all roads will be captured in every agency dataset and some locally important roads may be excluded.

Powerlines

Output value: The length of powerline infrastructure damaged per fire (m).

Inputs: Powerline lengths per cell, obtained from agencies, and PHOENIX output for fire intensity (kW/m).

Method of calculation: To calculate loss, a threshold based calculation was used where powerlines were considered destroyed if they were exposed to a fire with intensity greater than 10,000 kW/m (Deloitte 2015).

Limitations: The output of this calculation is binary; the infrastructure is either destroyed or not-destroyed. No consideration was given to the level of destruction, which will influence the repair cost. Additionally, powerline construction is not the same across all assets and their durability will be different. Furthermore, the length of loss is not necessarily equal to the impact. For example, one hundred metres of loss could be one powerline for one hundred metres or fifty metres for two separate powerlines. The consequences of these two scenarios are potentially very different.



Reliability: The locations from the infrastructure data are considered to be reliable and the thresholds used are based on observations and expertise from real fires. However, not all powerlines will be captured in every agency dataset.

Area Burnt Below Minimum Tolerable Fire Interval

Output value: The area (ha) of vegetation burnt below its minimum tolerable fire interval (TFI) per fire.

Inputs: PHOENIX outputs of intensity and fire rate of spread, fire history layer of each scenario, spatial map of vegetation types and agency information on the minimum TFI.

Method of calculation: Fire history layers for each scenario were converted to a time since fire (TSF) spatial layer. For each fire, the fire intensity and rate of spread values from PHOENIX were overlayed with the TSF and minimum TFI layers. A cell was considered affected if it was burnt before the minimum TFI was reached.

Limitations: This metric considers all fires equally and does not account for fire intensity.

Reliability: The reliability of the metric is dependent on the quality of the underlying spatial layers and the estimation of TFI for each vegetation type.

Environmental Cost

Output value: Environmental cost of fires (\$).

Inputs: PHOENIX hectares burnt per fire.

Method of calculation: Environmental cost was calculated at \$1,000/ha burnt based on the values presented in Stephenson (2012).

Limitations: Values were based on a sample of only five large fires. While two of these fires occurred in the East Central Victoria case study landscape, the spatial layout of resources is likely to have been a major driver of this estimate of the social, economic and environmental costs of wildfire.

Reliability: These values have not been derived for fires less than 100,000 ha in size and therefore the metric is considered untested for such fires.

Life Value Cost

Output value: Social and economic cost of fires.

Inputs: Life Loss: Harris Method (see above).

Method of calculation: To calculate the social cost of fires, the value of \$3,652,000 per life loss was applied (Stephenson 2010).

Limitations: Values were based on a sample of only five large fires. While two of these fires occurred in the East Central Victoria case study landscape, the spatial



layout of resources is likely to have been a major driver of this estimate of the social, economic and environmental costs of wildfire. This is a crude metric and does not include a range of other impacts e.g. psychological trauma, loss of personal belongings (Stephenson 2010).

Reliability: These values have not been derived for fires less than 100,000 ha in size and therefore the metric is considered untested for such fires.

House Value Cost

Output value: Social and economic cost of fires (\$).

Inputs: House loss.

Method of calculation: To calculate the cost of fires relating to house loss, the value of \$500,000 per house was applied, based on estimates of median property values across the various study areas (based on www.yourinvestmentproperty.com.au accessed November 2017)

Limitations: Housing prices vary considerably across the study area, but we did not want to bias results towards more expensive areas by incorporating actual house costs.

Reliability: N/A.

Treatment Cost

Output value: Cost of edge and landscape prescribed burning treatment (\$/ha).

Inputs: Area treated (ha).

Method of calculation: Treatment costs were calculated using the equations in Penman et al. (2014b) which had a log-log relationship between treatment size and cost per ha of treatment. Briefly, values are based on agency-supplied data which represent a wide range of costs: staff costs for planning and documenting the burn, informing neighbours through letterbox drops and advertising on the local radio and print media, preparation or maintenance of boundary trails, vehicle and staff costs for implementing the burn and vehicle and staff costs for patrolling and cleaning up after the burn. A greater number of these costs were relevant to edge burns, resulting in higher per ha costs than landscape burns.

Limitations: The estimates are limited by the input data – cost estimates and their application on a hectare-basis as documented in Penman et al. (2014b).

Reliability: These data are considered reliable but would likely benefit from regular review and updates.

RISK ACCOUNTING

We use Bayesian decision networks to estimate the level of risk mitigation available with different prescribed burning treatments. 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. The following features make them an ideal tool for bushfire risk assessment:

- Their graphical nature makes them easy to understand (See Figure 6)
- 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 the approach we used, 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 among case study landscapes. This makes it possible to investigate the trajectory of risk reduction for different values in a given region and to determine how such trajectories differ between regions, both in absolute as well as relative terms (e.g. compared to zero treatment). Trajectories can also be used as inputs into trade-off analyses, highlighting the ramifications of choosing particular values or sets of values. Identification of 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 BN. The impacts of bushfire can be wide-ranging, including those to livelihoods, human health, infrastructure, primary production and ecosystem services. Estimates of the cost of bushfires are therefore substantial, although they vary considerably depending on scope and method used. We included two classes of cost initially: treatment costs (with separate cost for edge and landscape) and impact costs (e.g. cost of house loss, road and powerline damage). Local trajectories of cost for given treatment rates and locations can be tracked and compared among bioregions, allowing identification of the most cost-effective prescribed burning strategies, either overall or for a given management value.

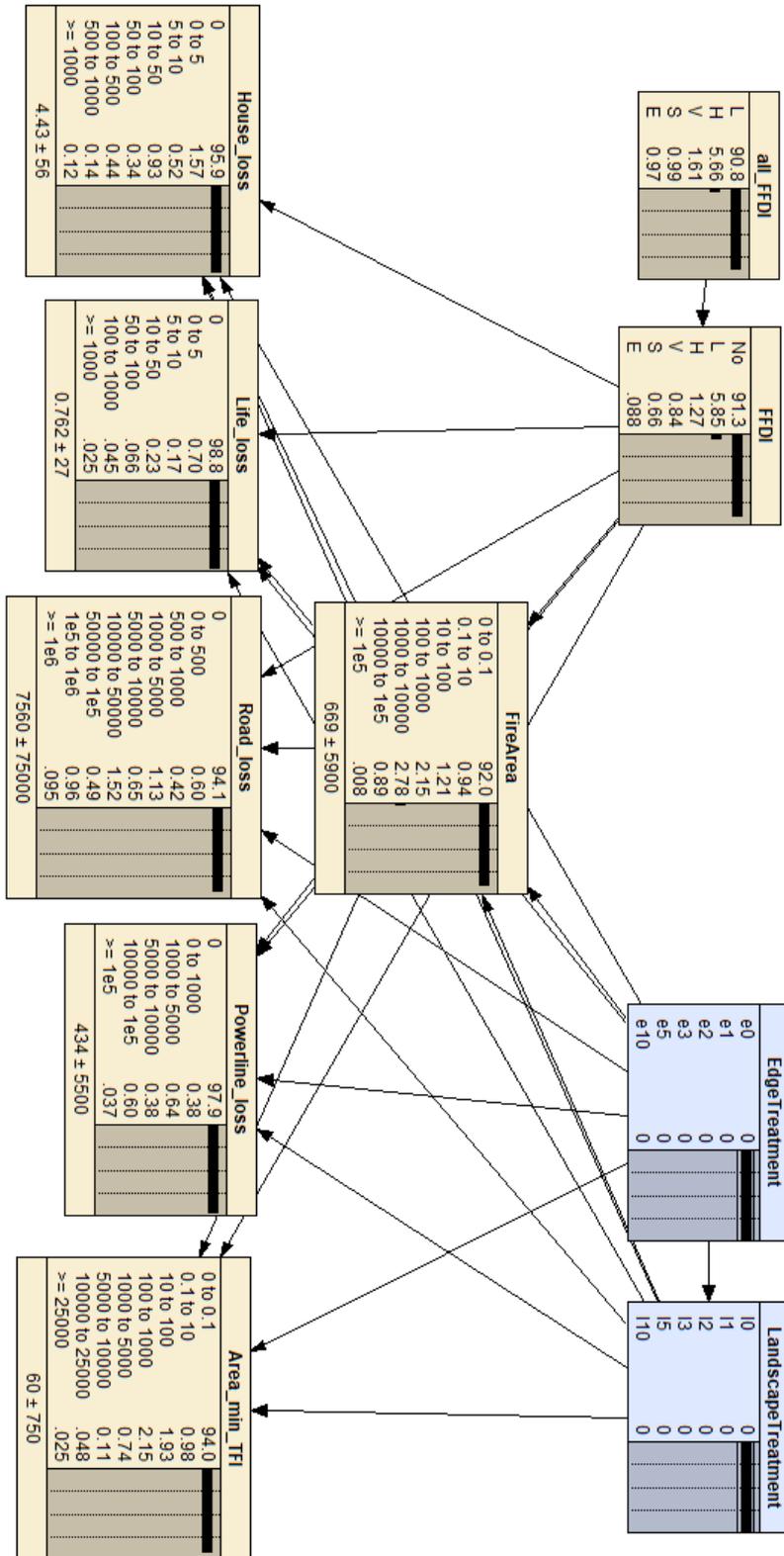


FIGURE 6: EXAMPLE OF THE BAYESIAN DECISION NETWORK STRUCTURE USED IN THE PROJECT. WEATHER (BOTH DIRECTLY (ALL_FFDI) AND INDIRECTLY VIA IGNITION PROBABILITY (FFDI)) AND EDGE AND LANDSCAPE TREATMENT RATE INFLUENCE AREA BURNT, HOUSE LOSS, LIFE LOSS, ROAD LENGTH DAMAGED, POWERLINE LENGTH DAMAGED AND AREA BURNT BELOW MINIMUM TOLERABLE FIRE INTERVAL (TFI).

