RISK MITIGATION FROM PRESCRIBED BURNING IN KANGAROO ISLAND AND MOUNT LOFTY RANGES

An extension to the Prescribed Burning Atlas project as part of the Black Summer research program

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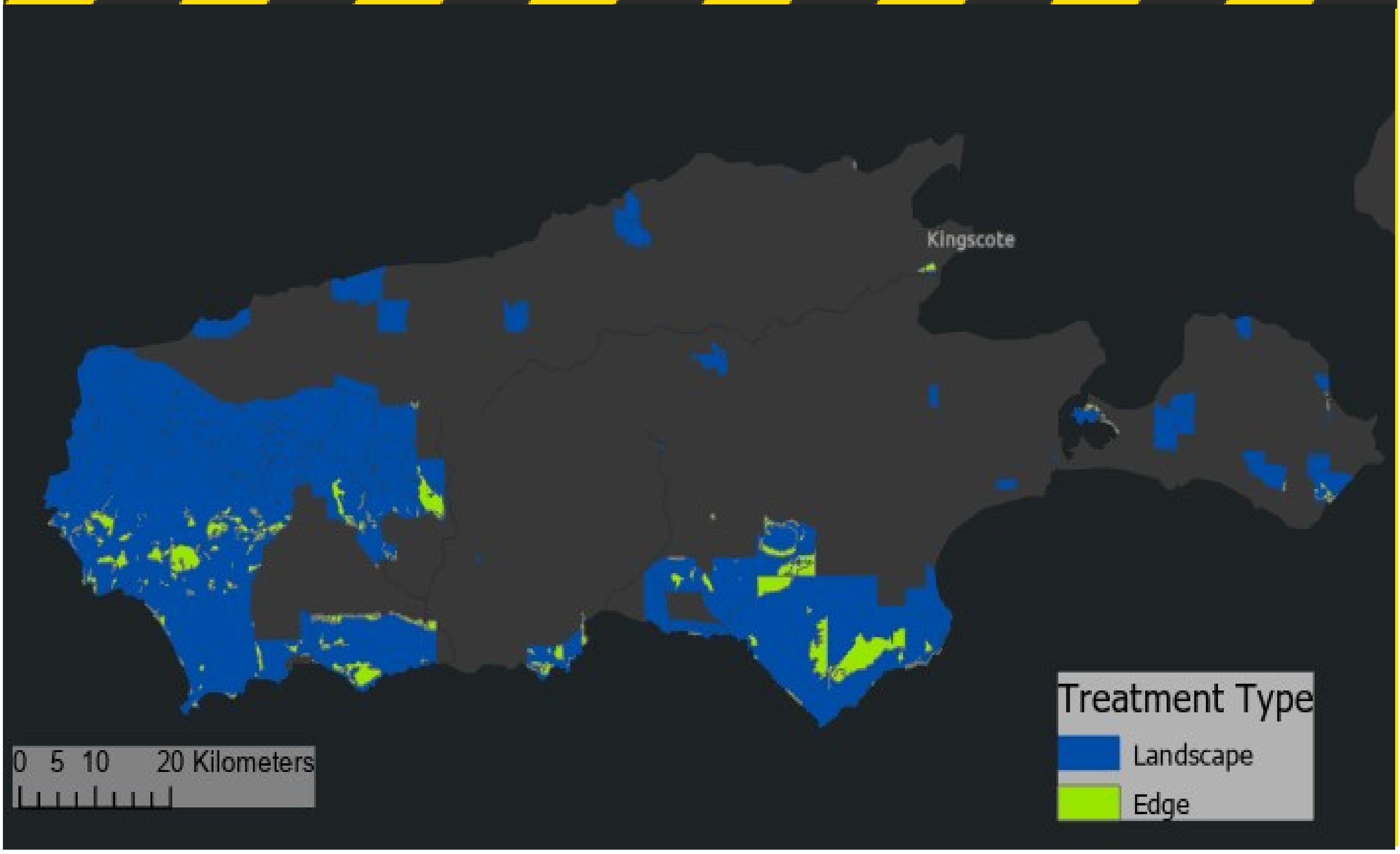

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Cover: Location of burn blocks, either edge or landscape, for fire behaviour simulations in Kangaroo Island.

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This research was part of the Bushfire and Natural Hazards Cooperative Research Centre's Black Summer research program, funded by the Australian Government and the CRC to investigate key issues from the 2019-20 bushfire season.

EXECUTIVE SUMMARY

According to the Independent Review into South Australia's 2019-20 Bushfire Season, conditions were the worst on record with fires resulting in the loss of three human lives, 196 homes, 660 vehicles, 68,000 livestock, $200m of agricultural production. Around 280,000 ha were burnt by the fires, including total or partial burning of several National Parks.

The Bushfire and Natural Hazards CRC commissioned this project as part of a larger set of Black Summer fires research projects aimed at understanding the record-breaking fire season. This project focuses on answering questions about the effectiveness of prescribed burning, also known as hazard reduction burning, in mitigating risk in two areas affected by fires during the season: The Mount Lofty Ranges east of Adelaide, and Kangaroo Island.

The key questions were:

1. How does risk respond to treatment in Kangaroo Island, an area with little formal quantification of prescribed burning benefits and costs?
2. What was the risk in the leadup to the 2019-20 fire season in the Mt Lofty Ranges, and how will risk change in the next five years as a result of the implied fuel reduction from the fires, as well as alternative prescribed burning strategies?

These questions were answered using a well developed methodology combining large scale fire behaviour simulations and Bayesian risk quantification. Similar analyses have been carried out for a range of case study landscapes in southern Australia as part of the *Hectares to tailor-made solutions* CRC project, with results available online via the end-user tool the Prescribed Burning Atlas, and also the NSW Bushfire Risk Management Research Hub's projects for the NSW Bushfire Inquiry.

We found a clear relationship between the rate of prescribed burning and area subsequently burnt by wildfire in the Kangaroo Island case study. This translated into reductions in loss of life and property as well. Risk mitigation was more sensitive to edge treatment than landscape treatment, although both reduced risk. Conversely, increasing treatment (particularly at the edge) resulted in higher areas of the landscape exposed to vegetation being burnt below its minimum tolerable fire interval.

In the Mt Lofty Ranges, we found complex patterns of risk are likely in the aftermath of the 2019-20 fires. In the absence of further wildfire events, risk of area burnt is likely to rise substantially by 2025, regardless of prescribed burning rates, with a similar result for vegetation exposed to too frequent fire. However, risk sto life, property and infrastructure are projected to remain similar to current levels.

Our work contributes to the evidence base for prescribed burning planning in South Australia, with future work potentially examining new management values (e.g. smoke health costs, new biodiversity measures) and exploring empirical relationships between prescribed burning and fire-affected area in 2019-20.

END-USER PROJECT IMPACT STATEMENT

Mike Wouters, *Manager Fire Science and Mapping, Department for Environment and Water, SA*

The Black Summer bushfires in SA (Kangaroo Island and Cudlee Creek) were significant events – both in their impacts to people and property and to the environment. The swift development and implementation of the PB Atlas research for Kangaroo Island and the Mt Lofty Ranges is greatly appreciated. The beneficial outcomes from this research for SA were:

1. testing and extending some of the PB Atlas research to SA
2. the 'quick' implementation of this work following the bushfires
3. provision of fire management scenario information based on the PB Atlas research, into the Fire Management planning that is occurring post-fires (these research outcomes are being used for the first time in SA).

The research has opened the opportunity for PB Atlas processes and tools to be regularly used in SA. Following the review of these research outcomes, we will be pursuing further modelling with the UoW and UoM research teams to address additional questions have been raised from these research projects and the post-fire planning that is occurring. We are keen to use the analyses and tools from this research to form part of our planning and decision support systems in both bushfire response and bushfire risk reduction planning in SA.

INTRODUCTION

Prescribed burning is a major tool used by fire and land management agencies, which need information on the likely effects of treatment on a range of management values (area burnt by wildfire, life loss, house loss, infrastructure loss, environmental impacts). Where possible, cost estimates are also required in order to design cost-effective strategies that are tailored to local conditions.

Our project team has developed a methodology for systematically and objectively comparing the risk reduction available from prescribed burning for a range of values and landscapes in southern Australia. We aim to provide decision makers with the ability to compare effects and costs of different treatment rates and locations, with project results currently available at the Prescribed Burning Atlas website, developed as part of a previous Bushfire and Natural Hazards CRC project.

This project builds on these methods to investigate prescribed burning effectiveness and risk to key values for two fire-prone areas in South Australia, Kangaroo Island and the Mt Lofty Ranges. Both were affected in the 2019-20 fire season.

Key project steps were:

- gather relevant data, including potential burn blocks and histories of wildfire and prescribed fire
- run large scale fire behaviour simulations using the Phoenix RapidFire model
- postprocess simulator output using Bayesian Decision Networks, arriving at annualised risk estimates
- for the Kangaroo Island landscape, upload key results to the Prescribed Burning Atlas, which currently holds results for 13 other case study landscapes in southern Australia.

BACKGROUND

In July, the Bushfire and Natural Hazards CRC was granted $2 million from the Australian Government to research the key issues arising from the 2019/20 bushfires, colloquially known as the Black Summer fires (although they extended well beyond summer). Research priorities were informed by end-user consultation, state inquiries and the Royal Commission into National Natural Disaster Arrangements, as well as discussions at Bushfire Science Roundtable meetings held in Canberra.

Three research areas and objectives were selected:

- fire predictive services – to boost situational awareness before and during bushfires, and to enhance the sharing of risk information and warnings with communities
- cultural land management – to better integrate cultural land management knowledge and practices with government-led risk reduction programs
- community-led recovery – to assist governments in enabling effective and efficient community participation and leadership in disaster preparation, relief and recovery

Within the *fire predictive services* area, one set of projects covered bushfire reconstruction data and demonstration projects: comprising several smaller projects across WA, SA, Vic, NSW and Qld. Each project looked at a specific bushfire in detail to understand what additional technology or tools are required to understand extreme fire behaviour specific to different geographical areas and vegetation types. These projects explored needs such as mapping specific vegetation types in certain areas, improving jurisdictional fire detection technology, identifying ways to automate local data collection and analysis, area-based fire atmosphere modelling, and assessing community behaviour during bushfires. The work described in this report was also part of these reconstruction and demonstration projects, focused on prescribed burning in SA.

THE 2019-20 FIRE SEASON IN SOUTH AUSTRALIA

The 2019-20 bushfires in the Mt Lofty Ranges (MLR)(Cudlee Ck) and Kangaroo Island (KI) in South Australia (SA) have resulted in significant community and environmental impacts. Major revisions of Fire Management Planning for these two areas are now needed (required by the SA Government). Both fires have occurred in regions previously affected by bushfire in the last decade, reinforcing the need for considered risk reduction action. The MLR fire caused major social and economic impacts to a mixed agricultural landscape very close to Adelaide, generating significant public and political (SA) concerns. The KI fire has significantly impacted the Island community which relies heavily on nature-based tourism as part of it's economy. More than half of the fire area severely burnt areas already severely burnt 12 years ago, impacting a large range of state and nationally significant environmental values. The KI Dunnart, which only occurred in the fire areas and surrounds, is now Australia's most threatened mammal due to the fire impacts on its habitat.

RESEARCH APPROACH

This project is divided into analyses of prescribed burning effectiveness in the Kangaroo Island and Mt Lofty Ranges.

PRESCRIBED BURNING IN KANGAROO ISLAND

The methods used to investigate prescribed burning effectiveness in Kangaroo Island were developed as part of the Bushfire and Natural Hazard CRC project *From hectares to tailor-made solutions for risk mitigation: systems to deliver effective prescribed burning across Australian ecosystems*. For a full description of these methods, see Cirulis et al. (2019). Further information about the project and key findings can be found in Clarke et al. (2019a), Penman et al. (2020) and webinars delivered by project team members and available via the CRC's YouTube channel.

The following information is drawn from the Final Report of the aforementioned report (Clarke et al. 2020a). 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 orographic 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. 2019b).
- 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.

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. 2019b). This BN has been found to be robust for NSW (unpublished data). See Figure 1 for Kangaroo Island ignition probabilities. 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 (Figure 2 shows Mt Lofty Range).

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. Burn-block datasets were then created (Figure 3).

