ACT State of the Environment Report

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Current role of fire management in altering risk to human and environmental assets within the ACT under current and future climates

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Contents

Executive summary

- Fire management is charged with reducing the risk to human and environmental assets.
- A large number of approaches are available to reduce fire risk, yet there is no ideal formula that works across landscapes.
- Recent simulation modelling in the ACT found that edge treatments and rapid suppression responses give the greatest risk reduction to houses and environmental values.
- Global shifts in climates will result in an increase in the number of days of weather conducive to dangerous fire spread.
- These changes will intensity fire regimes with an increase in the extent and average intensity of fires within and around the ACT.
- Moving forward, land planning decisions will have a significant role in determining the level of fire risk, and effectiveness of fire management.
- Fire agencies must be able to adopt an adaptive approach to fire management.
- Regardless, evidence suggests that the general principles of fire management for protection of human assets will remain relevant.
- Conservation managers face the greatest challenge coping with the direct impacts of climate change on species abundance and distribution, while accounting for intensification of fire regimes.

Introduction

Bushfires are a natural hazard that can result in significant losses (Gill 2005). Large losses of houses and lives have been reported across the globe over the past decade (Blanchi *et al.* 2010; Konovalov *et al.* 2011; Boustras *et al.* 2012). A range of other assets are impacted by fire such as biodiversity, powerlines, roads, communication towers, fencing, machinery and agricultural production (Ganewatta 2008). Therefore, the total costs of destructive fires can be high.

Fire and land management agencies invest significant resources to try and reduce the impacts of future fires (Calkin *et al.* 2005; Berry *et al.* 2006). There are a wide range of strategies available with the most common being fuel treatment (Fernandes and Botelho 2003; Penman *et al.* 2011), suppression (Wilson and Wiitala 2005; Finney *et al.* 2009; Plucinski 2012), ignition prevention (Bryant 2008; Prestemon and Butry 2008a; Plucinski 2014) and community engagement (Eriksen and Prior 2011; Paton and Buergelt 2012).

Global climatic change is resulting in the increased occurrence of hotter, drier conditions conducive to fire spread. As a consequence, shifts in fire regimes are occurring around the world. In the western USA, five of the six largest recorded fires occurred in 2020, resulting in over 10,000 structures being damaged or destroyed, and dozens of lives lost (Higuera and Abatzoglou 2021). The Black Summer fires of 2019/20 in south-eastern Australia burned over 18 million hectares, destroyed more than 3000 houses, and led to the deaths of 33 people (Filkov *et al.* 2020). The season was the result of record drought conditions and extreme fire weather (Nolan *et al.* 2020; Abram *et al.* 2021; Collins *et al.* 2021).

The Australian Capital Territory (ACT) has been impacted by a number of large fires over the last 25 years resulting in negative impacts on people and the environment. On the 18th of January 2003 fires entered the city of Canberra resulting in four deaths, 435 people injured and the loss of 510 houses. Approximately 70% of the area was burnt, and around 80% of Namadgi burnt during this time, with a similar amount burning during the record-breaking Black Summer fire season (2019/2020). Although Black Summer didn't result in losses within the ACT, residents of the ACT were exposed to the worst air quality in the world for a number of days which is predicted to have increased hospital admissions and the death rate (Borchers Arriagada *et al.* 2020).

Ongoing changes to climate and fire regimes suggest that the risk from fire will increase in the ACT, and across Australia. The Flare Wildfire Research Group at The University of Melbourne were engaged to provide a report on the current role of fire management in altering risk to human and environmental assets within the Australian Capital Territory under current and future climates.

In this report we cover three primary areas:

1. A short synthesis of current fire management literature relevant to the ACT. This section outlines the suitability of management techniques for reducing risk to assets, with a primary focus on prescribed burning, mechanical treatments such as mulching and thinning, and fire suppression actions.
2. Key results from a range of published and unpublished studies undertaken by the FLARE Wildfire Research Group of relevance to the ACT. In this section we provide a discussion of the key findings and implications on risk to human and environmental assets.
3. Forecasting the likely role of management in reducing future fire risk in the ACT. Combining learnings from the previous sections of the report, we provide a forward-looking assessment of the risks and challenges for managing fire in the ACT both now and into the future.