DETERMINING RISK MITIGATION

KEY OUTPUTS

The output across the entire project (fire behaviour simulations, risk estimations, applied analyses) is layered allowing for multiple levels of interrogation and interpretation (Figure 7). The most basic or 'raw' layer of project output relates to the fire behaviour simulations in each landscape, with a focus on the area burnt by wildfire in response to the various treatment, ignition and weather inputs, as simulated by Phoenix (Figure 8). These summarise the ~100,000 simulations per case study landscape. This raw output is then converted into risk estimates for individual management values, both for absolute values (Figure 9) as well as relative to the zero treatment (Figure 10). Such output can be visualised to compare different case study landscapes if just a single set of edge and landscape treatments are considered (e.g. equal edge and landscape treatment). Alternately, all combinations of edge and landscape treatment can be explored for individual case study landscapes (Figure 11). Additional analyses explore drivers and other features of results (Figure 12).

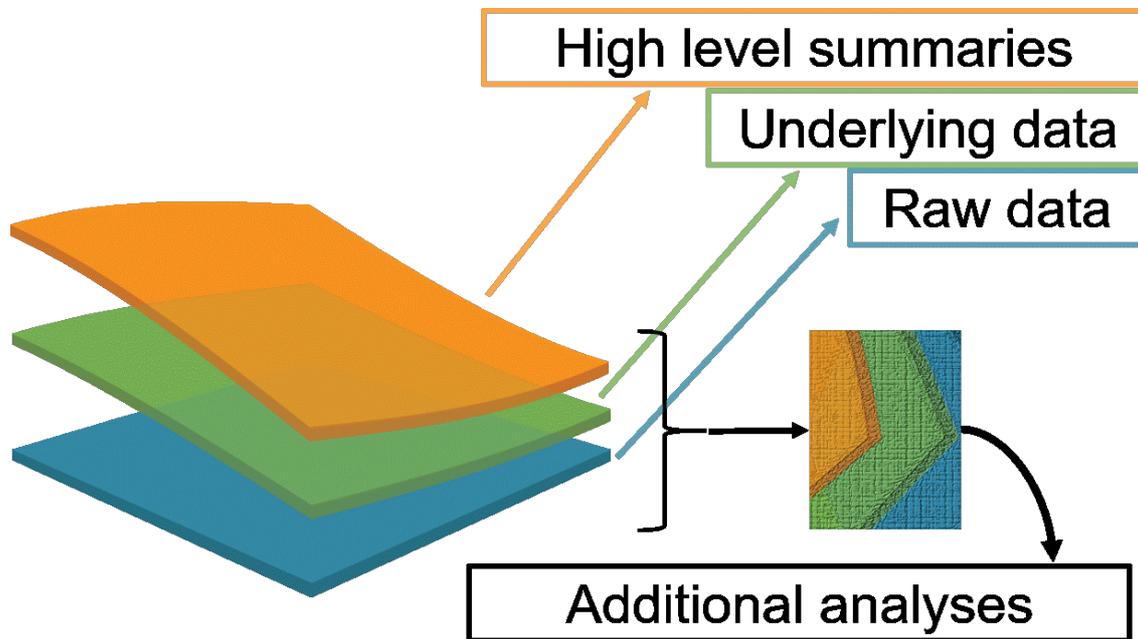


FIGURE 7 LAYERED NATURE OF PROJECT OUTPUT. THE RAW SIMULATIONS SPAN THOUSANDS OF COMBINATIONS OF CASE STUDY LANDSCAPES, WEATHER STREAMS, IGNITION LOCATIONS AND TREATMENT RATES AND LOCATIONS. THROUGH BAYESIAN DECISION NETWORKS, THIS RAW DATA IS TRANSFORMED INTO RISK DATA ('UNDERLYING DATA'), WHICH IS THEN REFINED FURTHER INTO HIGH LEVEL SUMMARIES SHOWING THE RESPONSE OF RISK TO TREATMENT. ADDITIONAL ANALYSES TAKE ONE OF THESE THREE DATA STREAMS AS THEIR INPUTS E.G. TRADE-OFFS, CLIMATE CHANGE PROJECTIONS.

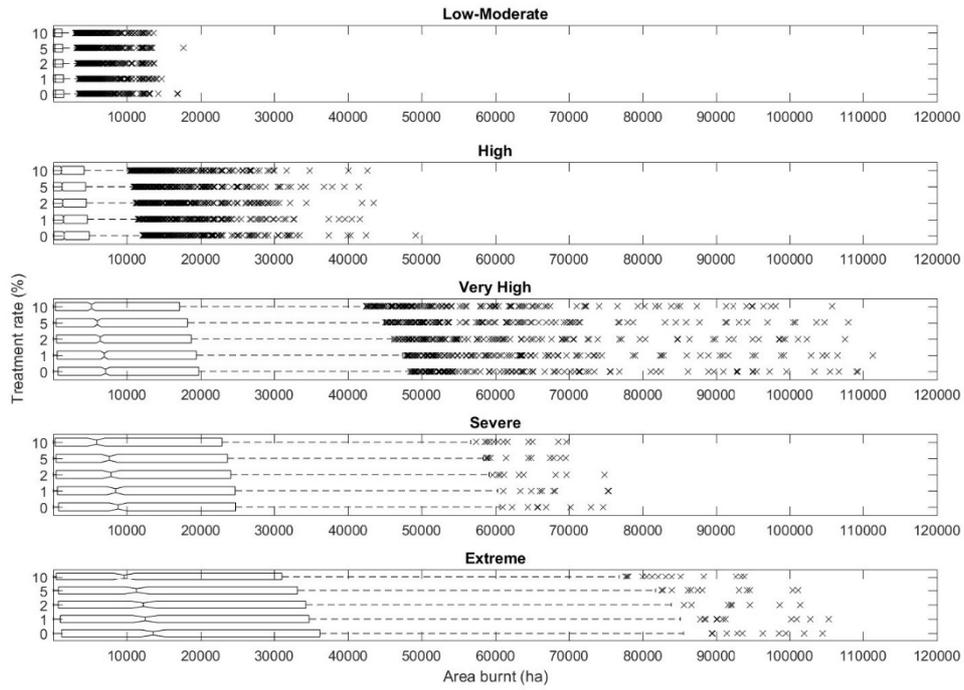


FIGURE 8: RAW SIMULATION OUTPUT SHOWING EFFECT OF DIFFERENT RATES (EQUAL EDGE AND LANDSCAPE TREATMENT) OF PRESCRIBED BURNING ON SIMULATED BURNT AREA UNDER DIFFERENT CATEGORIES OF FOREST FIRE DANGER INDEX FOR THE TASMANIA (HOBART) CASE STUDY LANDSCAPE (SITE 2 IN FIGURE 1).

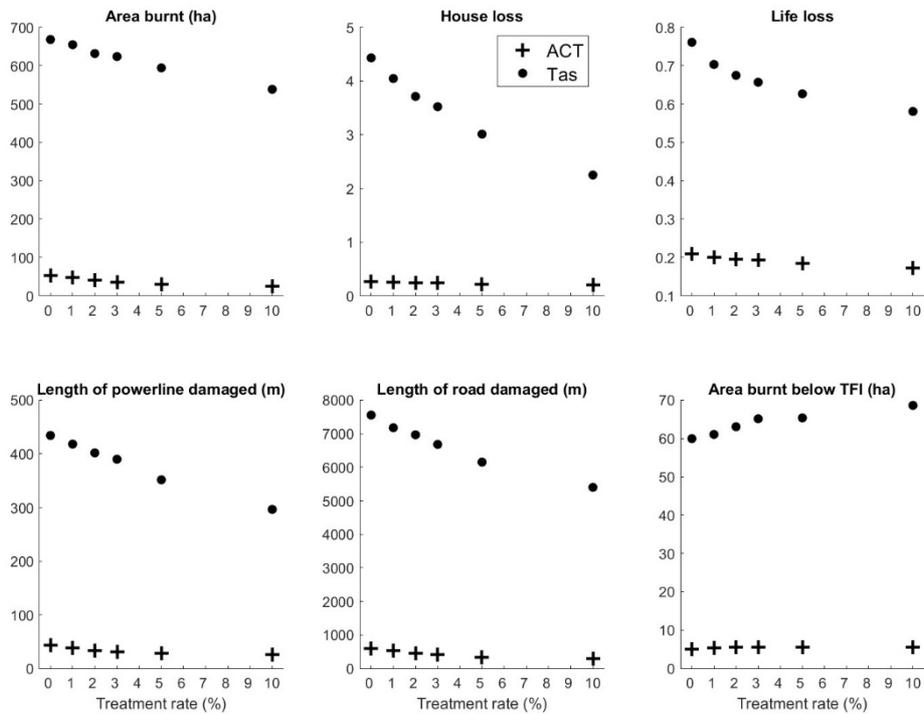


FIGURE 9: RISK DATA (OUTPUT FROM BAYESIAN DECISION NETWORK) SHOWING EFFECT OF DIFFERENT RATES OF PRESCRIBED BURNING (EQUAL EDGE AND LANDSCAPE TREATMENT) ON ABSOLUTE RISK ACROSS KEY MANAGEMENT VALUES FOR THE ACT AND TASMANIA (HOBART) CASE STUDY LANDSCAPES (SITES 1 AND 2 IN FIGURE 1).