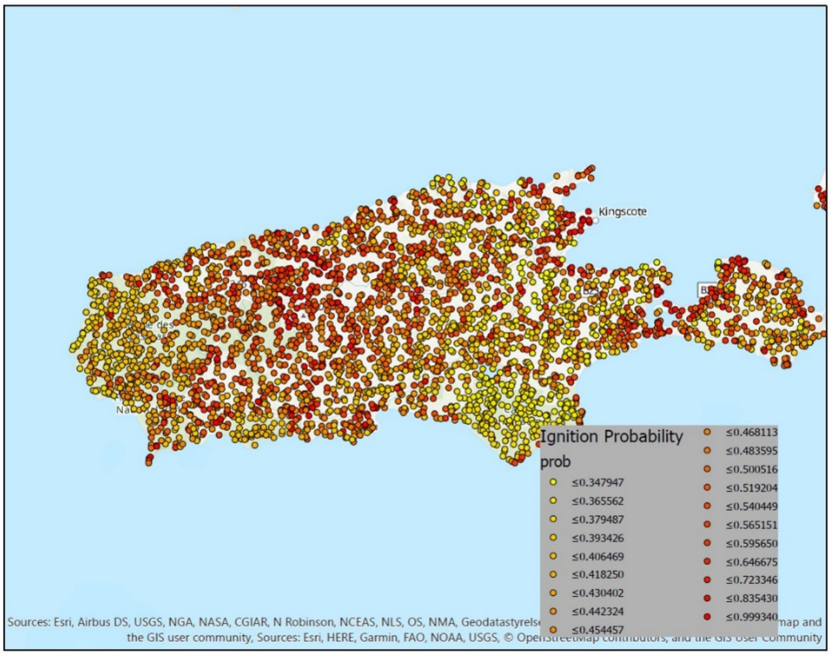

FIGURE 1 IGNITION PROBABILITY SURFACE, KANGAROO ISLAND CASE STUDY LANDSCAPE

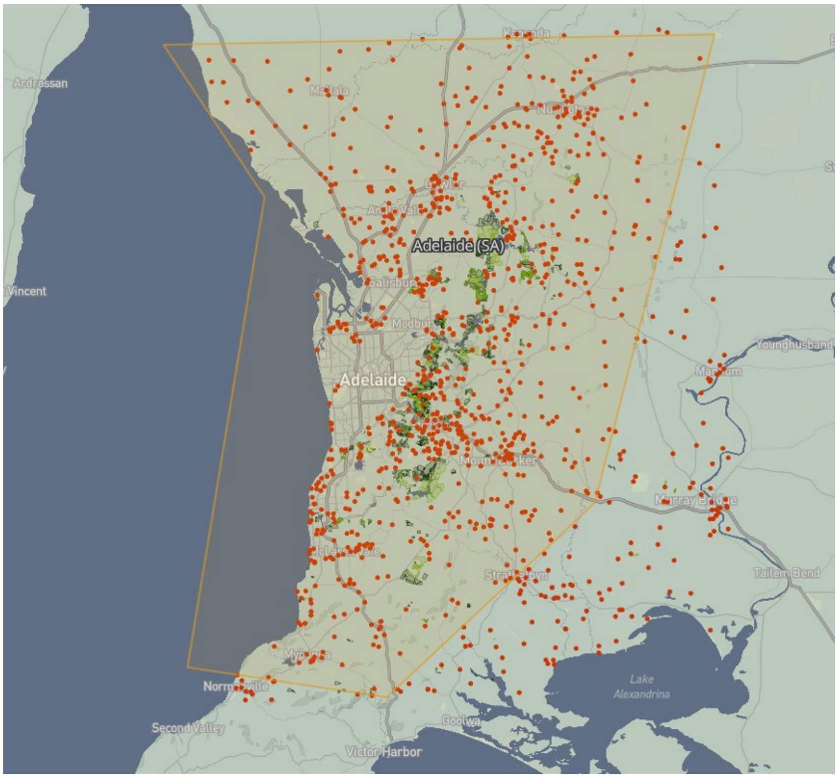

FIGURE 2 MAJOR IGNITION LOCATIONS (RED DOTS), MT LOFTY RANGES CASE STUDY LANDSCAPE

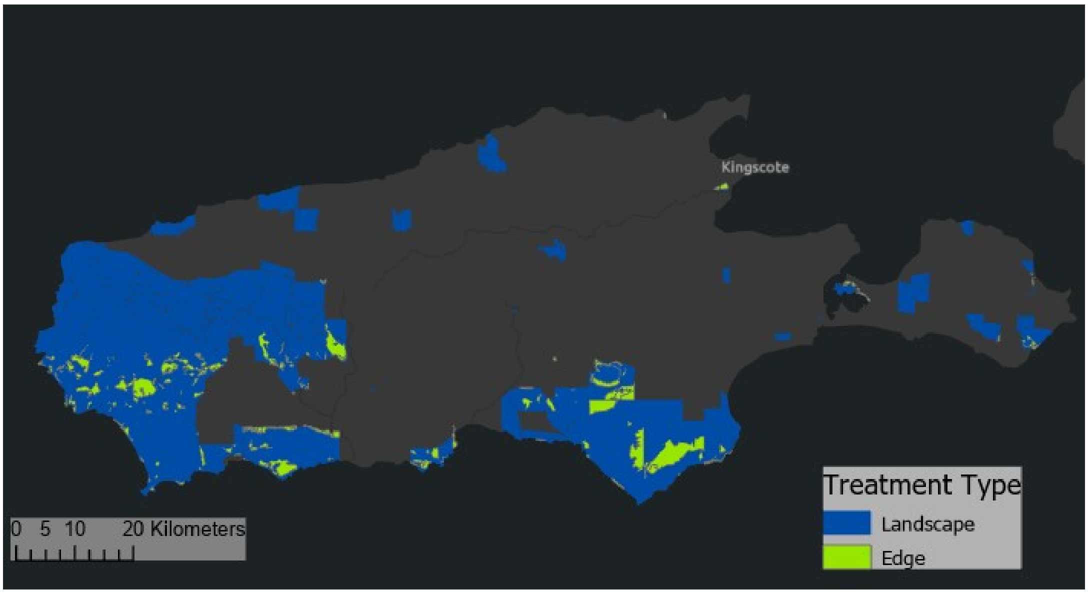

FIGURE 3 LOCATION OF EDGE AND LANDSCAPE BURN BLOCKS, KANGAROO ISLAND CASE STUDY LANDSCAPE

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.

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.

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: There is no means for translating TFI into economic values. These 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.

Carbon cost

Output value: Carbon emissions cost of fires ($).

Inputs: PHOENIX fuel consumption per fire.

Method of calculation: Carbon released was calculated from Byram's fire line intensity equation (Byram, 1959) using intensity and rate of spread values from PHOENIX to determine fuel consumed and multiplying by 0.5, the fraction of carbon in fuel (Roxburgh et al., 2006). This is a very coarse measure of carbon released but more specific could not be estimated from existing fire behavior models. Carbon released was calculated using the values of Hunt (2008) who estimated a cost of $AUD 61 per ton.

Live 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.yourinvestmentpropertymag.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 4)

- 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.

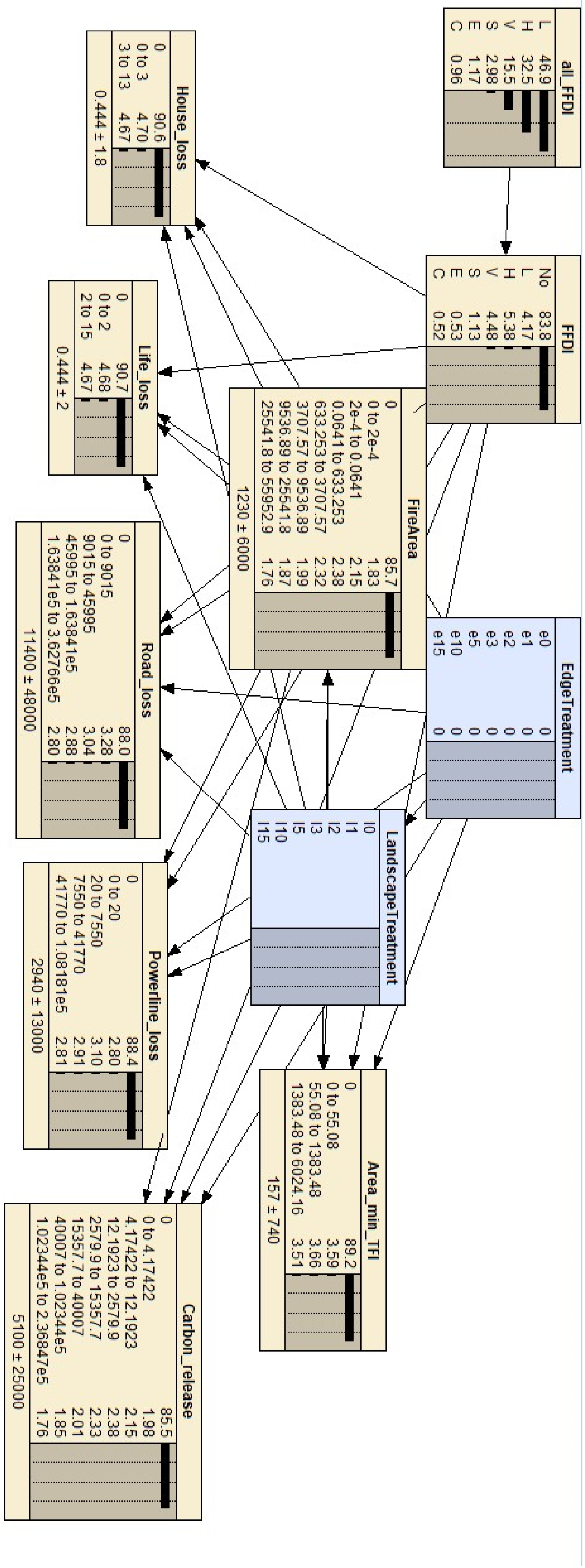

FIGURE 4: EXAMPLE OF THE BAYESIAN DECISION NETWORK STRUCTURE USED IN THE PROJECT. WEATHER (BOTH DIRECTLY (ALL_FFDI) AND INDIRECTLY VIA IGNITION PROBABILITY (FFDI)) AND EDGE AND LANDSCAPE TREATMENT RATE INFLUENCE AREA BURNT, HOUSE LOSS, LIFE LOSS, ROAD LENGTH DAMAGED, POWERLINE LENGTH DAMAGED AND AREA BURNT BELOW MINIMUM TOLERABLE FIRE INTERVAL (TFI).

PRESCRIBED BURNING IN MT LOFTY RANGES

The Mt Lofty Ranges analyses are based on the same methods described above, but with several important differences. These alterations are required in order to investigate the specific research questions and were first employed in Clarke et al. (2020b) and Clarke et al. (2020c). Relevant excerpts are reproduced below, while project findings, significance, limitations and management implications are adapted in the Findings section.

Risk in the lead up to the 2019-20 fire season

The key difference with the Kangaroo Island methods described above is that two sets of simulations were run:

1. with weather based on the full historical record of fire season observations (the control scenario)
2. with weather only from the 2019-20 fire season. Key features are paraphrased below.

Risk in the aftermath of the 2019-20 fire season

The key difference with the Kangaroo Island methods described above were that three sets of simulations were run:

1. with a fire history not including the 2019-20 fire season or any prescribed burning (the control scenario)
2. with a fire history including the 2019-20 fire season as well as various rates and locations of prescribed burning through to 2021 (i.e. 2 years after the 2019-20 season)
3. the same as (2) except through to 2025 (i.e. 6 years after the 2019-20 season).

Alternative treatment analysis

We originally planned to investigate risk mitigation based on alternative treatment blocks for the Mt Lofty Ranges case study landscape, which is already implemented in the Prescribed Burning Atlas.

However, the new burn blocks supplied by end-users did not have sufficient coverage of the case study landscape to allow the standard analysis. Therefore, it was decided to use the burn block algorithm described above to ensure coverage and compatibilty with existing results.

FINDINGS

This report focuses on the findings for the Mt Lofty Ranges analyses. However, a brief summary of Kangaroo Island results is presented first. Readers interested in exploring Kangaroo Island results further are referred to the Prescribed Burning Atlas, an interactive online tool https://prescribedburnatlas.science/.

PRESCRIBED BURNING IN KANGAROO ISLAND

Figures 5-8 show the residual risk under different prescribed burning treatment rates and locations for area burnt by wildfire, lives lost, houses lost and area burnt below minimum tolerable fire interval (TFI). Note that powerline and road analyses were omitted due to a lack of data for Kangaroo Island. Figures 9-10 show costs.

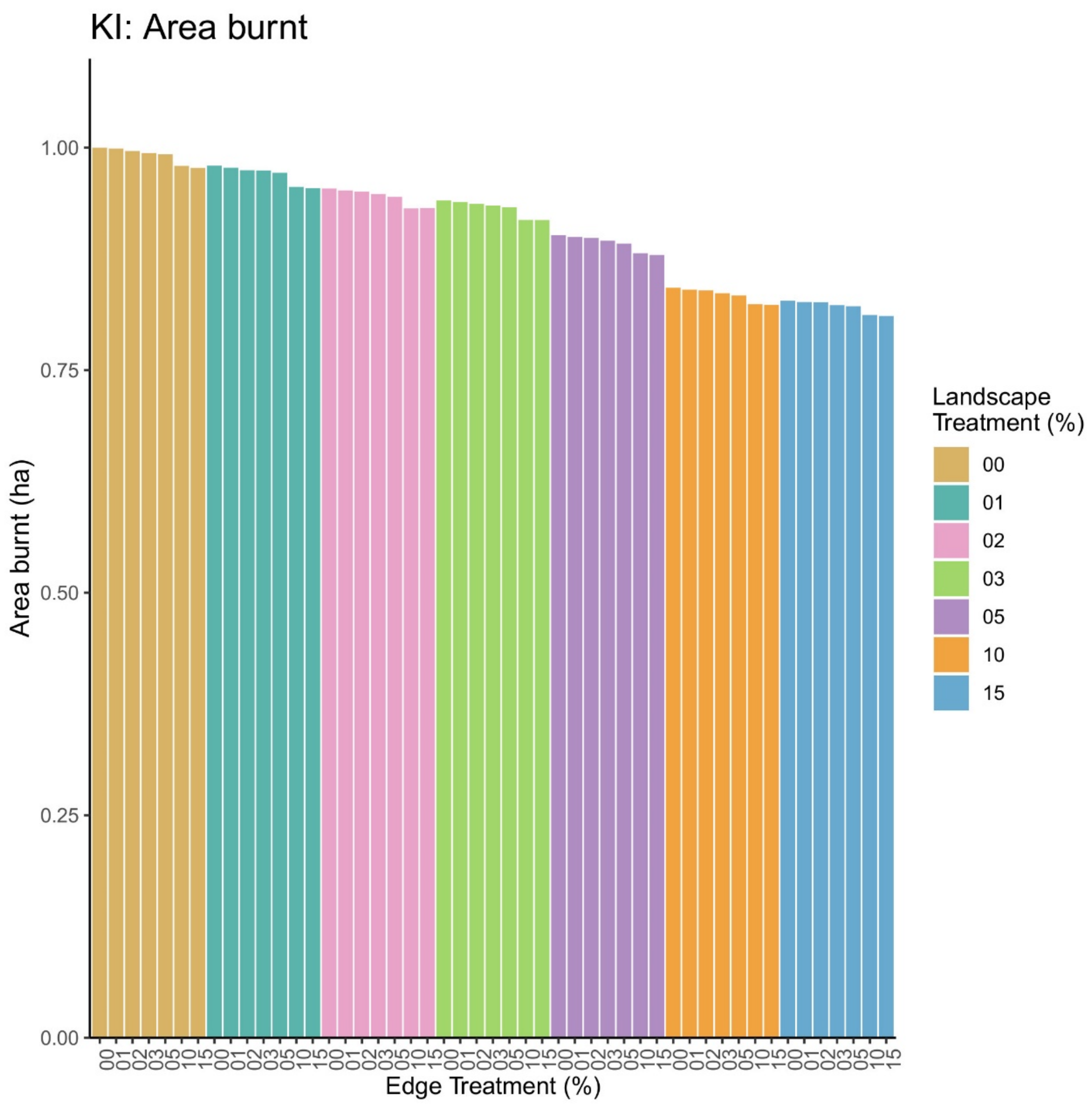

FIGURE 5: RESPONSE OF AREA BURNT TO DIFFERING TREATMENT STRATEGIES IN THE KANGAROO ISLAND CASE STUDY LANDSCAPE. THE LABELS ON THE X-AXIS REFER TO RATES OF LANDSCAPE AND EDGE TREATMENT E.G. L00E00 IS ZERO TREATMENT AT BOTH EDGE AND LANDSCAPE, WHILE L15E15 IS 15% TREATMENT AT BOTH EDGE AND LANDSCAPE. THE Y-AXIS IS IN RESIDUAL RISK OR RELATIVE RISK UNITS, WHERE 1 = ZERO TREATMENT.