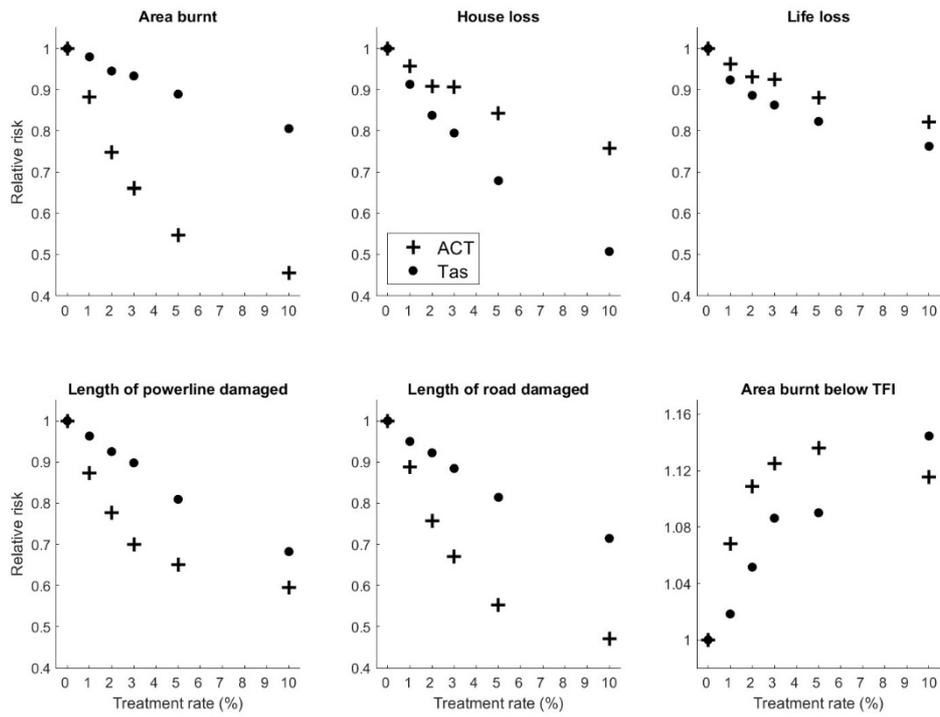


FIGURE 10: RISK DATA (OUTPUT FROM BAYESIAN DECISION NETWORK) SHOWING EFFECT OF DIFFERENT RATES OF PRESCRIBED BURNING (EQUAL EDGE AND LANDSCAPE TREATMENT) ON RELATIVE RISK ACROSS KEY MANAGEMENT VALUES FOR THE ACT AND TASMANIA (HOBART) CASE STUDY LANDSCAPES (SITES 1 AND 2 IN FIGURE 1).

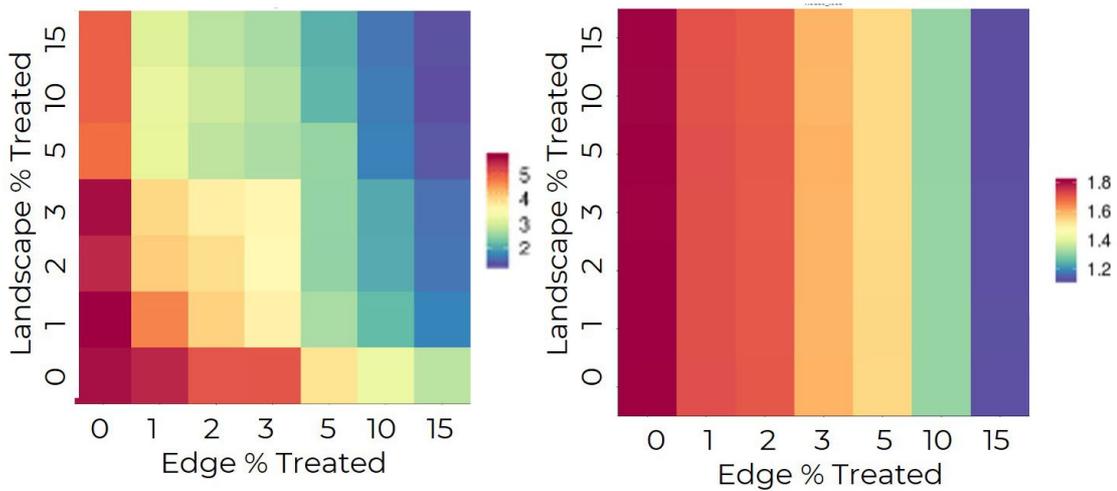


FIGURE 11 HIGH LEVEL SUMMARIES FOR HOUSE LOSS IN BLUE MOUNTAINS AND SOUTHEAST QUEENSLAND CASE STUDY LANDSCAPES (SITES 6 AND 4 IN FIGURE 1). EACH PLOT SHOWS THE TRAJECTORY OF RISK REDUCTION/INCREASE FOR HOUSE LOSS IN RESPONSE TO CHANGING RATES (0 TO 15%) AND LOCATIONS (EDGE ON X-AXIS; LANDSCAPE ON Y-AXIS) OF PRESCRIBED BURNING TREATMENT. RED REPRESENTS HIGHER LOSS, BLUE REPRESENTS LOWER LOSS.

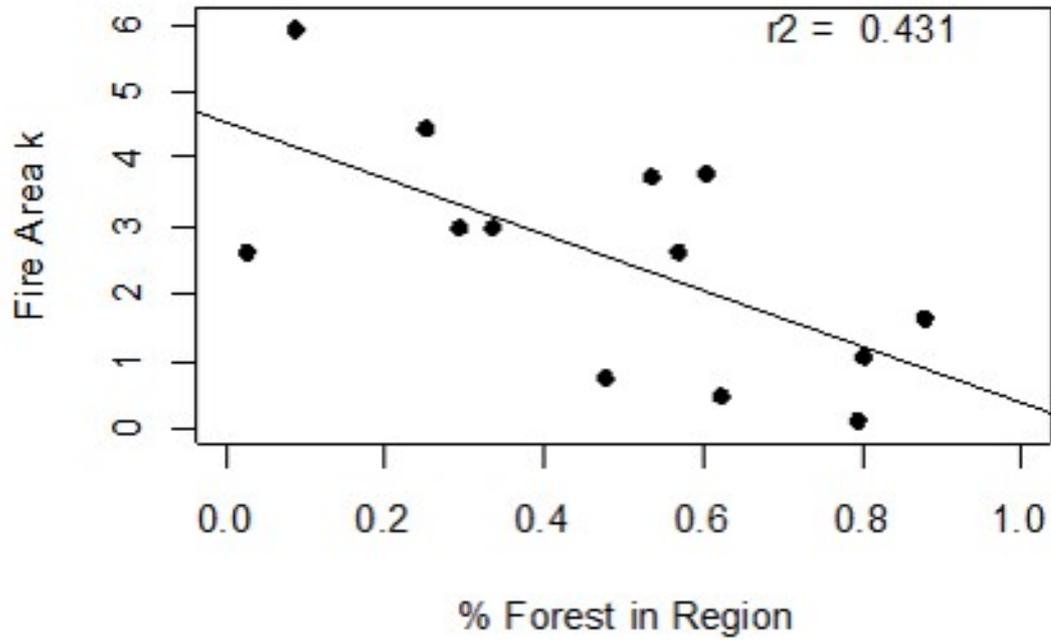


FIGURE 12 EXAMPLE OF ADDITIONAL ANALYSIS, SHOWING RELATIONSHIP BETWEEN FOREST COVER AND K, A PARAMETER DESCRIBING THE STRENGTH OF THE RELATIONSHIP BETWEEN AREA BURNT AND PRESCRIBED BURNING TREATMENT, FOR ALL CASE STUDY LANDSCAPES (I.E. SITES 1-13 IN FIGURE 1). AT LOW K VALUES, FIRE SIZE IS REDUCED MORE STRONGLY IN RESPONSE TO TREATMENT, WITH THIS OCCURRING MORE OFTEN IN FORESTED AREAS.



COST-EFFECTIVENESS, TRADE-OFFS AND CLIMATE CHANGE

By factoring in the cost of both prescribed burning treatment and costs related to the impact of bushfire, it is possible to begin to develop a comprehensive assessment of the true costs of fire management using prescribed burning. Differing prescribed burning strategies are likely to result in different levels of risk reduction to different management values, necessitating an approach for weighing up trade-offs. Multi-criteria decision analysis (MCDA) is a way of investigating such trade-offs, and can incorporate tools such as Pareto Surfaces, Robust Decision Making and Mutually Acceptable Outcomes (Driscoll et al. 2016).

Figure 13 shows the total cost of planned and unplanned bushfire, stratified by edge and landscape treatment, for a sample case study landscape (Victoria East Central). Different strategies result in different costs for individual management values in the same landscape, thus necessitating trade-offs (Figure 14). Taking this information a step further, the trajectory of total risk cost can be compared among case study landscapes (Figure 15), revealing several distinct groupings of case study landscapes with similar solutions for most cost-effective treatment strategies (Figure 16). Results shown in Figures 15 and 16 are based on 1) Spearman rank correlations to compare the ranking of the 49 treatments between the case study landscapes, with strong correlations between all case study landscapes expected if a single solution existed, and 2) non-metric Multi-Dimensional Scaling (nMDS) using Bray-Curtis similarity index to look for groupings in the relative costs of treatments and impacts. Total costs were standardised on a scale of 0–1, with 0 representing the minimum cost for the case study region and 1 representing the maximum cost, to remove the regional variations in the magnitude of the costs. nMDS helps identify regions with similar patterns in the cost data across treatments and impacts with less emphasis on the ordering.

Cost analyses can be separated into individual management values or aggregated into impacts associated with prescribed burning treatment or bushfire. An example of such analytical flexibility is shown for the case study landscape in the ACT (Figures 17 and 18).

Many studies assume a stationary climate, an assumption we know is incorrect, so here we factor in changes in the prevalence of fire weather conditions (Evans et al. 2014) to risk estimation values. The climate change results represent an ensemble of models, reflecting uncertainty in the potential response of climate to increased greenhouse gas emissions. This range of altered climates – and altered frequency of fire danger categories at each case study location – can be input into the Bayesian decision networks described above, influencing ignition probability and fire behaviour. As an example, the influence of climate change for risk mitigation afforded by prescribed burning treatments is shown for the NSW Nandewar case study landscape burnt by bushfire (Figure 19).