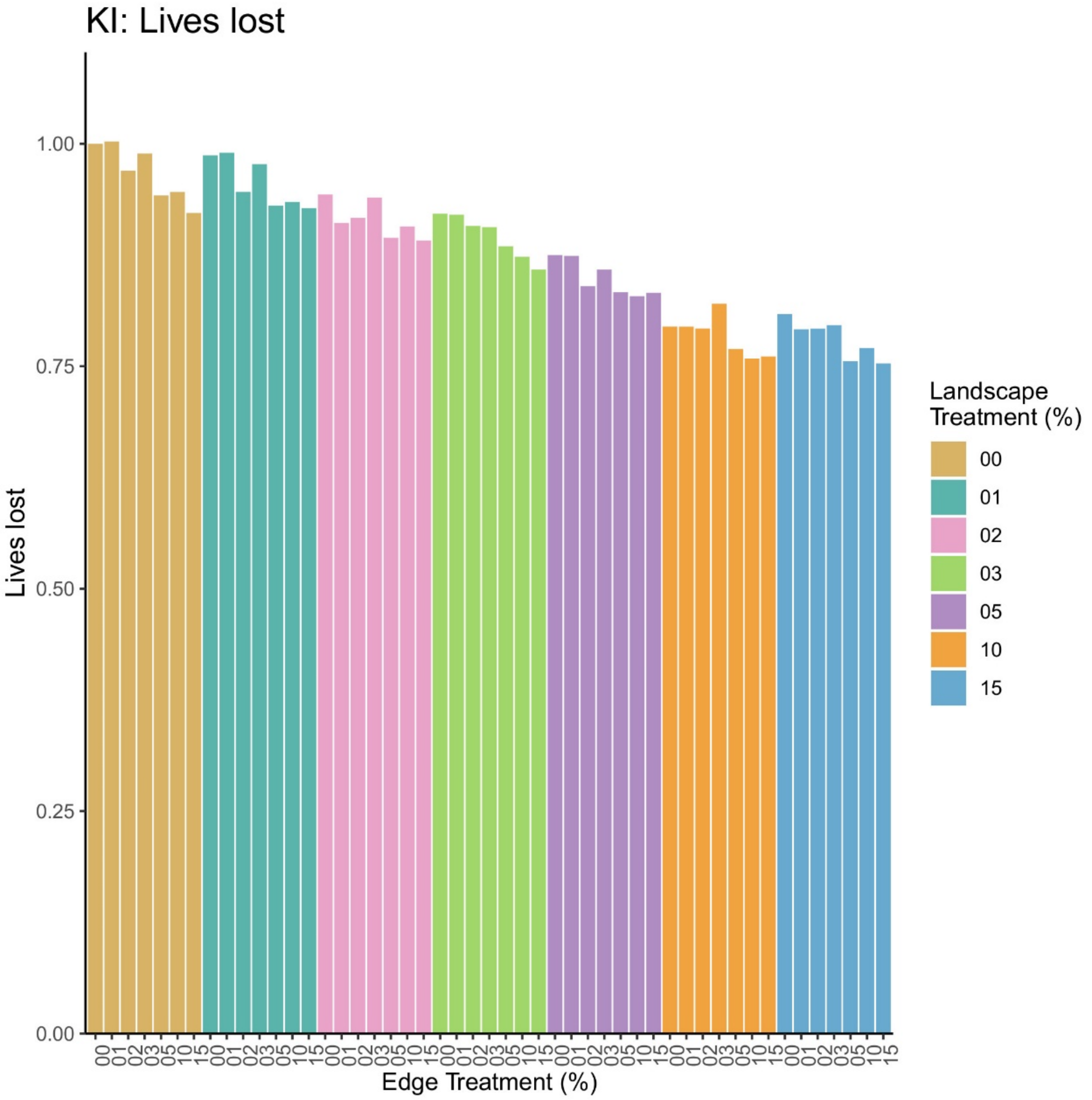

FIGURE 6: RESPONSE OF LIFE LOSS TO DIFFERING TREATMENT STRATEGIES IN THE KANGAROO ISLAND CASE STUDY LANDSCAPE. THE LABELS ON THE X-AXIS REFER TO RATES OF LANDSCAPE AND EDGE TREATMENT E.G. L00E00 IS ZERO TREATMENT AT BOTH EDGE AND LANDSCAPE, WHILE L15E15 IS 15% TREATMENT AT BOTH EDGE AND LANDSCAPE. THE Y-AXIS IS IN RESIDUAL RISK OR RELATIVE RISK UNITS, WHERE 1 = ZERO TREATMENT.

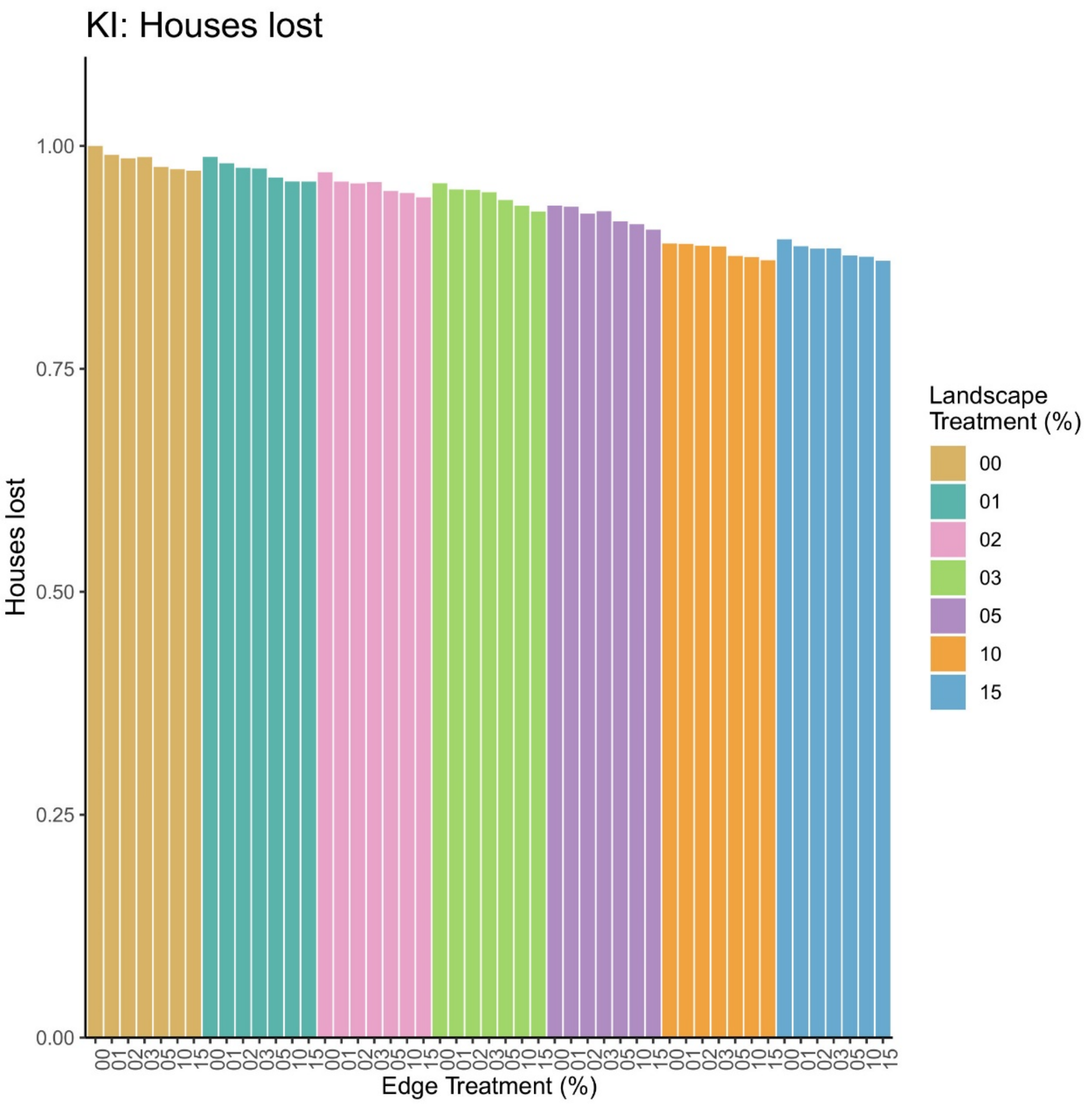

FIGURE 7: RESPONSE OF HOUSE LOSS TO DIFFERING TREATMENT STRATEGIES IN THE KANGAROO ISLAND CASE STUDY LANDSCAPE. THE LABELS ON THE X-AXIS REFER TO RATES OF LANDSCAPE AND EDGE TREATMENT E.G. L00E00 IS ZERO TREATMENT AT BOTH EDGE AND LANDSCAPE, WHILE L15E15 IS 15% TREATMENT AT BOTH EDGE AND LANDSCAPE. THE Y-AXIS IS IN RESIDUAL RISK OR RELATIVE RISK UNITS, WHERE 1 = ZERO TREATMENT.

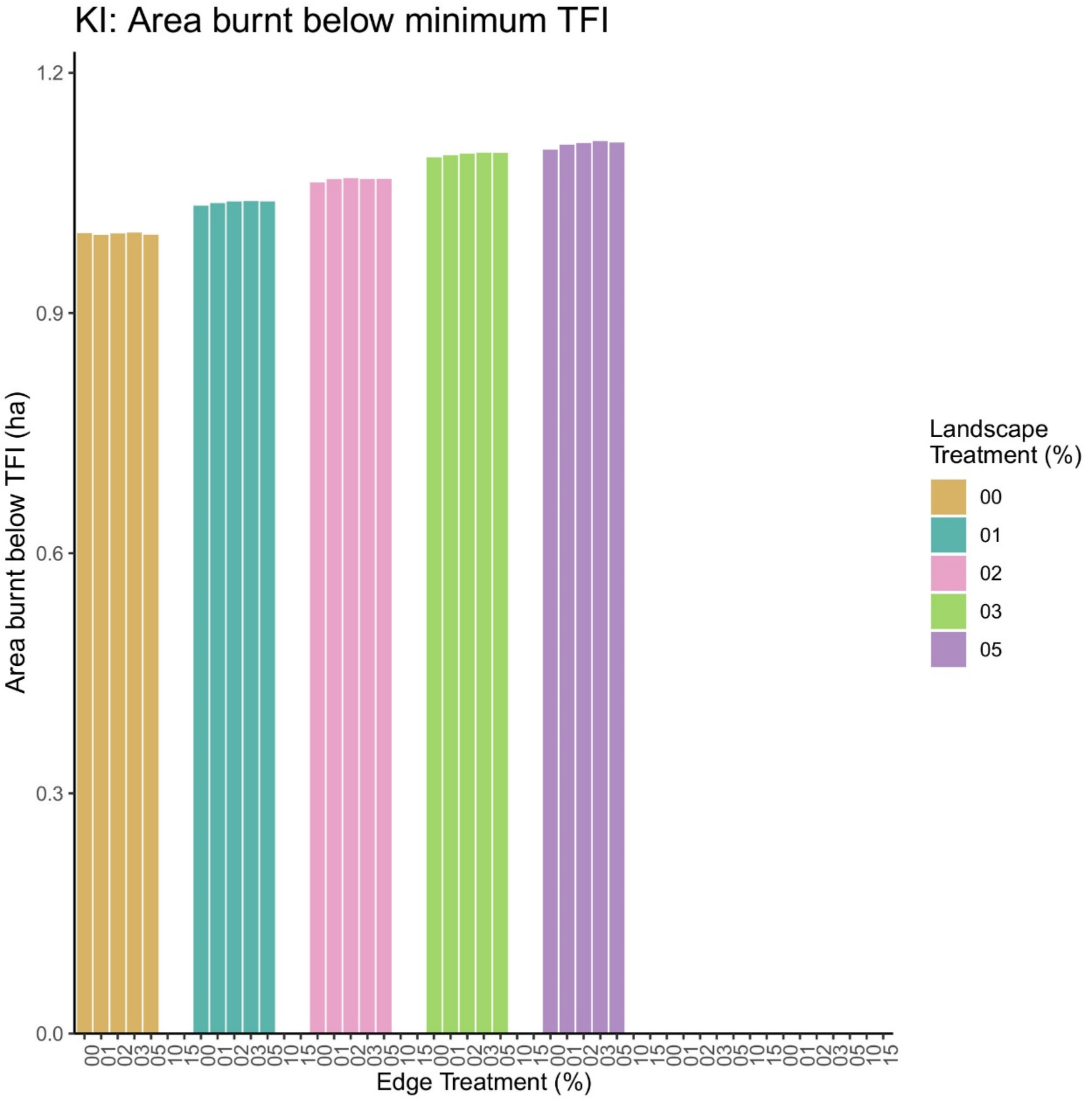

FIGURE 8: RESPONSE OF AREA BURNT BELOW MINIMUM TOLERABLE FIRE INTERVAL TO DIFFERING TREATMENT STRATEGIES IN THE KANGAROO ISLAND CASE STUDY LANDSCAPE. THE LABELS ON THE X-AXIS REFER TO RATES OF LANDSCAPE AND EDGE TREATMENT E.G. L00E00 IS ZERO TREATMENT AT BOTH EDGE AND LANDSCAPE, WHILE L15E15 IS 15% TREATMENT AT BOTH EDGE AND LANDSCAPE. THE Y-AXIS IS IN RESIDUAL RISK OR RELATIVE RISK UNITS, WHERE 1 = ZERO TREATMENT. TREATMENTS OF 10 AND 15% WERE NOT ACHIEVABLE IN THIS LANDSCAPE AND ARE THUS NOT SHOWN.