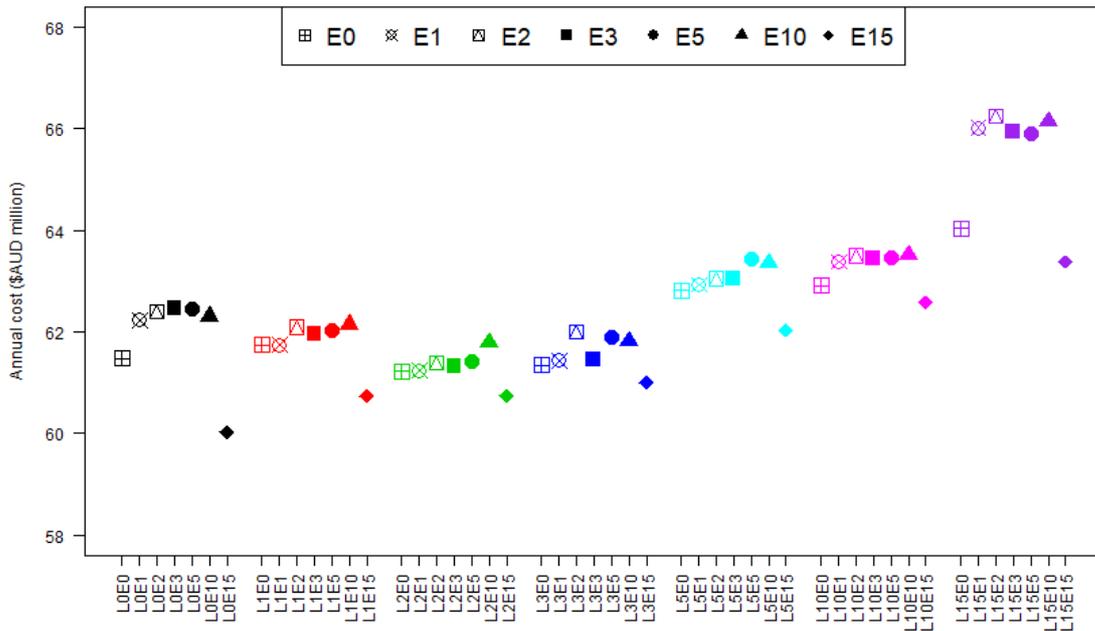


FIGURE 13 TOTAL ANNUAL RISK COST (INCLUDING TREATMENT AND BUSHFIRE IMPACT COSTS) UNDER DIFFERENT TREATMENT SCENARIOS FOR THE VICTORIA EAST CENTRAL LANDSCAPE (SITE 5 IN FIGURE 1). EACH MARKER SHOWS THE COMBINATION OF EDGE TREATMENT (SHAPE) AND LANDSCAPE TREATMENT (COLOUR).

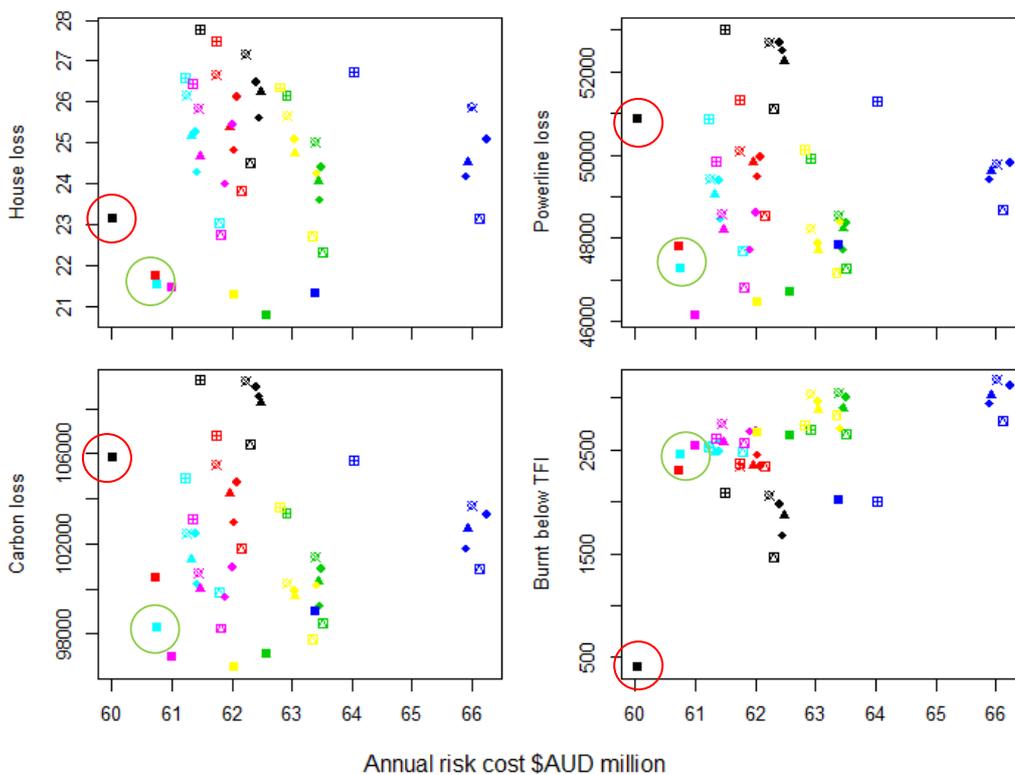


FIGURE 14 TRADE-OFFS ARE INHERENT GIVEN VARIATION IN RISK TO SPECIFIC MANAGEMENT VALUES UNDER DIFFERENT TREATMENT SCENARIOS IN THE VICTORIA EAST CENTRAL CASE STUDY LANDSCAPE (SITE 5 IN FIGURE 1). EACH MARKER SHOWS THE COMBINATION OF EDGE TREATMENT (SHAPE) AND LANDSCAPE TREATMENT (COLOUR). RED AND OLIVE CIRCLES INDICATE L0E3 AND L5E3 TREATMENTS, RESPECTIVELY: TWO LOW-COST TREATMENT OPTIONS WHICH RESULT IN STRONGLY CONTRASTING RISK MITIGATION FOR THE FOUR DIFFERENT ASSETS SHOWN ABOVE.

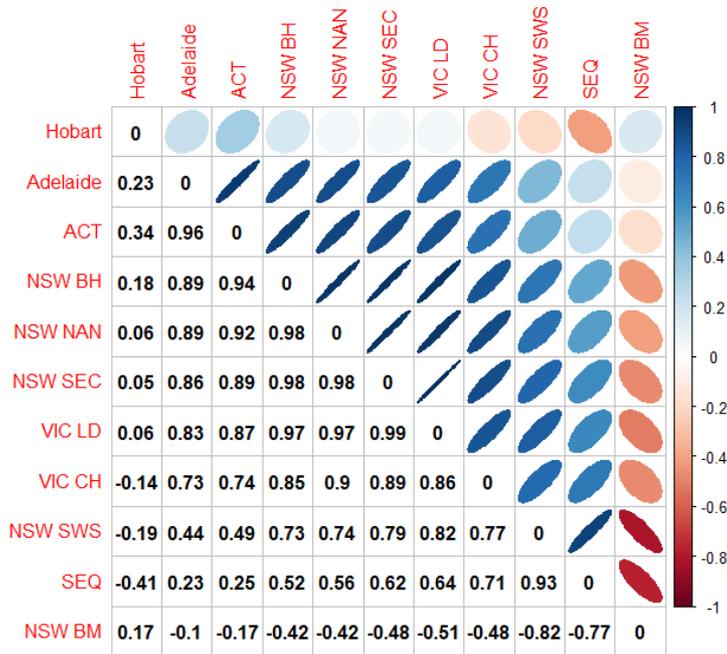


FIGURE 15 RANK CORRELATIONS OF TOTAL COST ACROSS THE 49 PRESCRIBED BURNING SCENARIOS TESTED. BLUE ELLIPSES REPRESENT POSITIVE RELATIONSHIPS AND RED REPRESENT NEGATIVE RELATIONSHIPS. THIN ELLIPSES REPRESENT A STRONG RELATIONSHIP WHEREAS BROAD ELLIPSES INDICATE GREATER UNCERTAINTY IN THE CORRELATION. THE LOWER LEFT TRIANGLE SHOWS THE CORRELATION COEFFICIENTS SEE FIGURE 1 AND TABLE 1 FOR CASE STUDY LANDSCAPE DETAILS.

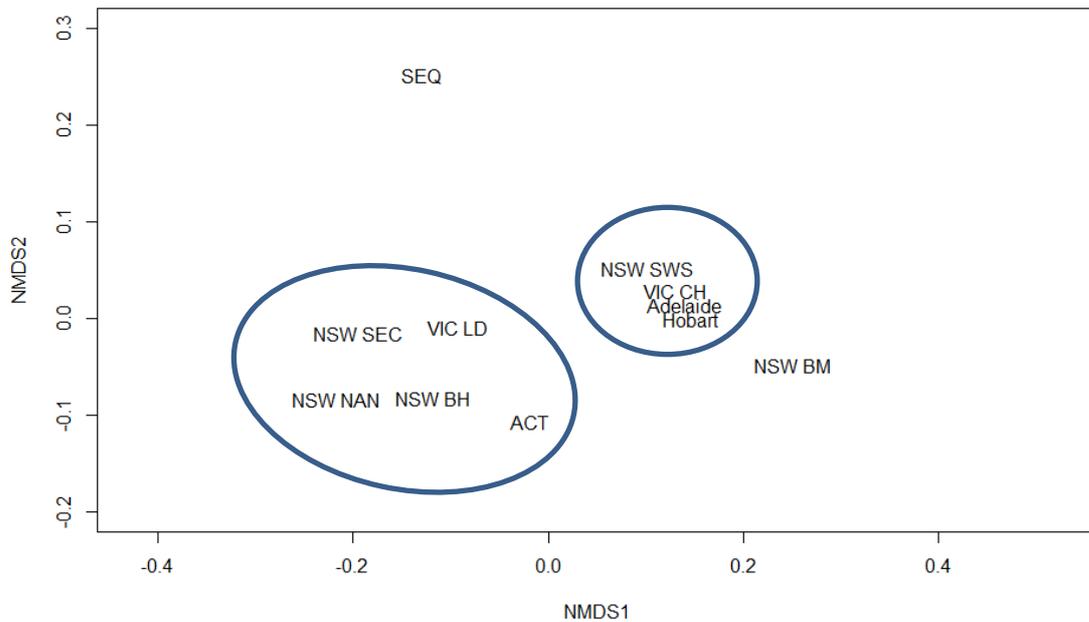


FIGURE 16 MOST CASE STUDY LANDSCAPES FALL INTO ONE OF TWO CLUSTERS (CIRCLED), IN TERMS OF THE BROAD RESPONSE OF TOTAL COST TO PRESCRIBED BURNING STRATEGIES IN THESE LANDSCAPES. BLUE MOUNTAINS AND SOUTHEAST QUEENSLAND RESPOND DIFFERENTLY TO MOST OTHER CASE STUDY LANDSCAPES. RESULTS ARE BASED ON NON-METRIC MULTIDIMENSIONAL SCALING RESULTS OF NORMALISED COST DATA, WHICH SHOW HOW CONSISTENT THE ORDERING OF BEST TREATMENT STRATEGIES ARE ACROSS ALL LANDSCAPES.