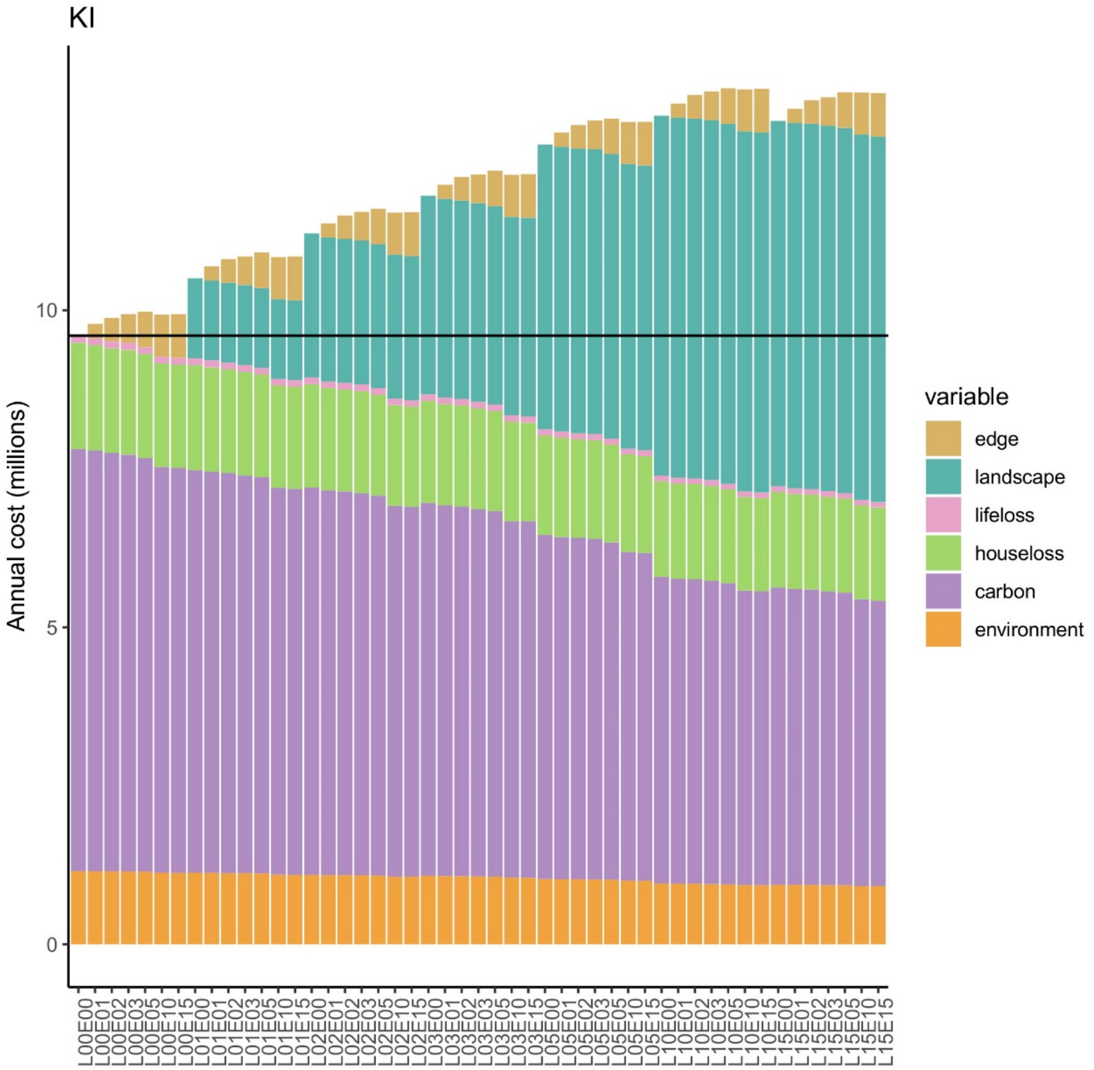

FIGURE 9: COST DATA FOR EDGE TREATMENT, LANDSCAPE TREATMENT AND THREE COSTS ASSOCIATED WITH WILDFIRE: LIFE LOSS, HOUSE LOSS AND CARBON EMISSIONS. LINES SHOW RESPONSE OF COST TO DIFFERING TREATMENT STRATEGIES IN THE KANGAROO ISLAND CASE STUDY LANDSCAPE. THE LABELS ON THE X-AXIS REFER TO RATES OF LANDSCAPE AND EDGE TREATMENT E.G. L00E00 IS ZERO TREATMENT AT BOTH EDGE AND LANDSCAPE, WHILE L15E15 IS 15% TREATMENT AT BOTH EDGE AND LANDSCAPE.

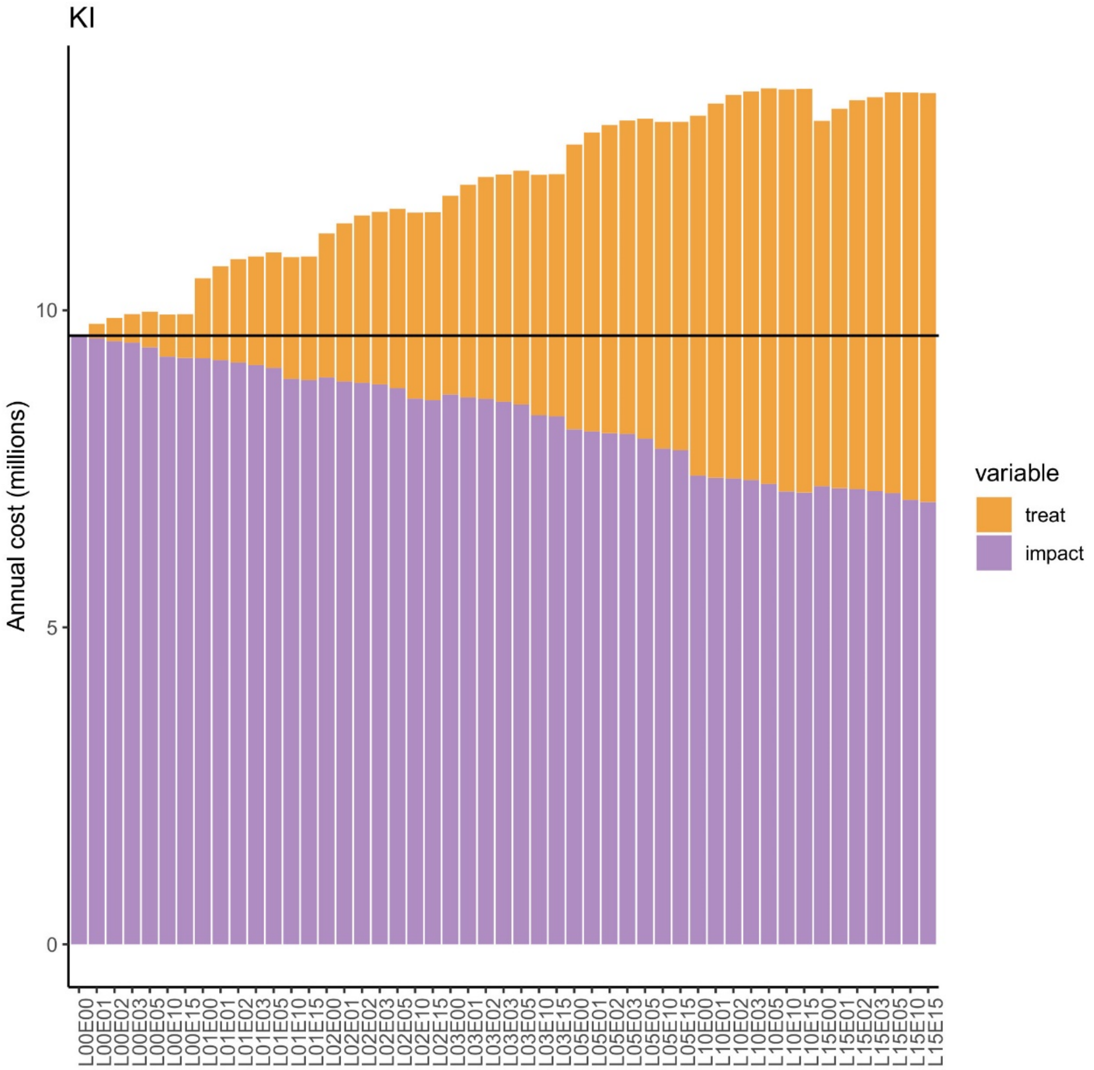

FIGURE 10: AS FOR FIGURE 9, BUT WITH ALL TREATMENT COSTS GROUPED TOGETHER AND ALL WILDFIRE IMPACT COSTS GROUPED TOGETHER.

PRESCRIBED BURNING IN MT LOFTY RANGES

Risk in the lead up to the 2019-20 fire season

Key findings

- Levels of prescribed burning leading up to the 2019/20 fire season were estimated to leave considerable residual risk for all values (e.g. 80-90% of a zero treatment scenario).
- The marginal effects of treatment were slight, such that increasing treatment levels from current rates (~2% p.a.) to 5% or 10% p.a. would have reduced risk by only a few percent.
- Weather conditions based on the severe weather conditions experienced during the 2019-20 fire season were estimated to result in higher risk than the long-term scenarios based on the full range of weather conditions for the historical record.
- The 2019-20 weather conditions essentially super-charged risk to all values, adding about 20% to long term averages, regardless of treatment rate.
- In general, increasing rates of prescribed burning treatment were predicted to decrease risks to assets, but only marginally: i.e. overall area burnt by wildfire, life loss, house loss, damage to roads and damage to powerlines. At the same time, increasing rates of prescribed burning treatment were predicted to increase the area burnt below minimum tolerable fire interval – again only marginally – and associated risk to some elements of biodiversity.

Significance of findings in context of previous studies

These findings are consistent with previous studies which have found that:

- prescribed burning may offer partial risk mitigation, not risk elimination (e.g. Cirulis et al. 2019, Penman et al. 2020)
- risk mitigation in some landscapes is less sensitive to prescribed burning, likely due to vegetation type and the spatial configuration of vegetation and assets within the landscape
- the risk mitigation potentially resulting from prescribed burning varies considerably between regions and management values (e.g. Cirulis et al. 2019). That is, there is not a 'one size fits all' solution to prescribed burning treatment
- Prescribed burning is likely to be less effective at mitigating risk to lives, property and infrastructure under severe fire weather conditions (e.g. Price and Bradstock 2012).

Limitations and remaining knowledge gaps

This analysis was based on large scale fire behaviour simulations under a range of ignition locations, prescribed burning treatment rates and locations, and fire weather conditions.

This approach assumes that fire spread is a function of fire weather, fuel load and factors such as topography. Fire behaviour simulators built on these assumptions have recently been evaluated (Faggian et al. 2017). The approach also assumes that planned and unplanned fires consume most fuel and that fuel begins to accumulate after fire as a function of time since fire, eventually stabilising at an equilibrium amount. In reality fuel consumption rates vary considerably within any given fire and are typically lower in prescribed fires than wildfires.

These results represent simulated properties of a wildfire originating from a single ignition. These simulations do not take into account the specific fire history leading up to the 2019-20 fire season.

Implications for fire management

- Based on these results prescribed burning in the Mt Lofty Ranges landscape offers only modest risk mitigation to people, property and infrastructure, but can increase the risk of vegetation being burnt below its tolerable ecological threshold.
- The effectiveness of prescribed burning depends on the specific risk being mitigated (e.g. house loss, life loss, infrastructure damage, environmental condition) as well as properties of the specific landscape being treated (e.g. vegetation type, climate, population density and arrangement of assets in the landscape).
- Fire seasons characterised by increased frequency of extreme weather conditions have substantially increased risks from wildfire regardless of treatment strategy. Further, the increase in risk due to extreme weather typically strongly outweighs the decrease in risk associated with even the highest rates of prescribed burning.

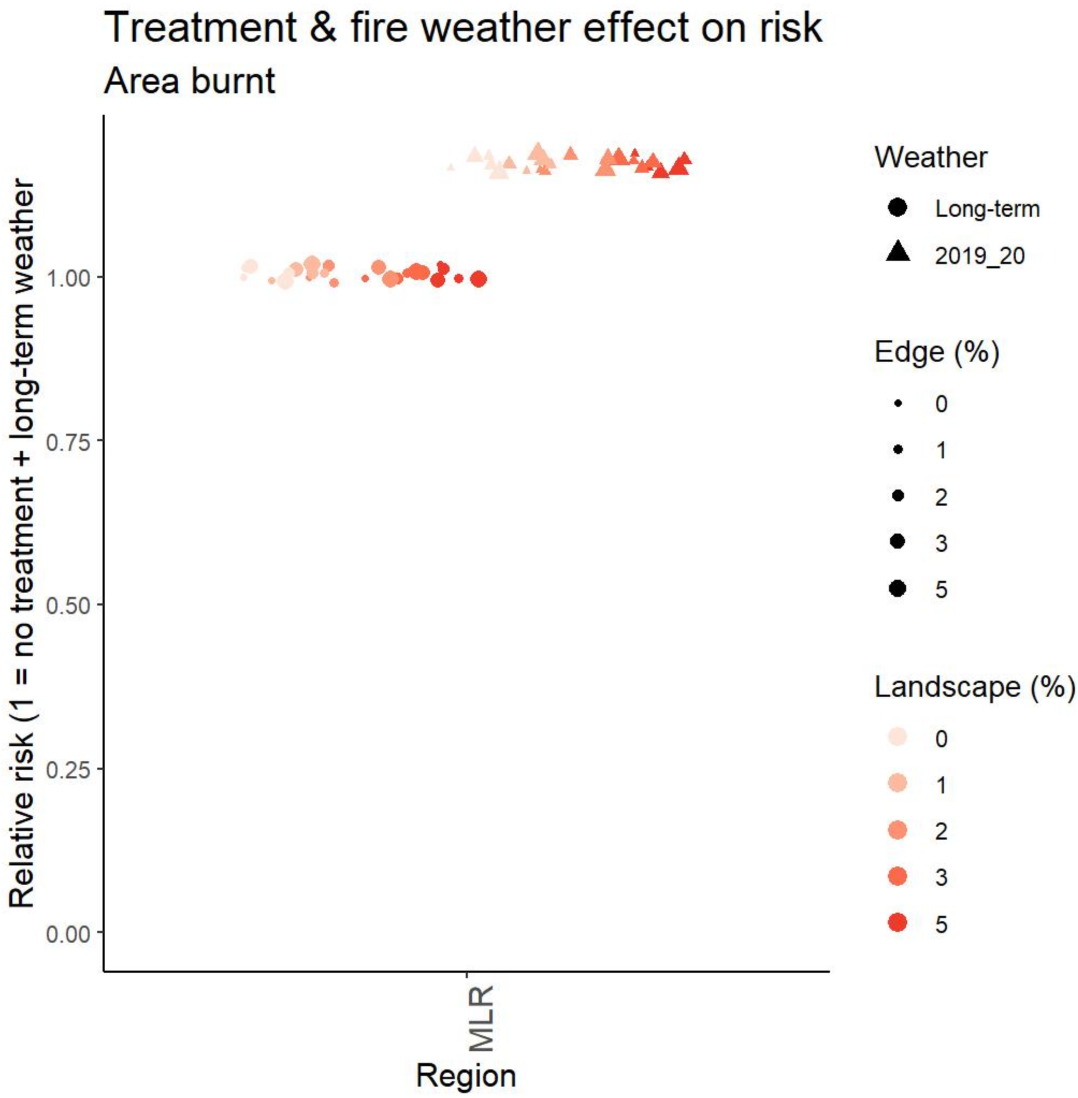

FIGURE 11: RISK TRAJECTORY FOR AREA BURNT UNDER DIFFERENT TREATMENT STRATEGIES AND WEATHER CONDITIONS. RISK IS RELATIVE TO A CONTROL SCENARIO (NO PRESCRIBED BURNING AND LONG-TERM WEATHER = 1, GREY DOTTED LINE INDICATES 50% RISK REDUCTION). MARKER SIZE REPRESENTS RATE OF EDGE TREATMENT, MARKER COLOUR REPRESENTS RATE OF LANDSCAPE TREATMENT AND MARKER SHAPE REPRESENTS WEATHER CONDITIONS (CIRCLES ON LEFT REPRESENT LONG-TERM WEATHER, TRIANGLES ON RIGHT INDICATE WEATHER FROM 2019/20 FIRE SEASON).

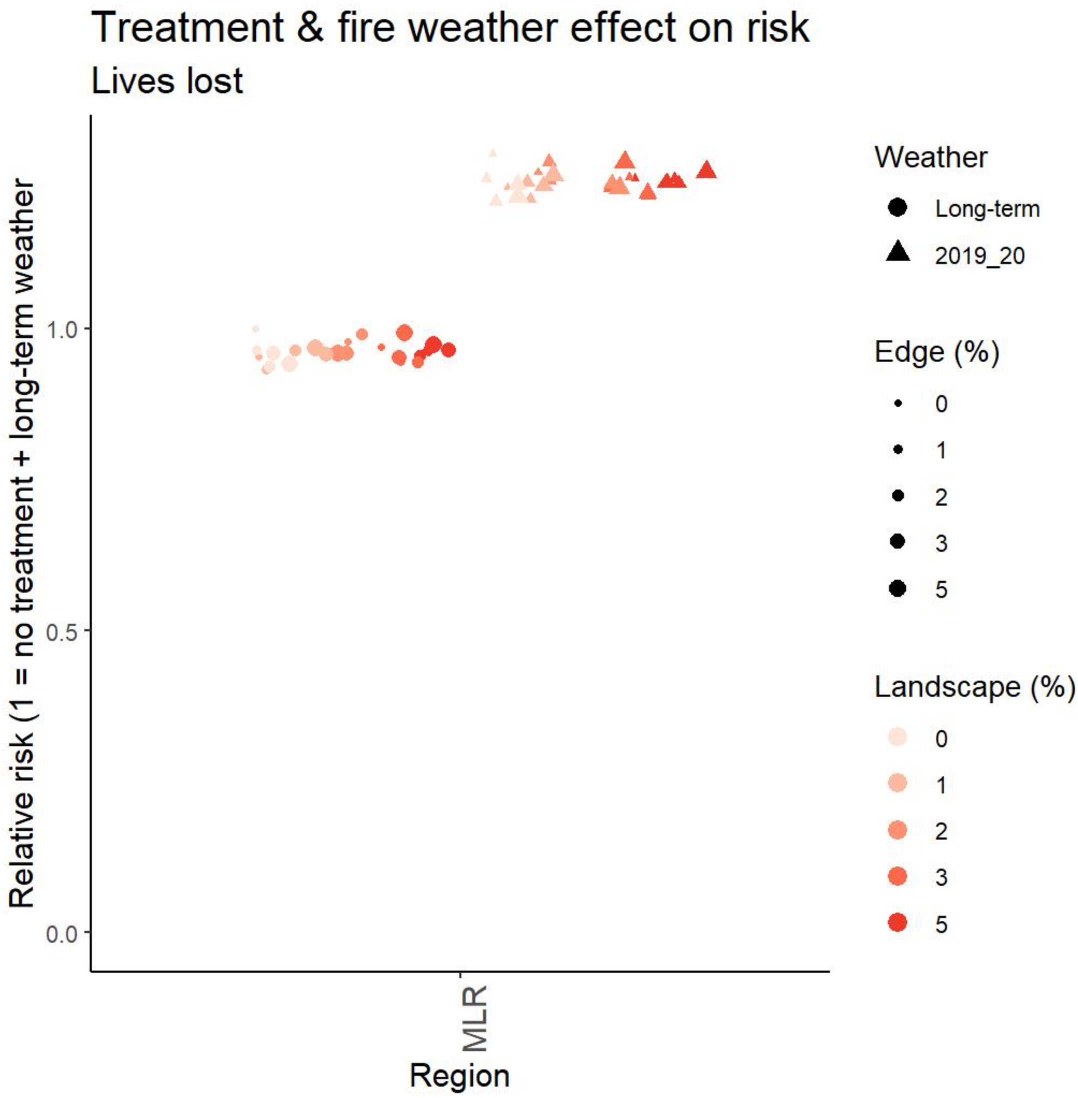

FIGURE 12: RISK TRAJECTORY FOR LIFE LOSS UNDER DIFFERENT TREATMENT STRATEGIES AND WEATHER CONDITIONS. RISK IS RELATIVE TO A CONTROL SCENARIO (NO PRESCRIBED BURNING AND LONG-TERM WEATHER = 1, GREY DOTTED LINE INDICATES 50% RISK REDUCTION). MARKER SIZE REPRESENTS RATE OF EDGE TREATMENT, MARKER COLOUR REPRESENTS RATE OF LANDSCAPE TREATMENT AND MARKER SHAPE REPRESENTS WEATHER CONDITIONS (CIRCLES ON LEFT REPRESENT LONG-TERM WEATHER, TRIANGLES ON RIGHT INDICATE WEATHER FROM 2019/20 FIRE SEASON).

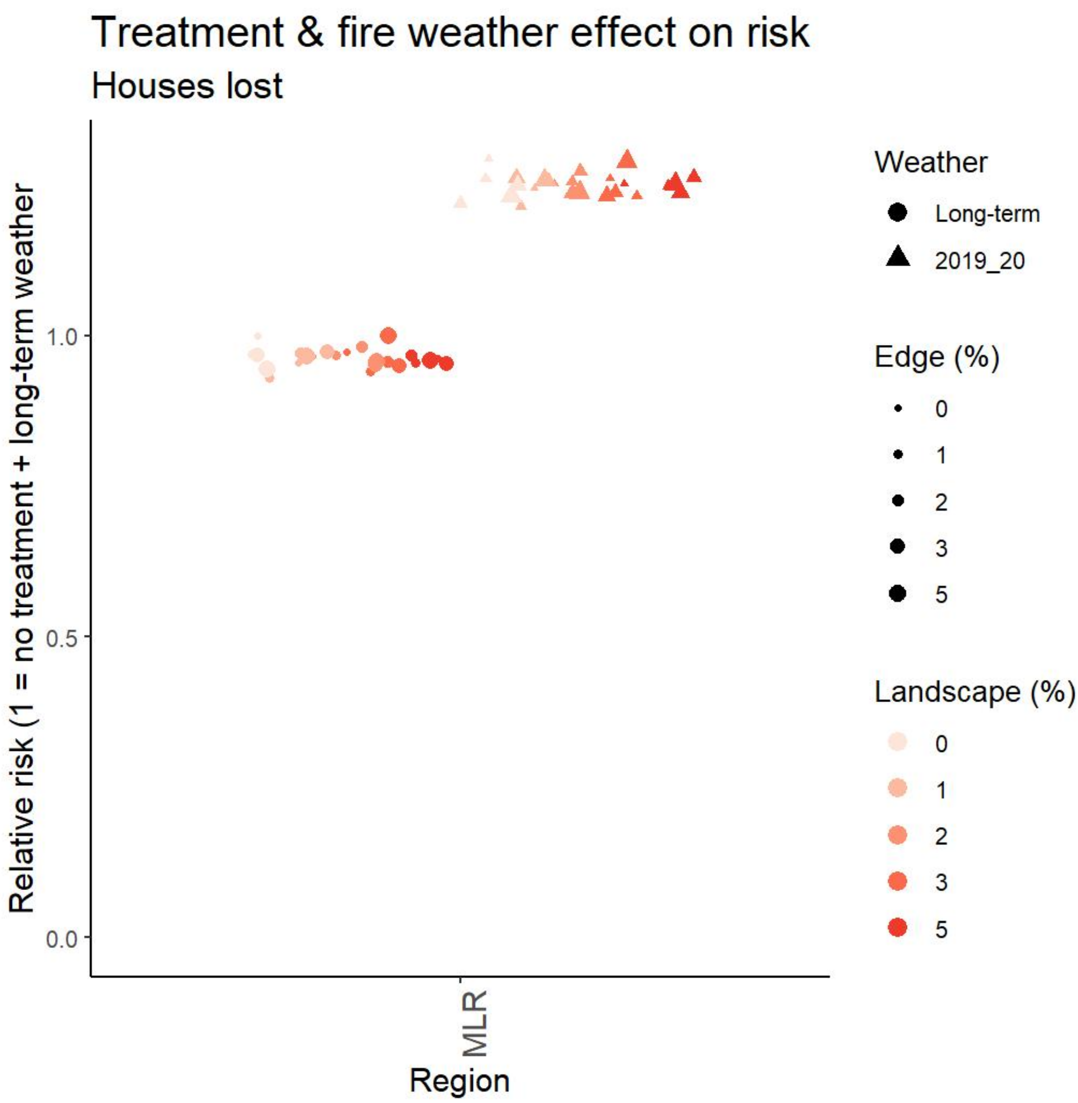

FIGURE 13: RISK TRAJECTORY FOR HOUSE LOSS UNDER DIFFERENT TREATMENT STRATEGIES AND WEATHER CONDITIONS. RISK IS RELATIVE TO A CONTROL SCENARIO (NO PRESCRIBED BURNING AND LONG-TERM WEATHER = 1, GREY DOTTED LINE INDICATES 50% RISK REDUCTION). MARKER SIZE REPRESENTS RATE OF EDGE TREATMENT, MARKER COLOUR REPRESENTS RATE OF LANDSCAPE TREATMENT AND MARKER SHAPE REPRESENTS WEATHER CONDITIONS (CIRCLES ON LEFT REPRESENT LONG-TERM WEATHER, TRIANGLES ON RIGHT INDICATE WEATHER FROM 2019/20 FIRE SEASON).

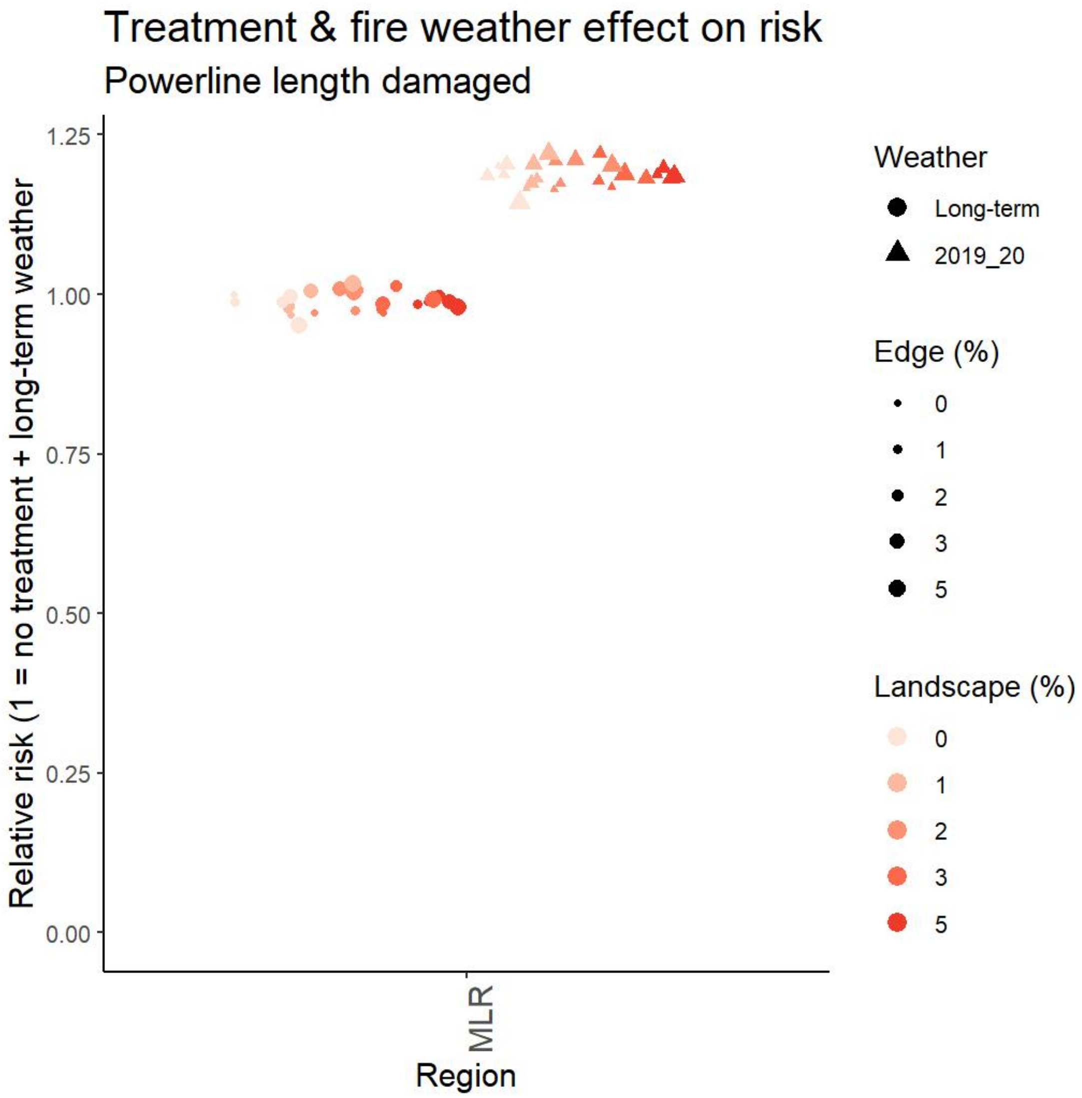

FIGURE 14: RISK TRAJECTORY FOR LENGTH OF POWERLINE DAMAGED UNDER DIFFERENT TREATMENT STRATEGIES AND WEATHER CONDITIONS. RISK IS RELATIVE TO A CONTROL SCENARIO (NO PRESCRIBED BURNING AND LONG-TERM WEATHER = 1, GREY DOTTED LINE INDICATES 50% RISK REDUCTION). MARKER SIZE REPRESENTS RATE OF EDGE TREATMENT, MARKER COLOUR REPRESENTS RATE OF LANDSCAPE TREATMENT AND MARKER SHAPE REPRESENTS WEATHER CONDITIONS (CIRCLES ON LEFT REPRESENT LONG-TERM WEATHER, TRIANGLES ON RIGHT INDICATE WEATHER FROM 2019/20 FIRE SEASON).