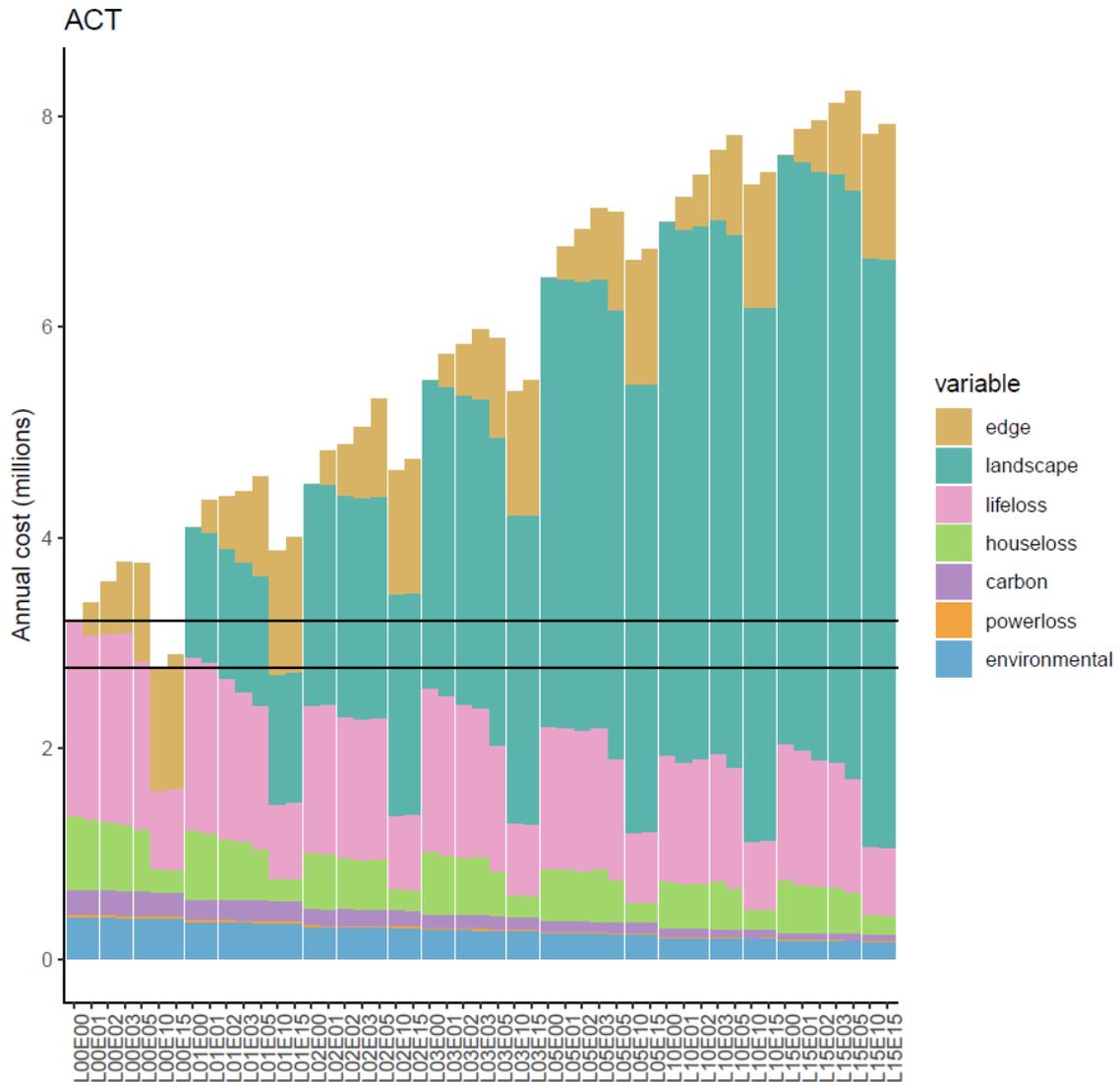


FIGURE 17 COST DATA FOR INDIVIDUAL MANAGEMENT VALUES IN RESPONSE TO DIFFERING TREATMENT STRATEGIES IN THE ACT CASE STUDY LANDSCAPE (SITE 1 IN FIGURE 1). THE LABELS ON THE X-AXIS REFER TO RATES OF LANDSCAPE AND EDGE TREATMENT E.G. L00E00 IS ZERO TREATMENT AT EITHER EDGE OR LANDSCAPE, WHILE L15E15 IS 15% TREATMENT AT BOTH EDGE AND LANDSCAPE.

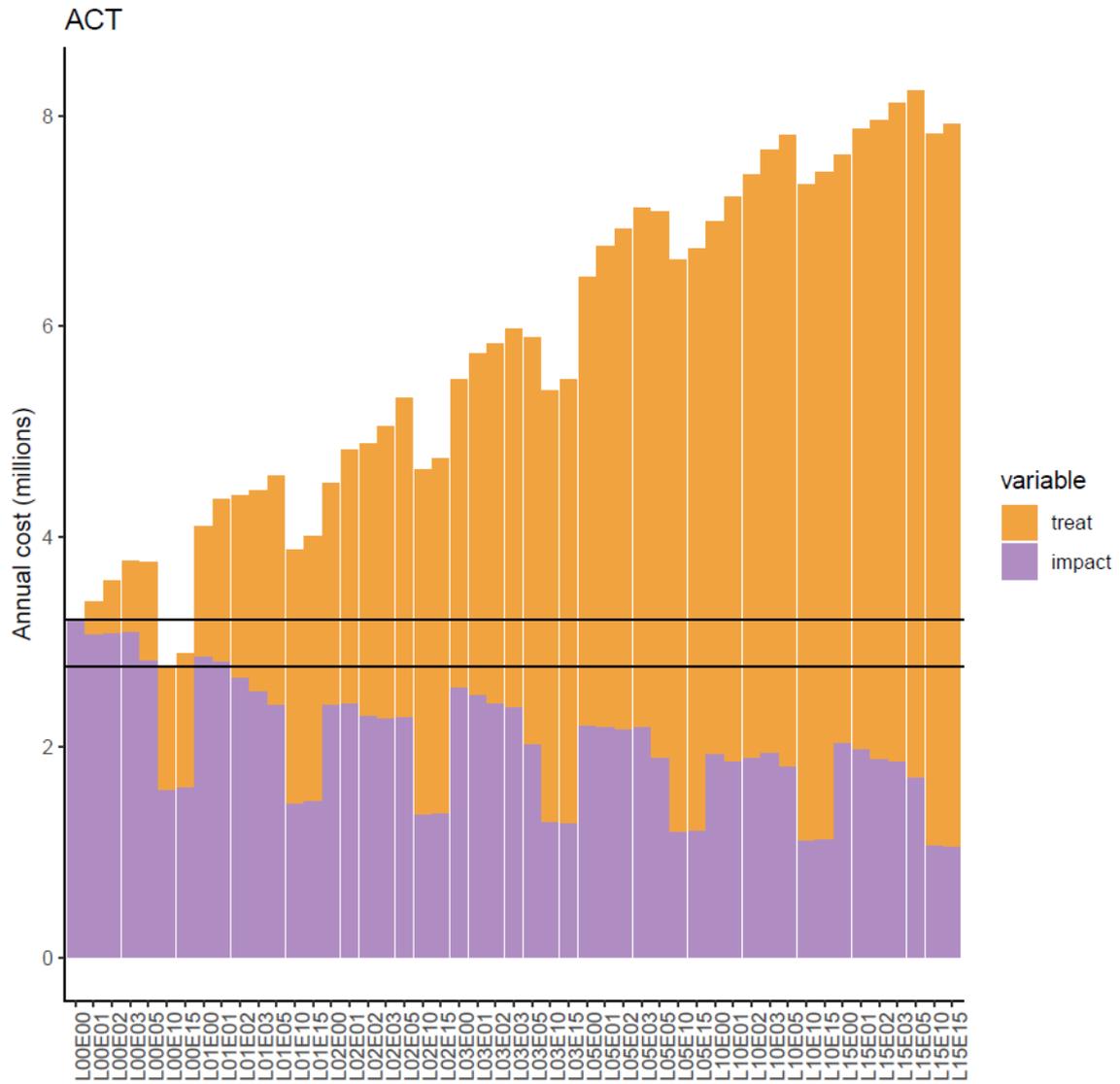


FIGURE 18 COST DATA FOR THE TWO MAJOR CATEGORIES OF FIRE MANAGEMENT – TREATMENT AND IMPACT OF WILDFIRE -IN RESPONSE TO DIFFERING TREATMENT STRATEGIES IN THE ACT CASE STUDY LANDSCAPE (SITE 1 IN FIGURE 1). THE LABELS ON THE X-AXIS REFER TO RATES OF LANDSCAPE AND EDGE TREATMENT E.G. L00E00 IS ZERO TREATMENT AT EITHER EDGE OR LANDSCAPE, WHILE L15E15 IS 15% TREATMENT AT BOTH EDGE AND LANDSCAPE.