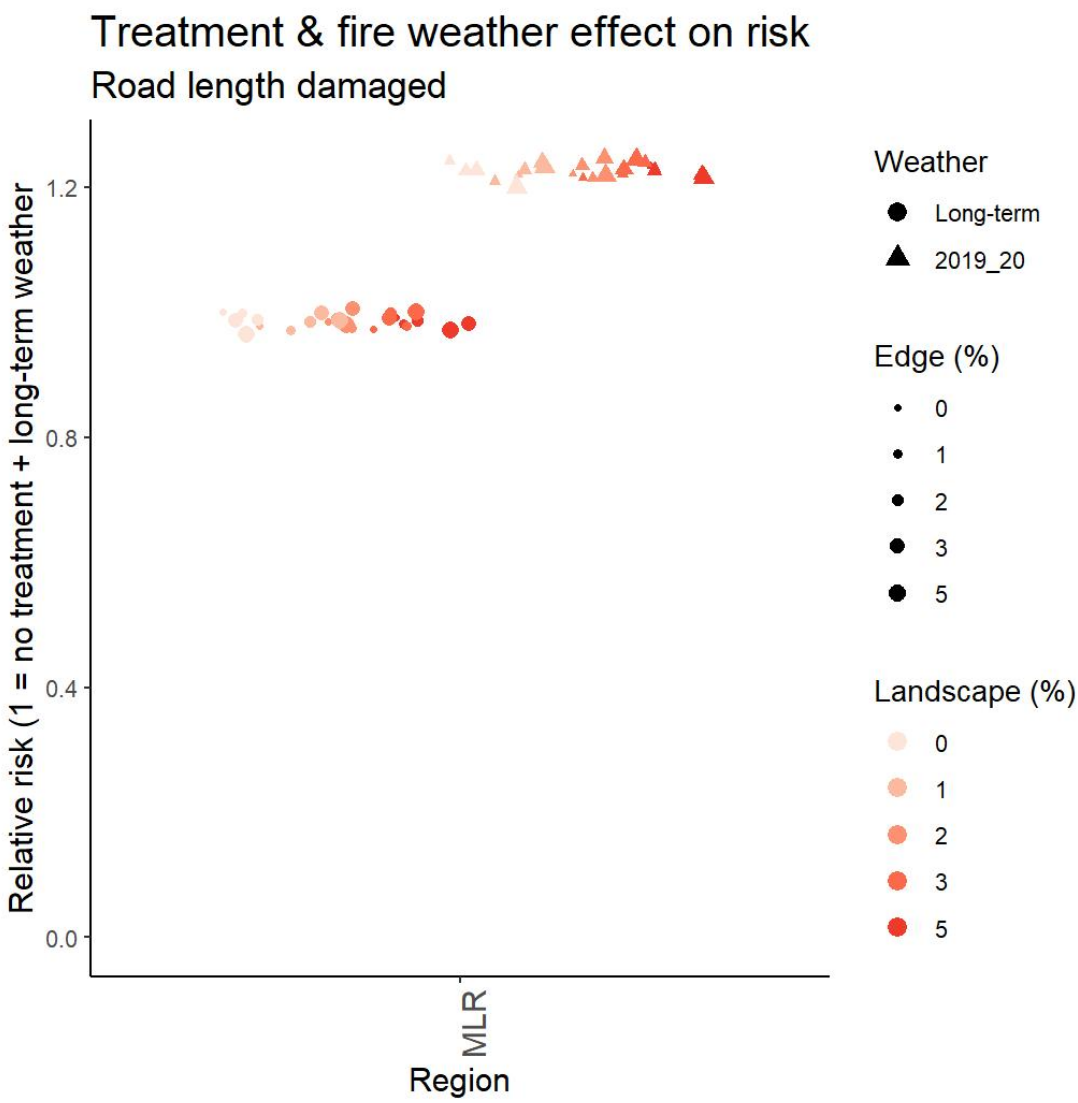

FIGURE 15: RISK TRAJECTORY FOR LENGTH OF ROAD DAMAGED UNDER DIFFERENT TREATMENT STRATEGIES AND WEATHER CONDITIONS. RISK IS RELATIVE TO A CONTROL SCENARIO (NO PRESCRIBED BURNING AND LONG-TERM WEATHER = 1, GREY DOTTED LINE INDICATES 50% RISK REDUCTION). MARKER SIZE REPRESENTS RATE OF EDGE TREATMENT, MARKER COLOUR REPRESENTS RATE OF LANDSCAPE TREATMENT AND MARKER SHAPE REPRESENTS WEATHER CONDITIONS (CIRCLES ON LEFT REPRESENT LONG-TERM WEATHER, TRIANGLES ON RIGHT INDICATE WEATHER FROM 2019/20 FIRE SEASON).

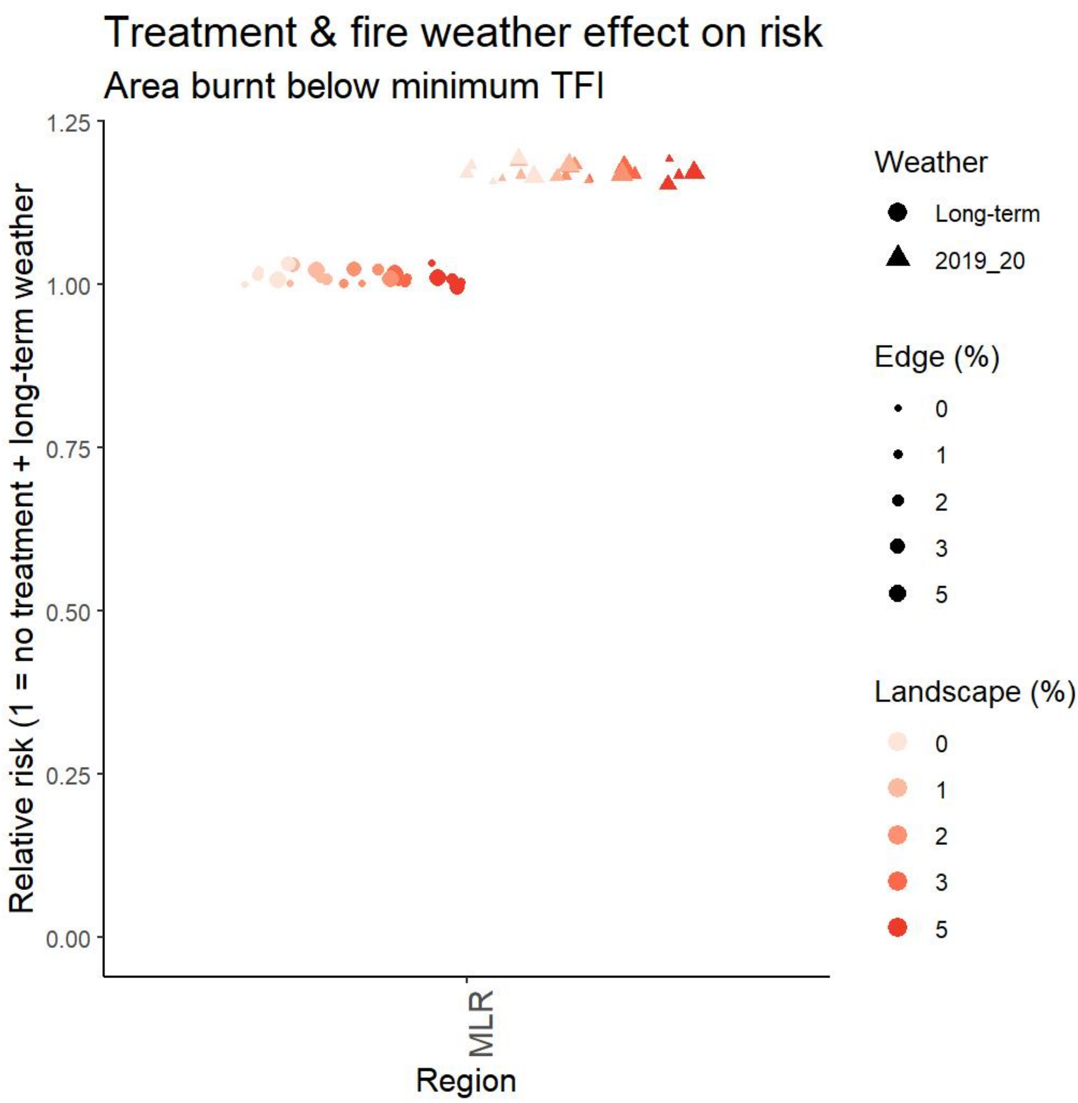

FIGURE 16: RISK TRAJECTORY FOR AREA BURNT BELOW MINIMUM TFI UNDER DIFFERENT TREATMENT STRATEGIES AND WEATHER CONDITIONS. RISK IS RELATIVE TO A CONTROL SCENARIO (NO PRESCRIBED BURNING AND LONG-TERM WEATHER = 1, GREY DOTTED LINE INDICATES 50% RISK REDUCTION). MARKER SIZE REPRESENTS RATE OF EDGE TREATMENT, MARKER COLOUR REPRESENTS RATE OF LANDSCAPE TREATMENT AND MARKER SHAPE REPRESENTS WEATHER CONDITIONS (CIRCLES ON LEFT REPRESENT LONG-TERM WEATHER, TRIANGLES ON RIGHT INDICATE WEATHER FROM 2019/20 FIRE SEASON).

Risk in the aftermath of the 2019-20 fire season

Key findings

- Through 2021, estimated reductions in fuel load due to the 2019-20 fire season are not predicted to substantially change the potential area burnt by wildfire or associated risks: i.e. loss of houses, infrastructure damage and area burnt below minimum TFI. An exception is the risk of loss of life, which is predicted to decline somewhat.
- By 2025, in the absence of wildfire and under a range of prescribed burning scenarios, the potential area burnt by wildfire is predicted to increase substantially over pre-2019/20 and 2021 levels. The same holds true for road damage and area burnt below minimum tolerable fire interval.

- In contrast, life loss and powerline damage are predicted to remain well below pre-2019/20 and 2021 levels, while house loss is predicted to remain stable under most treatment scenarios.
- The changes in future wildfire risk as a result of the 2019-20 fire season are striking in their strong dependence on the value or asset in question. Even with reduced fuel loads in some areas, considerable residual risk remains and over the next six years the risk of area burnt and area burnt below minimum TFI is predicted to increase strongly.
- Increased risk of area burnt by wildfire by 2025 likely relates to the specific footprint of the 2019-20 fires, which burnt close to homes in pastures but left other fuel sources undisturbed.
- The diverging results for life loss and house loss relate to our impact functions, which model life loss as a function of houses exposed to fire, but house loss as a function of not just exposure but fire properties such as intensity and flame length. These results suggest lower overall exposure of houses in the aftermath of the 2019-20 fire season, but greater loss due to the properties of fires simulated e.g. in higher fuel load areas.
- Prescribed burning offers only modest mitigation of the risk associated with the accumulation of fuel after the 2019-20 fire season, depending on management value.

Significance of findings in context of previous studies

These findings are consistent with previous studies which have found that:

- prescribed burning may offer partial risk mitigation, not risk elimination (Price et al. 2015)
- the risk mitigation potentially resulting from prescribed burning varies considerably between management values (Cirulis et al. 2019). That is, there is not a 'one size fits all' solution to prescribed burning treatment.

Limitations and remaining knowledge gaps

This analysis was based on large scale fire behaviour simulations under a range of fire weather conditions, ignition locations and prescribed burning treatment rates and locations, conducted with and without the area burned in the 2019-20 fire season.

This approach assumes that fire spread is a function of fire weather, fuel load and factors such as topography. An evaluation of fire behaviour simulators was recently conducted (Faggian et al. 2017). The approach also assumes that planned and unplanned fires consume most fuel and that fuel begins to accumulate after fire as a function of time since fire, eventually stabilising at an equilibrium amount. In reality fuel consumption rates vary considerably within any given fire and are typically lower in prescribed fires than wildfires (see Project Report on fire severity).

These results represent simulated properties of a wildfire originating from a single ignition. Simulations include relatively short histories of prescribed burning (two years for the 2021 case, 6 years for the 2025 case). Some of the effects of different prescribed burning treatment strategies may take longer than this to become apparent. This may explain why 2025 risk exceeds pre-2019-20 levels in some cases, along with the fact that the 2019-20 control does not include any treatment. These simulations do not take into account any future changes in climate or fuel moisture.

Implications for fire management

- Wildfire risk in the immediate aftermath of the 2019-20 fire season may not be greatly reduced, with residual risk substantial.
- By 2025 wildfire risk is predicted to increase substantially, associated with reaccumulation of fuel <u>assuming the absence of wildfires</u> in the intervening period.