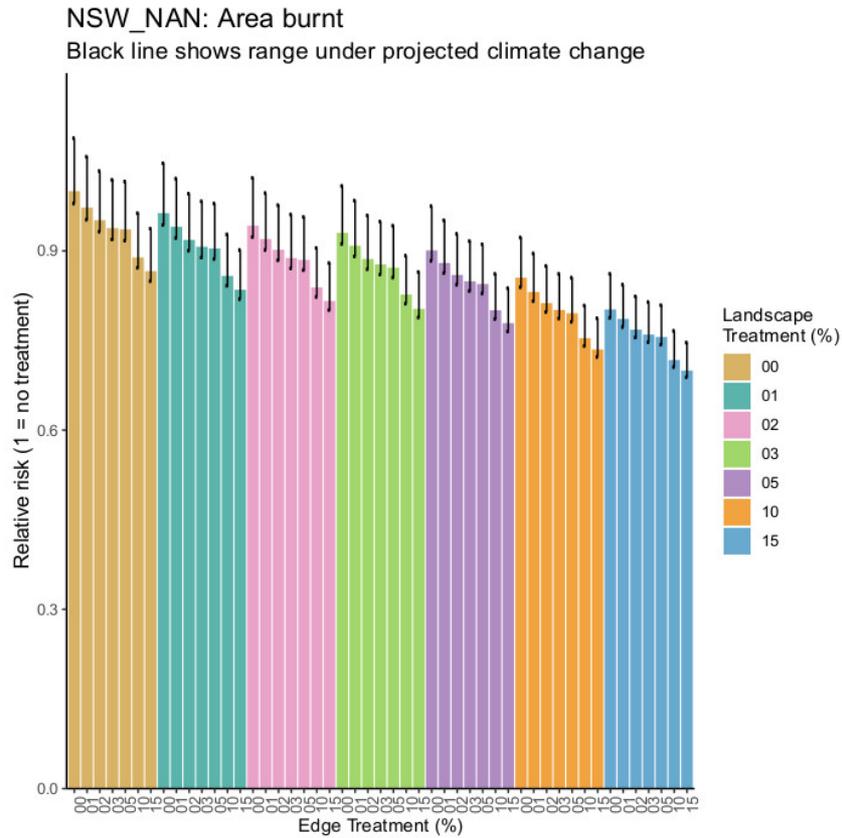


FIGURE 19 PROJECTED INFLUENCE OF CLIMATE CHANGE ON AREA BURNT BY WILDFIRE IN THE NSW NANDEWAR CASE STUDY LANDSCAPE (SITE 11 IN FIGURE 1). COLOURS SHOW AMOUNT OF LANDSCAPE TREATMENT, WHILE NUMBERS ON X-AXIS SHOW AMOUNT OF EDGE TREATMENT. BLACK BARS SHOW THE RANGE OF RESULTS UNDER CLIMATE CHANGE PROJECTIONS (EVANS ET AL. 2014). OVERALL CLIMATE CHANGE IS PROJECTED TO INCREASE THE POTENTIAL FOR INCREASED AREA BURNT AND HENCED DECREASED RISK MITIGATION FROM PRESCRIBED BURNING, ALTHOUGH THERE ARE SCENARIOS WITH LITTLE CHANGE OR EVEN SMALL DECREASES.



SUMMARY OF KEY FINDINGS

In this project we have developed 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. The tool in its current form is strategic, rather than tactical in nature, analysing long term, landscape-scale effectiveness of prescribed burning rather than pros and cons of burning individual blocks at specific dates.

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. Hosting, maintenance, evaluation and monitoring of the Prescribed Fire Atlas are important issues, particularly in light of funding for the CRC 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.

The key findings across the analysis of all 13 case study landscapes are as follows:

- In most cases, increasing rates of prescribed burning treatment reduces the risk of area burnt by bushfire, life loss, house loss, damage to roads and powerlines.
- In most cases, increasing rates (as a proportion of land area) of prescribed burning treatment increases the risk of area burnt below minimum tolerable fire interval.
- There is substantial variation among case study landscapes in the absolute values of risk mitigation in response to prescribed burning.
- There is also variation among case study landscapes in the relative reduction of risk with prescribed burning treatments.
- Cost-effectiveness of prescribed burning varies widely among regions, with variations relating primarily to the spatial configuration of assets and natural vegetation.
- Regions with continuous wildland-urban interface adjacent to continuous vegetation had the most cost-effective fuel treatment strategies. In contrast, regions with fragmented vegetation and discontinuous interfaces demonstrated the lowest cost-effectiveness of treatments.
- Climate change is expected to decrease the potential for risk mitigation available from prescribed burning, via an increase in the frequency of extreme fire weather conditions.



KEY MILESTONES

The key project milestones were as follows:

- Data compilation
 - National-scale datasets on ignitions, fuel accumulation, area burned, fire severity across south eastern bioregions in Australia
 - High resolution datasets dealing with biophysical variation (i.e. terrain, vegetation, climate) and human activity (e.g. population density)
- Selection of case study landscapes for fire spread simulations across south eastern Australia
- Analyses of effects of prescribed burning on area burnt, fire severity and fire frequency, along with biophysical, climatic and human influences
- Risk estimation using probabilistic modelling approaches for case study landscapes
- Cost-effectiveness analysis
- Trade-off analysis
- Modelling of climate change effects
- Development of data, models and software for the 'Prescribed Burning Atlas'



UTILISATION AND IMPACT

SUMMARY

Utilisation has been strongly embedded in this project, with the development of a tool that can be used by end-users planned since its inception. This tool, the Prescribed Burning Atlas, has now been released and is available at <https://prescribedburnatlas.science> (see Figures 20-22 for screenshots). The Atlas allows end-users to explore the implications of different treatment rates on risk to key values.

PRESCRIBED BURNING ATLAS

Output description

The Prescribed Burning Atlas is a tool for end-users to explore, query and use outputs of the project. It can be used to guide the implementation of 'tailor-made' prescribed burning strategies to suit the biophysical, climatic and human context of all bioregions across south eastern Australia. Output are provided at the landscape-scale (~200,000 ha) and draws on all case study locations across southern Australia. In the most simple use case, users click on a landscape, design a treatment strategy (one or more combinations of edge and landscape treatment), and then compare risks to key values, including the total costs and the change in risk mitigation under climate change.

Extent of use

After an end-user workshop and feedback on early prototypes from a small group of end-users, a number of changes have been made. We are currently socialising the Atlas with a wide group of stakeholders, something which will continue at local workshops and national and international conferences well beyond the official project closing date. It has taken on additional relevance in light of the 2019-2020 megafires in Eastern Australia.

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.

Utilisation potential

- The Atlas is primarily a device for looking at strategic options and their comparative outcome in terms of risk mitigation and cost. It can be used to compare effects of different treatment rates and locations on risk to



different values and associated costs, including relative risk mitigation and residual risk. It can also be used to compare results between similar or different landscapes and to explore effects of climate change on prescribed burning effectiveness.

- The Atlas is therefore at this point a strategic tool and is not intended to guide tactical decisions about which particular block to burn when. Analyses have been designed and presented so as to incorporate long term risk across each landscape, incorporating their unique mix of vegetation, climate, ignition probability, weather and asset arrangement.
- 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.
- 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.

Utilisation impact

Representatives of the following organisations have already used the Prescribed Burning Atlas:

- NSW National Parks and Wildlife Service
- NSW Department of Planning, Industry and Environment
- NSW Rural Fire Service
- Tasmania Fire Service
- ACT Parks and Conservation Service
- South Australian Department for Environment and Water
- Victorian Department of Environment, Land, Water and Planning
- Victorian Country Fire Authority
- Bushfire and Natural Hazards Cooperative Research Centre
- Royal Commission into National Natural Disaster Arrangements

The Atlas itself allows for tracking of impact in a number of ways including:

- page visits
- number of registered users
- origin of registered users (e.g. fire management agencies, researchers, other)
- time spent on individual pages



- most popular case study landscapes
- number of contacts from end-users

In addition to this, we will monitor utilisation through scheduled follow ups with our lead end-user, ongoing consultation with our existing network of end-users, and targeted consultation with new users identified via registration through the Atlas.



Utilisation and impact evidence

A detailed list of references including peer reviewed scientific journal publications and conference presentations is found in the Publications List section of this report.

Because there has only been a 'soft launch' so far, our evidence of use of the Atlas is restricted to our core end-user group. As noted previously, we have a wealth of means for tracking the ongoing utilisation and impact of the Atlas.

Media articles

"Answering burning questions", Future-Makers, 3, 2019, Nature Research Custom Media available at <https://www.westernsydney.edu.au/future-makers.html>

Presentations

Clarke H, Cirulis B, Boer M, Price O, Bradstock R (2020) How does prescribed burning affect risk? NSW National Parks and Wildlife Service, Fire and Incident Management Branch, webinar, Australia.

Clarke H, Cirulis B, Boer M, Price O, Bradstock R (2019) From hectares to tailor-made solutions: planned and unplanned fire risk with a twist of climate change. UNSW Centre for Ecosystem Science, Kensington, Australia.

Clarke H, Tran B, Boer MM, Price O, Kenny B and Bradstock R (2019) Goldilocks and global warming – a study of climate change effects on prescribed burning weather conditions. Prescribed Burning Centre of Excellence, webinar, Australia.

Book chapters

Bradstock R (2020) Prescribed burning: The view from the top down. In Leavesley A, Wouters M and Thornton R Eds, Prescribed Burning in Australasia: The science practice and politics of burning the bush, Australasian Fire and Emergency Service Authorities Council Limited (Melbourne: Victoria).

Penman TD, Collins L, Duff TD, Price OF and Cary GJ (2020) Scientific evidence regarding the effectiveness of prescribed burning. In Leavesley A, Wouters M and Thornton R Eds, Prescribed Burning in Australasia: The science practice and politics of burning the bush, Australasian Fire and Emergency Service Authorities Council Limited (Melbourne: Victoria).



East Central (VIC)

Location
Based on Victoria's East Central Bushfire Risk Landscape, stretching from northeast fringes of Melbourne to Central Highlands.

Population
Several hundred thousand people.

Land use
Includes urban and peri-urban areas, agricultural areas, native forests.

Vegetation
Major vegetation types are dry and wet eucalypt forests, eucalypt woodlands.