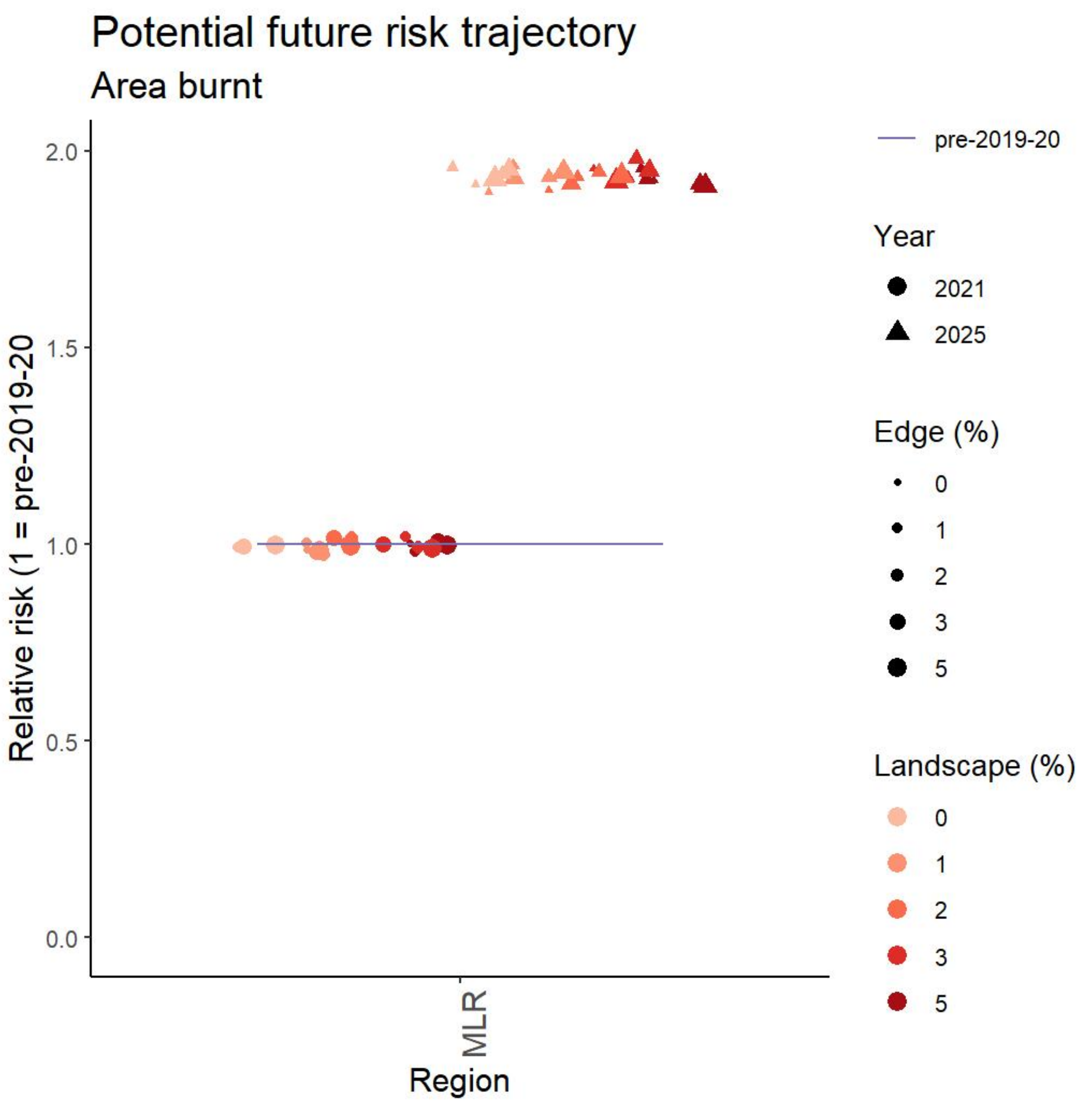

FIGURE 17: POTENTIAL FUTURE RISK TRAJECTORY FOR AREA BURNT. RISK IS RELATIVE TO CONTROL SCENARIO (WITH PRE-2019/20 FUEL LOAD AND NO PRESCRIBED BURNING). INDIVIDUAL MARKERS REPRESENT RISK UNDER DIFFERENT RATES (0-5%) AND LOCATIONS (EDGE = SIZE, LANDSCAPE = COLOUR) OF PRESCRIBED BURNING.

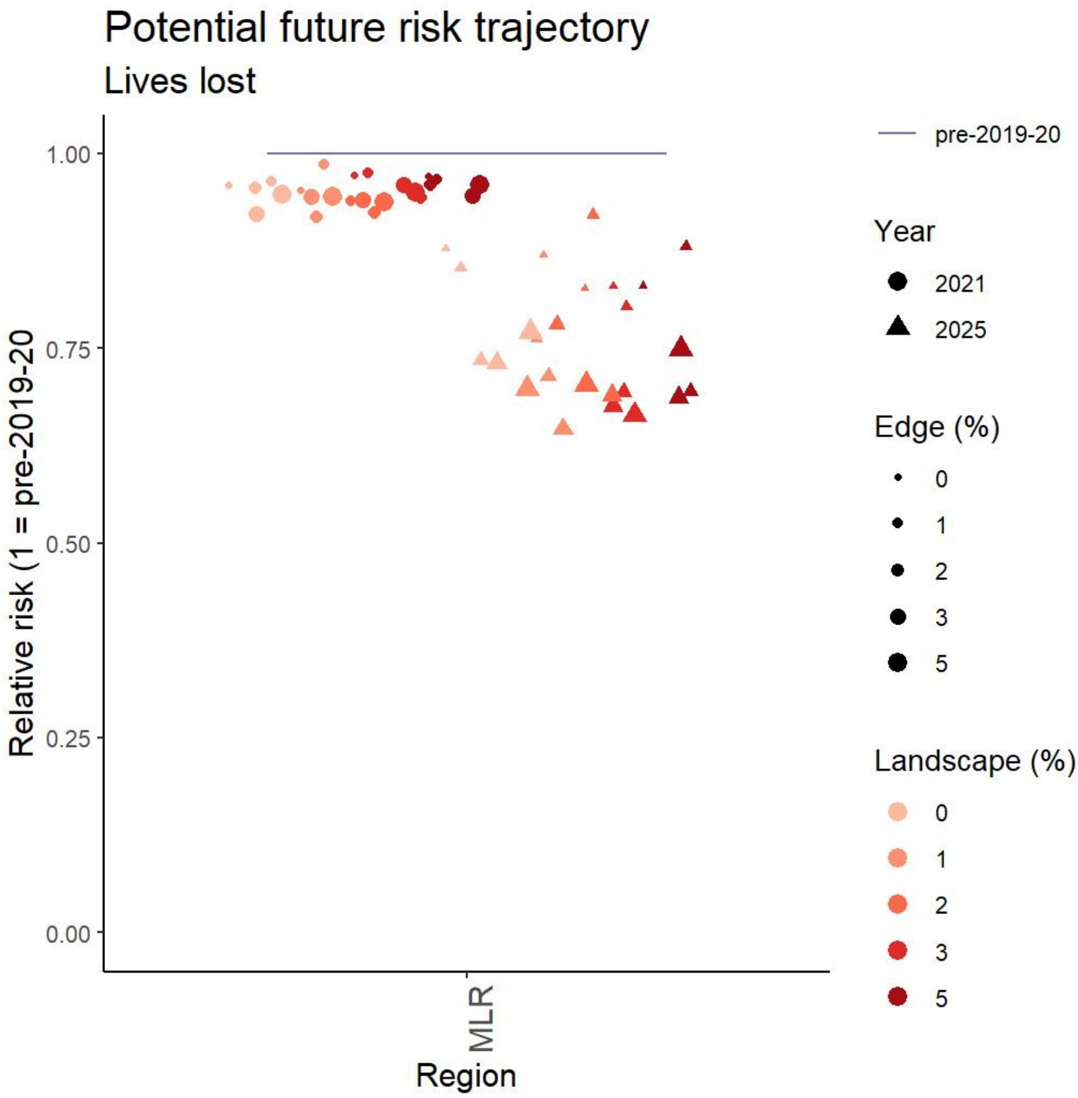

FIGURE 18: POTENTIAL FUTURE RISK TRAJECTORY FOR LIFE LOSS. RISK IS RELATIVE TO CONTROL SCENARIO (WITH PRE-2019/20 FUEL LOAD AND NO PRESCRIBED BURNING). INDIVIDUAL MARKERS REPRESENT RISK UNDER DIFFERENT RATES (0-5%) AND LOCATIONS (EDGE = SIZE, LANDSCAPE = COLOUR) OF PRESCRIBED BURNING.

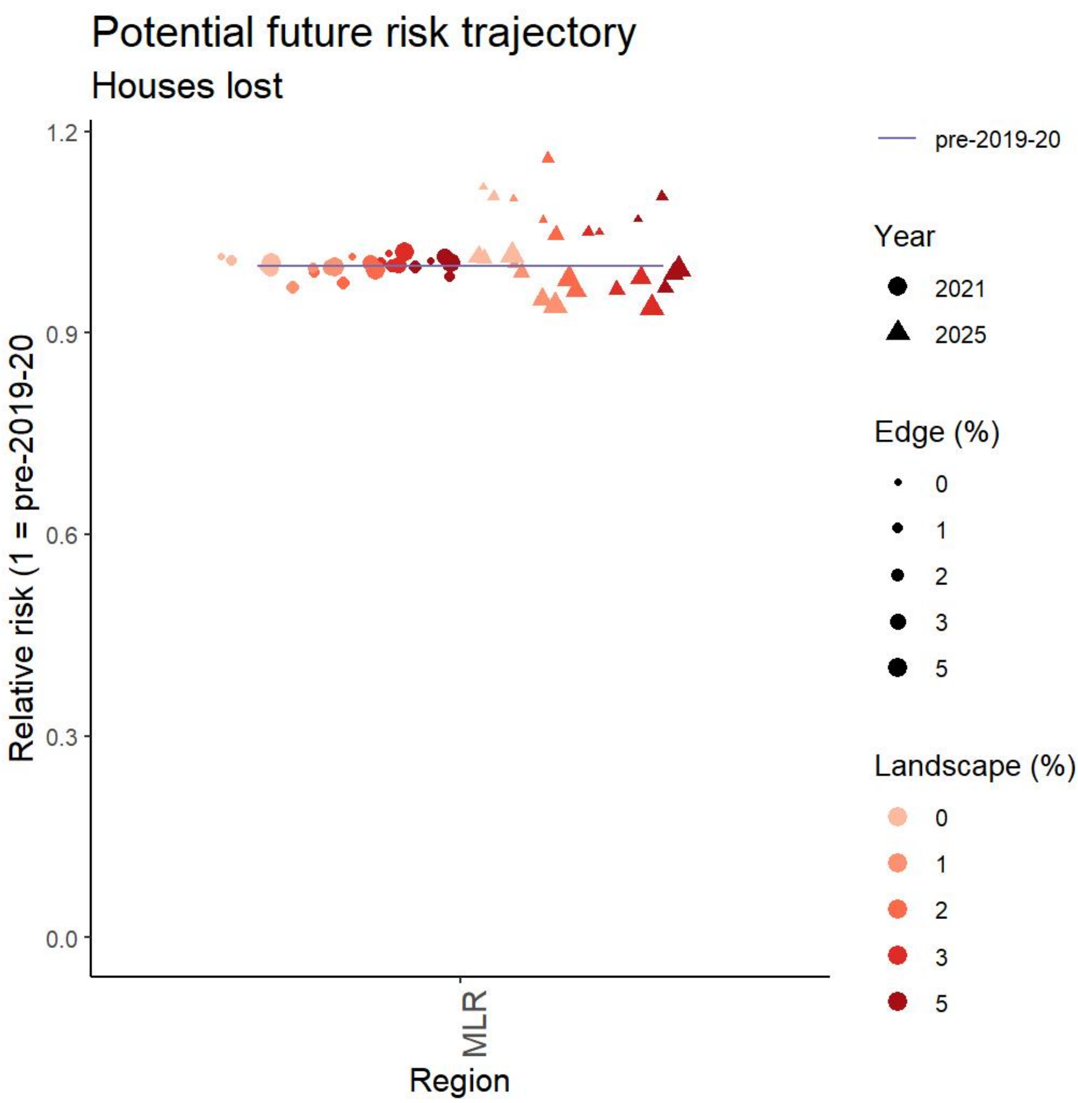

FIGURE 19: POTENTIAL FUTURE RISK TRAJECTORY FOR HOUSE LOSS. RISK IS RELATIVE TO CONTROL SCENARIO (WITH PRE-2019/20 FUEL LOAD AND NO PRESCRIBED BURNING). INDIVIDUAL MARKERS REPRESENT RISK UNDER DIFFERENT RATES (0-5%) AND LOCATIONS (EDGE = SIZE, LANDSCAPE = COLOUR) OF PRESCRIBED BURNING.

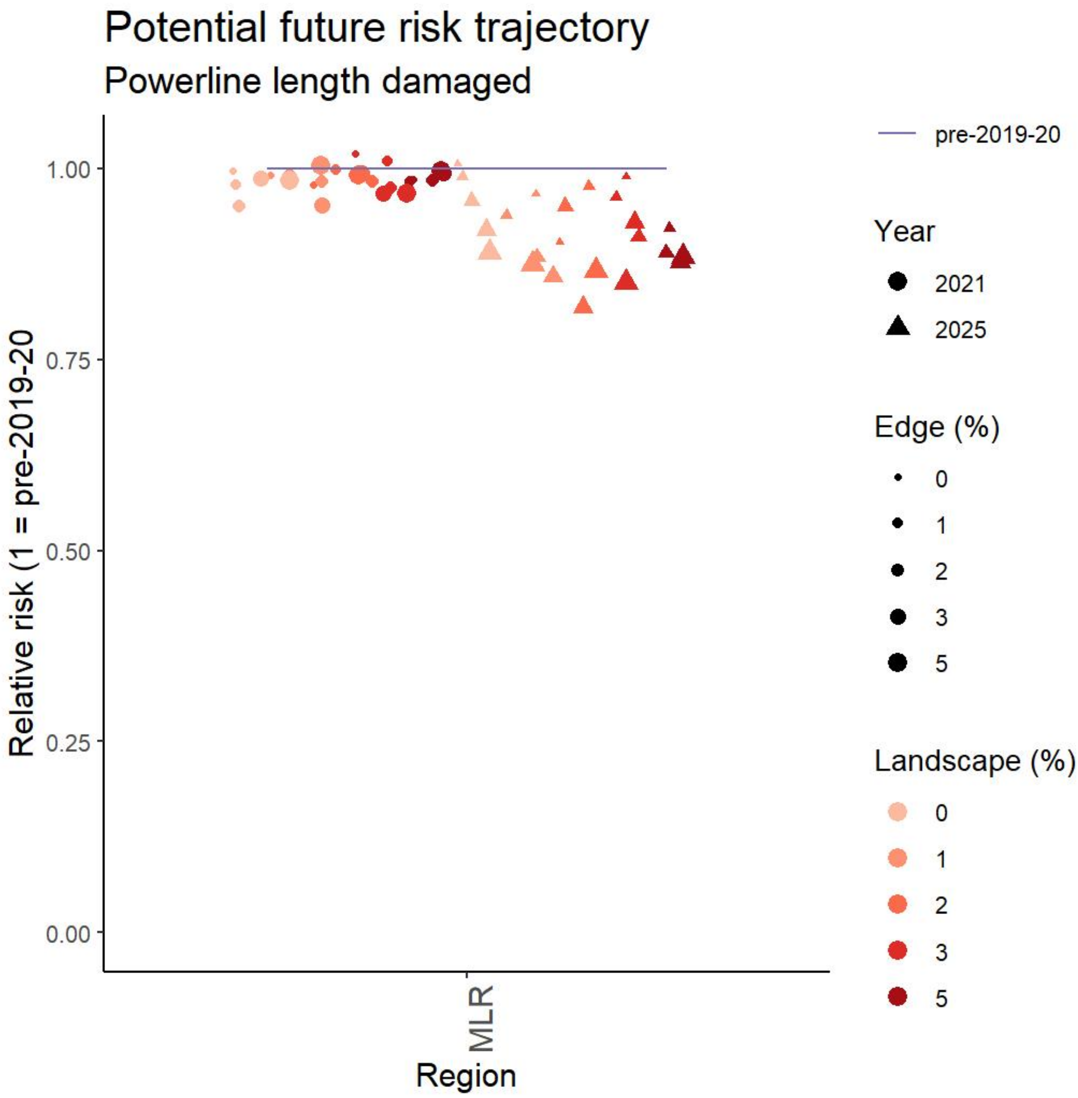

FIGURE 20: POTENTIAL FUTURE RISK TRAJECTORY FOR LENGTH OF POWERLINE DAMAGED. RISK IS RELATIVE TO CONTROL SCENARIO (WITH PRE-2019/20 FUEL LOAD AND NO PRESCRIBED BURNING). INDIVIDUAL MARKERS REPRESENT RISK UNDER DIFFERENT RATES (0-5%) AND LOCATIONS (EDGE = SIZE, LANDSCAPE = COLOUR) OF PRESCRIBED BURNING.