Climate
Mean annual rainfall ranges from 735 mm at Coldestream to 1,111 mm at Noojee. Mean summer daily maximum temperatures are 27.1°C at Coldestream and 24.3 at Noojee.

Fire Regime
Part of the eucalypt forest (temperate) fire regime niche, a high-productivity niche characterised by infrequent low-intensity/inter fires in spring and medium-intensity shrub fires in spring and summer. Typically, fire intensity ranges from 1 000 to 5 000 kW m⁻¹, although under extreme weather conditions, fire intensity may reach 10 000–50 000 kW m⁻¹. Fires typically recur every 5–20 years, although the interval between fires can be as long as 20–100 years. Includes tall eucalypt forest (temperate) fire regime niche, a high-productivity niche characterised by very infrequent high-intensity crown fires in summer. Typically, fire intensity ranges from 5 000 to 10 000 kW m⁻¹, although under extreme weather conditions, fire intensity may exceed 50 000 kW m⁻¹. Fires typically recur every 20–100 years, although the interval between fires can be over 100 years.

Map coordinates: Lon: 145.4624974865124, Lat: -37.46848958204092

FIGURE 20 SCREENSHOT FROM PRESCRIBED BURNING ATLAS – KEY FEATURES OF VICTORIA EAST CENTRAL CASE STUDY LANDSCAPE.

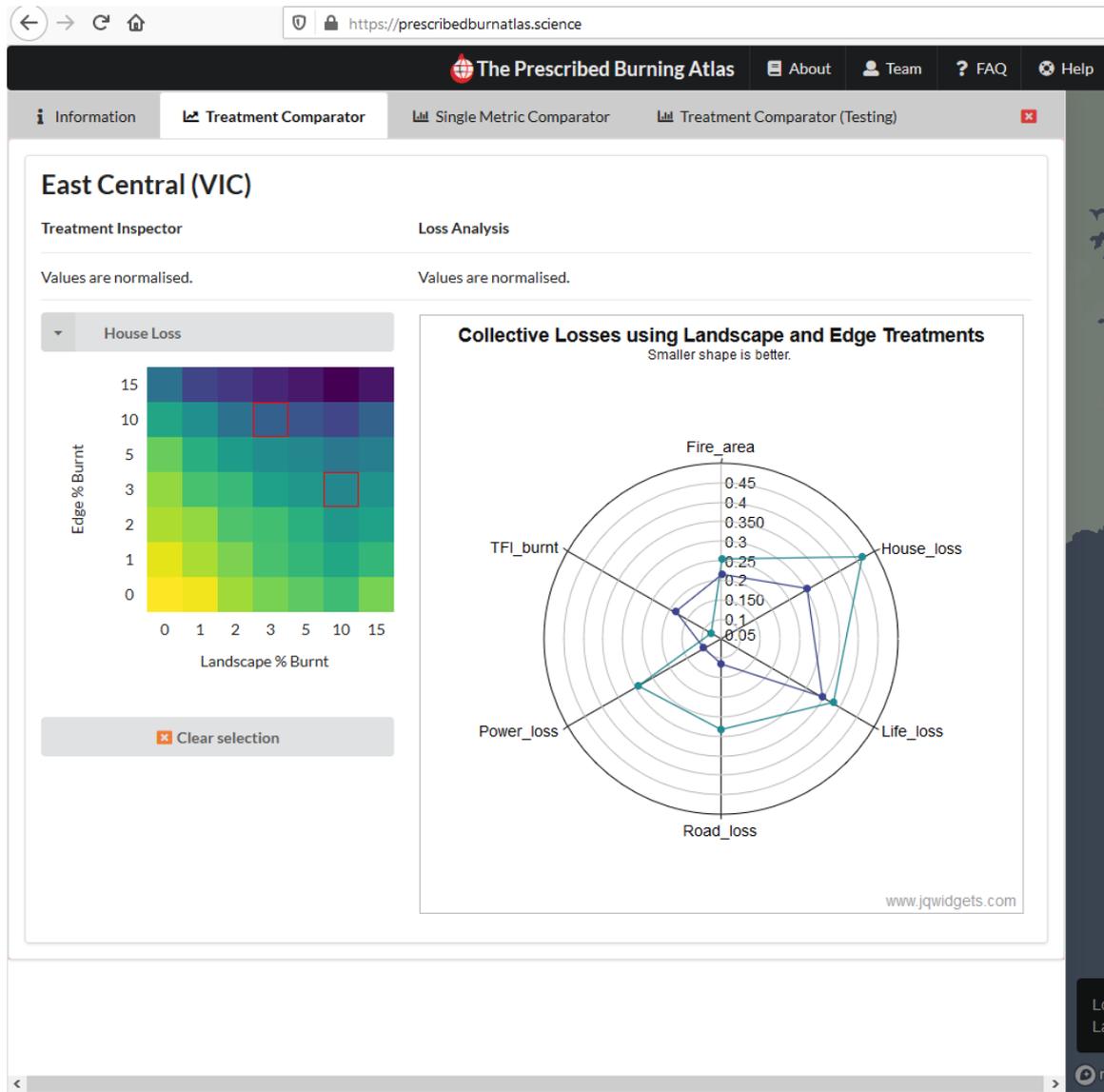


FIGURE 21 SCREENSHOT FROM PRESCRIBED BURNING ATLAS – TREATMENT COMPARATOR ALLOWS COMPARISON OF EFFECTS OF DIFFERENT TREATMENT RATES AND LOCATIONS (RED SQUARES ON LEFT HAND SIDE) ON LOSSES TO ASSETS.



https://prescribedburnatlas.science/faq

The Prescribed Burning Atlas About Team ? FAQ Help Contact Us Publications Study Areas Profile Log Out

Frequently Asked Questions

- ▶ What is the Prescribed Burning Atlas?
- ▶ How do I use the Prescribed Burning Atlas?
- ▼ How were the study areas chosen?

Twelve case study areas were selected as the locations for detailed landscape-scale simulation case studies, based on the project criteria of exploration of climatic, population and land use variations across southern Australia.

Key features, similarities and differences between study areas are shown in the table.

Terrestrial Ecoregion	Bioregion	Notes
Temperate Broadleaf and Mixed Forest	Southeastern Queensland	These form a gradient of mainly forested landscapes along the east coast, ranges and slopes, encompassing wide variations in population and land uses. These complement existing risk modelling exercises done in the Sydney region and Otways.
	Victoria Midlands	
	South East Corner	
	South Eastern Highlands	
	Tasmanian Southern Ranges	
	Murray Darling Depression	

FIGURE 22 SCREENSHOT FROM PRESCRIBED BURNING ATLAS – FREQUENTLY ASKED QUESTIONS.



CONCLUSION

We are proud of what the research team and end-user group have achieved through our project, *From hectares to tailor-made solutions for risk mitigation: systems to deliver effective prescribed burning across Australian ecosystems*".

Prescribed burning remains a critical component of contemporary fire management in Australia and elsewhere. Through our project we have systematically explored the risk mitigation available from prescribed burning across a wide range of fire regimes, climate zones and human settlement and land use patterns in southern Australia. We now have a quantitative basis for understanding and comparing the effectiveness of prescribed burning for mitigating risk across different landscapes. Key project results have culminated in a dedicated end-user tool, the Prescribed Burning Atlas, which is now available to support agency decision makers for strategic and planning purposes.

NEXT STEPS

The project team is focusing on socialising the Prescribed Burning Atlas in workshops, conferences and through peer networks, while continuing to analyse and publish project outputs in international peer-reviewed scientific journals. We will continue to respond to formal and informal end-user feedback, including through features embedded in the Atlas. An unexpected outcome of the mega-fires of 2019-2020 in eastern Australia has been that end-users have expressed interest in using the Atlas to help them understand the effect these fires will have on future bushfire risk.



PUBLICATIONS LIST

PEER-REVIEWED JOURNAL ARTICLES

- 1 Cirulis B, Clarke H, Boer M, Penman T, Price O and Bradstock R (2019) Quantification of inter-regional differences in risk mitigation from prescribed burning across multiple management values. *International Journal of Wildland Fire*. <https://doi.org/10.1071/WF18135>
- 2 Clarke H, Cirulis B, Bradstock R, Boer M, Penman T, Price O (2019) A new decision support tool for prescribed burning risk assessment. In AFAC19 powered by INTERSCHUTZ Research Proceedings from the Bushfire and Natural Hazards CRC Research Forum (peer reviewed); Australian Journal of Emergency Management, Monograph No. 4.
- 3 Clarke H, Gibson R, Cirulis B, Bradstock RA, Penman TD (2019) Developing and testing models of the drivers of anthropogenic and lightning-caused wildfire ignitions in south-eastern Australia. *Journal of Environmental Management* 235, 34-41. <https://doi.org/10.1016/j.jenvman.2019.01.055>
- 4 Clarke H, Tran B, Boer MM, Price O, Kenny B, Bradstock R (2019) Climate change effects on the frequency, seasonality and interannual variability of suitable prescribed burning weather conditions in south-eastern Australia. *Agricultural and Forest Meteorology* 271, 148-157. <https://doi.org/10.1016/j.agrformet.2019.03.005>
- 5 Clarke H, Cirulis B, Penman T, Price O, Boer M, Bradstock R (in preparation) Comparing wildfire risk mitigation from prescribed burning and effective climate change action.
- 6 Duff TJ, Cawson JG, Penman TD (2019) Determining burnability: predicting completion rates and coverage of prescribed burns for fuel management. *Forest Ecology and Management* 433, 431-440. <https://doi.org/10.1016/j.foreco.2018.11.009>
- 7 Penman T, Cirulis B, Marcot B (2020) Bayesian decision network modeling for environmental risk management: a wildfire case study. *Journal of Environmental Management* 270, 110735. <https://doi.org/10.1016/j.jenvman.2020.110735>
- 8 Penman T, Clarke H, Cirulis B, Boer M, Price O, Bradstock R (in press) Cost-effective prescribed burning solutions vary between landscapes in eastern Australia. *Frontiers in Forests and Global Change*. doi: 10.3389/ffgc.2020.00079
- 9 Price O, Cirulis B, Clarke H, Boer M, Penman T, Bradstock R (in preparation) Continental-scale variation in prescribed burning effectiveness as revealed by fire simulation experiments.