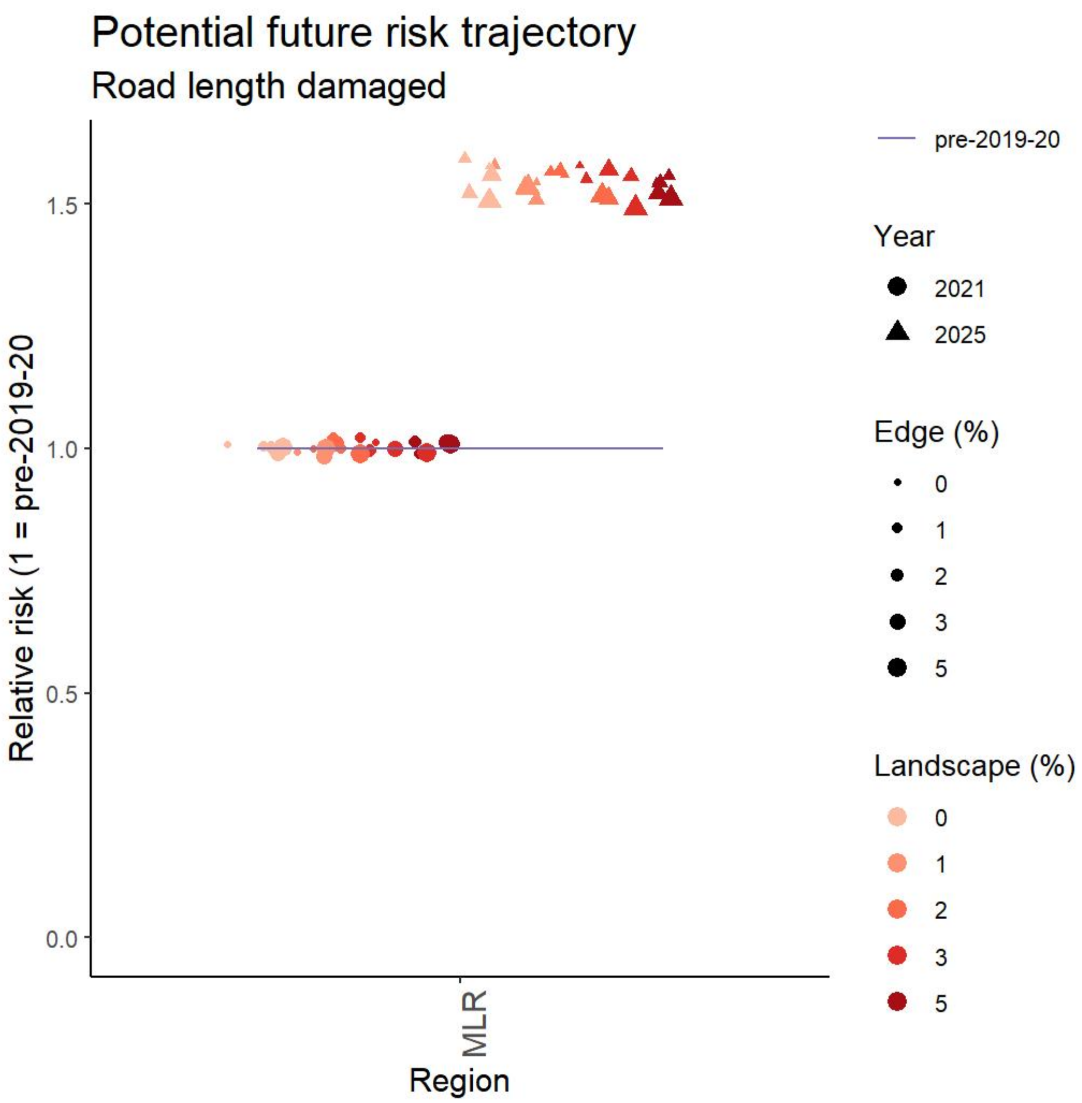

FIGURE 21: POTENTIAL FUTURE RISK TRAJECTORY FOR LENGTH OF ROAD DAMAGED. RISK IS RELATIVE TO CONTROL SCENARIO (WITH PRE-2019/20 FUEL LOAD AND NO PRESCRIBED BURNING). INDIVIDUAL MARKERS REPRESENT RISK UNDER DIFFERENT RATES (0-5%) AND LOCATIONS (EDGE = SIZE, LANDSCAPE = COLOUR) OF PRESCRIBED BURNING.

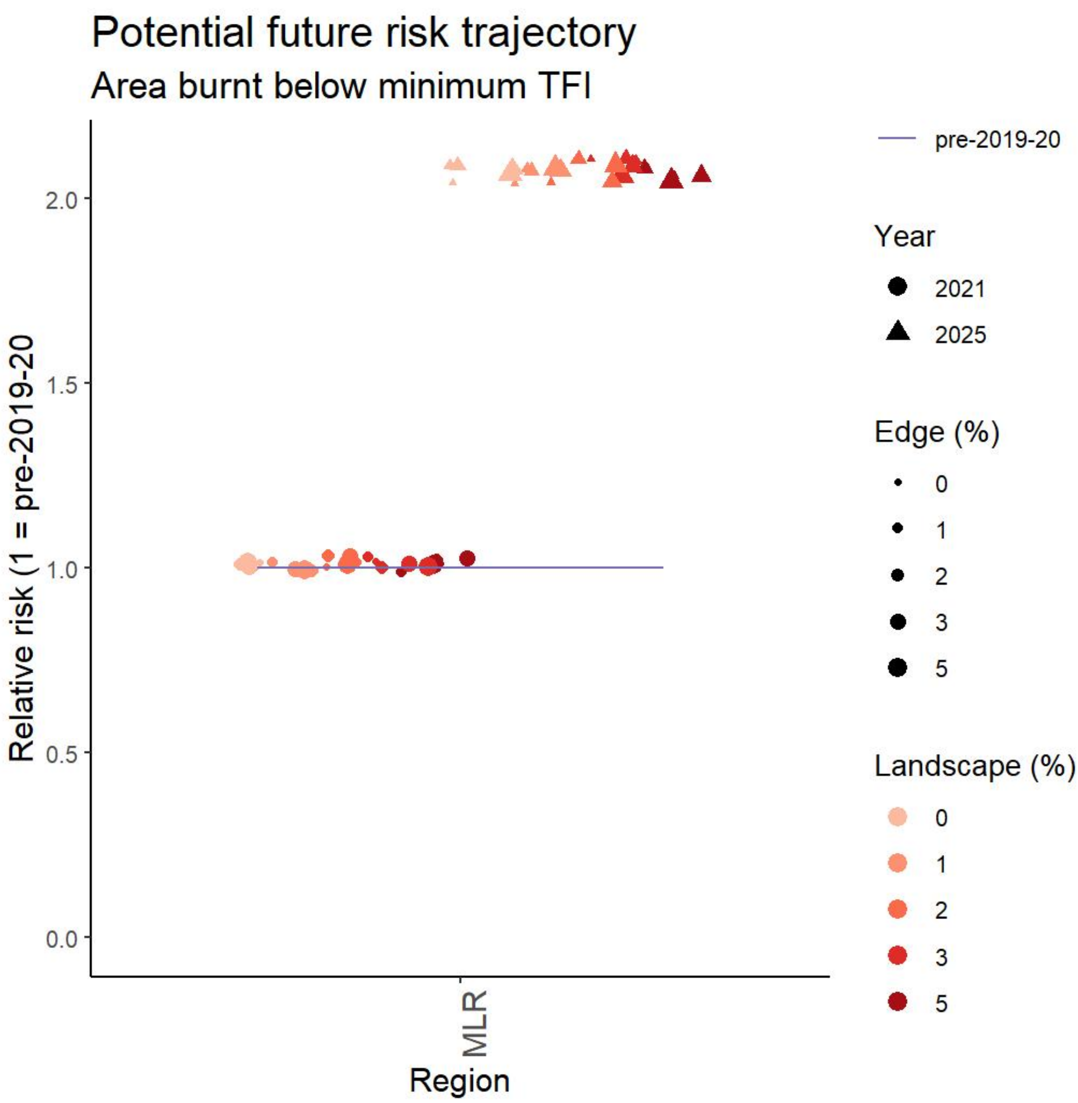

FIGURE 22: POTENTIAL FUTURE RISK TRAJECTORY FOR AREA BURNT BELOW MINIMUM TFI. RISK IS RELATIVE TO CONTROL SCENARIO (WITH PRE-2019/20 FUEL LOAD AND NO PRESCRIBED BURNING). INDIVIDUAL MARKERS REPRESENT RISK UNDER DIFFERENT RATES (0-5%) AND LOCATIONS (EDGE = SIZE, LANDSCAPE = COLOUR) OF PRESCRIBED BURNING.

KEY MILESTONES

The key project milestones were as follows:

- New Kangaroo Island landscape
  - prepare landscape incl new biophysical layers, fire history and burn blocks
  - run simulations
  - postprocess simulations, run Bayesian Decision Network
  - incorporate output as new landscape in Prescribed Burning Atlas
- Mount Lofty Ranges landscape
  - pre-2019/20 risk analysis
    - prepare landscape incl willdfire and prescribed fire history
    - run simulations
    - postprocess simulations, run Bayesian Decision Network
  - post-2019/20 risk analysis
    - prepare landscape incl willdfire and prescribed fire history
    - run simulations
    - ostprocess simulations, run Bayesian Decision Network
  - alternative treatment analysis (as noted above, this element was withdrawn because agency supplied burn blocks did not have sufficent coverage of the study area to allow analysis)
    - prepare landscape including burn blocks in consultation with end-user
    - run simulations
    - postprocess simulations, run Bayesian Decision Network
  - analysis of MLR outputs
  - draft report summarising findings of risk analyses

UTILISATION AND IMPACT

SUMMARY

As with its parent project, utilisation has been strongly embedded in this project, through links to the end-user tool, the Prescribed Burning Atlas. Pathways to impact for other parts of the project are more traditional and will likely include meetings, webinars and scientific publications.

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.

The key output for this project is the addition of a new case study landscape, Kangaroo Island, to the Atlas.

Extent of use

- The launch of the Atlas attracted over 250 attendees from a range of fire and land managemnt agencies, academics, the private sector, media and NGOs. Over 100 people have registered with the website in order to use it.
- We anticipate there will be interest among the broader user group, not just our end-users in South Australia, in the results of the Kangaroo Island case study.

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.

Utilisation impact

- The main benefit of the Atlas and our related research on risk mitigation in the lead up to and aftermath of fire seasons is in helping fire managers think through potential costs and benefits of different prescribed burning strategies in particular landscapes.
- We have been approached by a agencies, academics and private sector organisations interested in learning more about the Atlas, supporting additional case study landscapes, or extracting further information about prescribed burning cost-effectiveness from our sizeable datasets.
- There are already discussions amongst researchers about how to incorporate improvements in fire behaviour simulators and our understanding of the relationship between planned fire, unplanned fire and various management values, into future studies, whether simulation- or observation-based, which will further improve our knowledge base about risk mitigation and support fire management in Australia.
- We are confident that, beyond any direct use of the Prescribed Burning Atlas or the results presented here for the Mt Lofty Ranges, our approach is setting a tone for systematic, objective quantification of the effects of prescribed burning on a wide range of risks, well beyond what we have explored so far.

CONCLUSION

This project successfully demonstrated the capacity to add new landscapes to the Prescribed Burning Atlas, bringing in Kangaroo Island. The project also examined risk in the lead up to and aftermath of the 2019-20 fire season in the Mt Lofty Ranges, an analysis that can readily be expanded to other fire affected regions during that season or fire seasons to come. Overall our project supports fire managers efforts to understand and compare the effectiveness of prescribed burning for mitigating risk in different landscapes and under different fire weather conditions and fire history.

NEXT STEPS

We will continue to socialise the Prescribed Burning Atlas and other results from our CRC projects through workshops, conferences (eg AFAC2021) and peer networks. We will also continue to write up our results for publication in international peer reviewed journals, including end-users as coauthors where appropriate. We continue to discuss extension and parallel projects with end-users, such as development and implementation of new values (e.g. smoke health costs) and expect to remain highly active and engaged with end-users in the field of prescribed burning risk assessment.

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 (179 publications, 8,468 citations). The project team also includes Associate Professor Owen Price (UOW), Professor Trent Penman (UOM), Associate Professor Matthias Boer (WSU), Dr Hamish Clarke (UOW, WSU), Mr Brett Cirulis (UOM) and Mr Anthony Rawlins (UOW, UOM). Price, Penman and Boer are leaders in bushfire research nationally and internationally, with 97, 84 and 68 publications respectively. Dr Clarke is an emerging leader in bushfire and climate change research (20 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. For this project, our lead end-users are Mike Wouters and Simeon Telfer from the South Australian Department of Environment and Water.

End-user organisation	End-user representative	Extent of engagement (Describe type of engagement)
SA DEW	Mike Wouters	Project scoping, design, feedback
SA DEW	Simeon Telfer	Data supply, feedback

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