CONFERENCE PAPERS

- 1 Bradstock R, Boer MM, Clarke H, Cirulis B, Penman T, Price O (2019) How much does it cost to save a life or a house: the comparative cost-effectiveness of using alternative prescribed burning strategies for risk mitigation. 8th International Fire Ecology and Management Congress, Arizona.
- 2 Clarke H, Cirulis B, Bradstock R, Boer M, Penman T and Price O (2019) From hectares to tailor-made solutions for risk mitigation: An integrated prescribed burning research project. AFAC 2019 Annual Conference, Melbourne.
- 3 Bradstock R, Boer MM, Clarke H, Cirulis B, Penman T, Price O (2019) How much does it cost to save a life or a house?: the comparative cost-effectiveness of using alternative prescribed burning strategies for risk mitigation. 6th International Fire Behaviour and Fuels Conference, Sydney.
- 4 Penman T, Cirulis B, Bradstock R, Boer MM, Clarke H, Price O, Marcot B (2019) Investing in fire management: What are the costs? 6th International Fire Behaviour and Fuels Conference, Sydney.
- 5 Clarke H, Price O, Cirulis B, Penman T, Boer MM, Bradstock R (2019) From code to crown: comparing the drivers of simulated and observed wildfire severity. 6th International Fire Behaviour and Fuels Conference, Sydney. **POSTER** Judge's award for best conference poster.
- 6 Bradstock R, Boer M, Penman T, Price O, Cirulis B, Clarke H (2019) From hectares to tailor-made solutions for prescribed burning. BNHCRC 2019 Research Advisory Forum, Sydney.
- 7 Bradstock RA, Bedward M, Boer MM, Cirulis B, Clarke H, Penman T, Price O (2018) Multi-criteria decision analysis and cost-effectiveness trade-offs. La Paradoja del Fuego: un abordaje multidisciplinario para la gestion de incendios en un mundo inflamable, Cordoba. *invited Talk*.
- 8 Bradstock R, Boer M, Penman T, Price O, Cirulis B, Clarke H (2018) From hectares to tailor-made solutions for prescribed burning. AFAC 2018 Annual Conference, Perth.
- 9 Bradstock R, Boer M, Penman T, Price O, Cirulis B, Clarke H (2018) From hectares to tailor-made solutions for prescribed burning. BNHCRC 2018 Research Advisory Forum, Sydney.
- 10 Bradstock R, Boer M, Penman T, Price O, Cirulis B, Clarke H (2017) From hectares to tailor-made solutions for prescribed burning. AFAC 2017 Annual Conference, Sydney.
- 11 Bradstock R, Boer M, Penman T, Price O, Cirulis B, Clarke H (2017) From hectares to tailor-made solutions for prescribed burning. BNHCRC 2017 Research Advisory Forum, Melbourne.
- 12 Bradstock R, Boer M, Penman T, Price O, Cirulis B, Clarke H (2016) From hectares to tailor-made solutions for prescribed burning. BNHCRC 2016 Research Advisory Forum, Canberra.
- 13 Bradstock R, Boer M, Penman T, Price O, Cirulis B, Clarke H (2016) From hectares to tailor-made solutions for prescribed burning. AFAC 2016 Annual Conference, Adelaide.
- 14 Bradstock R, Bedward M, Boer M, Collins L, Horsey B, Penman T, Price O, Clarke H (2015) Delivering effective prescribed burning across Australia. AFAC 2015 Annual Conference, Adelaide.
- 15 Bradstock R, Boer M, Penman T, Price O, Cirulis B, Clarke H (2015) From hectares to tailor-made solutions for



prescribed burning. BNHCRC 2015 Research Advisory Forum, Brisbane.

TECHNICAL REPORTS

- 1 Clarke H, Cirulis B, Penman T, Price O, Boer M, Bradstock R (2019) From hectares to tailor-made solutions for risk mitigation – 2018-2019 Annual Report. Bushfires and Natural Hazards CRC, Melbourne, Victoria.
- 2 Clarke H, Cirulis B, Penman T, Price O, Boer M, Bradstock R (2018) From hectares to tailor-made solutions for risk mitigation – 2017-2018 Annual Report. Bushfires and Natural Hazards CRC, Melbourne, Victoria.
- 3 Clarke H, Cirulis B, Penman T, Price O, Boer M, Bradstock R (2017) From hectares to tailor-made solutions for risk mitigation – 2016-2017 Annual Report. Bushfires and Natural Hazards CRC, Melbourne, Victoria.
- 4 Clarke H, Cirulis B, Penman T, Price O, Boer M, Bradstock R (2016) From hectares to tailor-made solutions for risk mitigation – 2015-2016 Annual Report. Bushfires and Natural Hazards CRC, Melbourne, Victoria.



TEAM MEMBERS

The project was coordinated among three universities, each of which has direct links to the relevant end-users, with the Centre for Environmental Risk Management of Bushfires (CERMB) based at the University of Wollongong (UOW) taking the lead role. The CERMB is the country's leading bushfire risk research group, with strengths in ecology and environmental management. The Hawkesbury Institute for the Environment at Western Sydney University (WSU) is a world leader in global change biology research due to the scope and quality of its staff and facilities (e.g. EucFACE). The Department of Forest and Ecosystem Science at the University of Melbourne (UOM) is Australia's largest teaching, research and development department dedicated to forests, forest products and forested landscapes.

RESEARCH TEAM

The project team has an outstanding track record in research on bushfire risk and fire science. It is led by Senior Professor Ross Bradstock (UOW), one of the world's leading authorities on fire ecology and the environmental risk management of bushfires (163 publications, 8,468 citations). The project team also includes Associate Professor Owen Price (UOW), Associate Professor Trent Penman (UOM), Associate Professor Matthias Boer (WSU), Dr Hamish Clarke (UOW, WSU), Mr Brett Cirulis (UOM) and Mr Anthony Rawlins (UOW, UOM). Associate Professors Price, Penman and Boer are leaders in bushfire research nationally and internationally, with 90, 69 and 62 publications respectively. Dr Clarke is an emerging leader in bushfire and climate change research (14 publications), Mr Cirulis is a leading bushfire modeller (6 publications) and Mr Rawlins is a recognised web developer and scientific programmer. Further detail about the project team can be found at <https://prescribedburnatlas.science/team>.

END-USERS

The project has been able supported by a network of end-users from fire and land management agencies across southern Australia, led initially by Naomi Stephens and then by Dr Felipe Aires, both from the NSW National Parks and Wildlife Service within the NSW Department of Planning, Industry and Environment. End-user representatives attended research advisory forums, seminars and workshops, received quarterly email updates and provided feedback on annual reports and the development of the Prescribed Burning Atlas. A much longer list of representatives of end-user agencies has been involved with the project in other ways, for instance through the extremely helpful supply and provision of guidance about data, and beta testing of the Prescribed Burn Atlas. The official end-user group and other end-users are listed below.

End-user organisation	End-user representative	Extent of engagement (Describe type of engagement)
NSW NPWS	Felipe Aires	Lead end-user rep



NSW NPWS	Naomi Stephens	Lead end-user rep (former)
NSW RFS	Melissa O'Halloran	End-user rep
NSW RFS	Belinda Kenny	End-user rep
Tas Fire	Rochelle Richards	End-user rep
Tas Fire	Louise Mendel	End-user rep
ACT Parks	Adam Leavesley	End-user rep
SA DEWNR	Mike Wouters	End-user rep
SA DEWNR	David McKenna	End-user rep
VIC DELWP	Liam Fogarty	End-user rep
VIC DELWP	Dominic Passaportis	End-user rep
NSW DPIE	Matthew Adams	End-user update recipient
NSW NPWS	Donald McDonald	End-user update recipient
NSW NPWS	Carl Hollis	End-user update recipient
NSW NPWS	Eric Claussen	End-user update recipient
NSW NPWS	Matthew Ford	End-user update recipient
NSW NPWS	Simon Nicol	End-user update recipient
NSW NPWS	Rachel Hannan	End-user update recipient
NSW RFS	Simon Heemstra	End-user update recipient
NSW RFS	Brad Davies	End-user update recipient
WA DPAW	Paul Brennan	End-user update recipient
NSW RFS	Maree Larkin	Meetings / data supply
NSW RFS	Patrick Schell	Meetings / data supply
NSW RFS	Warwick Hehir	Meetings / data supply
NSW RFS	Stuart Matthews	Meetings / data supply
NSW RFS	Zach Porter	Meetings / data supply
NSW Forestry	Tim McGuffog	Meetings / data supply
ACT Parks	Ryan Lawrey	Meetings / data supply
ACT Parks	Neil Cooper	Meetings / data supply
ACT Parks	Tony Scherl	Meetings / data supply
ACT Parks	Brian Levine	Meetings / data supply
Tas Fire	Sandra Whight	Meetings / data supply
Tas Fire	Chris Collins	Meetings / data supply



Tas Fire	David van Geytenbeek	Meetings / data supply
Tas Fire	Sam Ferguson	Meetings / data supply
VIC DELWP	Naomi Withers	Meetings / data supply
VIC DELWP	Andy Ackland	Meetings / data supply
VIC DELWP	Andrew Blackett	Meetings / data supply
VIC DELWP	Liam Fogarty	Meetings / data supply
VIC DELWP	Darcy Prior	Meetings / data supply
SA DEWNR	Simeon Telfer	Meetings / data supply
SA DEWNR	Damon Ezis	Meetings / data supply
WA DFES	Mark Taylor	Meetings / data supply
WA DFES	Tim McNaught	Meetings / data supply
WA DFES	Gary Floyd	Meetings / data supply
WA DPAW	Glen Daniel	Meetings / data supply
QLD PSBA	Robert Preston	Meetings / data supply
QLD PSBA	Andrew Sturgess	Meetings / data supply
QLD QFES	Ben Twomey	Meetings / data supply
QLD QFES	Russel Stephens-Peacock	Meetings / data supply



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