Summary of current fire management practices relevant to the ACT

Fuel management is the primary means for land and fire managers to reduce the occurrence and severity of future fires, while also increasing capacity for suppression (Agee and Skinner 2005; Wilson and Wiitala 2005; Finney *et al.* 2009; Penman *et al.* 2011). There are multiple fuel management strategies used in Australia, with varying levels of effectiveness. Each strategy has a diverse and complex set of challenges, benefits and limitations.

Fuel management in the Australian Capital Territory (ACT) occurs on both public and private land. Fire management on public land in the ACT is the responsibility of several agencies, including the ACT Emergency Services Agency; the ACT Rural fire Service, and Parks and Conservation. On private land, there are no formal objectives, but fuel management is usually undertaken to reduce fuel loads, remove dead material and reduce stubble. All fire-related fuel management activities on public land in the ACT are guided by the Strategic Bushfire Management Plan (SBMP) which establishes a framework for the efficient, effective, and comprehensive management of fire and fire-related activities for protecting human life, property, assets and the environment.

The primary objectives for fuel management in this plan include:

1. **Broad area bushfire fuel reduction across the natural and rural landscape of the ACT,** to establish and maintain a range of differing fuel loads across the broader natural and rural landscape of the ACT, to assist in suppressing bushfires and reducing the impact of bushfires on life, property and the environment.
2. **Access for vehicles and firefighters to undertake bushfire fighting and fuel reduction.** Government and private land managers will work together to provide a network of fire trails and helipads that provide safe and effective access for firefighting and fuel reduction operations.

Here we provide a brief summary of different fuel management techniques for reducing risk to assets, relevant to the ACT and the above SBMP objectives. While there are other fuel management techniques available to land and fire managers in this region, we focus on the primary strategies of prescribed burning, mulching/mastication and suppression, noting that these strategies rarely occur in isolation. These strategies are part of a 'toolbox' of techniques utilised by land and fire managers in an attempt to reduce future fire risk.

Prescribed fire

Prescribed fire is 'the controlled application of fire under specified environmental conditions to a pre-determined area and at the time, intensity, and rate of spread required to attain planned resource management objectives, undertaken in specified environmental conditions' (AFAC 2015). Prescribed burning is an overarching term used to describe a diverse array of fire treatments (Duff *et al.* 2018b), including hazard reduction burning, ecological burning and cultural burning. Prescribed burning typically occurs outside of the bushfire season under conditions that facilitate burning at low intensities with slow rates of spread (McArthur 1967; Cheney *et al.* 1992; Penman *et al.* 2007). Prescribed burning may differ slightly in the way it is implemented in different fire-prone regions, though the objectives which drive its use are largely universal. The primary objectives for undertaking prescribed burning are to reduce future fire impacts on people, property and assets; increase containment likelihood; and reduce ignition likelihood.

Below we summarise some key aspects regarding prescribed burning and the known evidence-base for the suitability of this approach for reducing risk to assets.

- **The scale at which fuel treatments are applied to yield the best possible risk reduction is complex and will vary depending on landscape context.** Careful consideration of the costs of implementation, impacts on values (positive or negative), and the risk reduction achieved through prescribed burning (or other approaches) is important. Fuel management at any scale will result in altered fuel loads and modified fire behaviour, however this does not necessarily result in a meaningful reduction in fire risk to key assets. Currently, there is little consensus over where, when, how, how frequently and at what scale fuel management should be undertaken to effectively reduce the risk of future fires, and as such the application of fuel treatment options is frequently argued by scientists, managers, the media and the general public (Parkins *et al.* 2021).

- **Prescribed burning can reduce future fire severity, though the effect is generally short-lived**, **and largely dependent on fire weather conditions and site productivity**. Fire weather is the dominant driver of fire severity, with time since fire and topography being of secondary importance (Bradstock 2010; Storey *et al.* 2016). Recently burnt areas (less than five years since fire) are more likely to result in lower severity fire than long unburnt areas (Bradstock *et al.* 2010; Murphy and Russell-Smith 2010; Storey *et al.* 2016; Tolhurst and McCarthy 2016), however these affects are reduced or disappear as fire weather increases (Price and Bradstock 2012; Tolhurst and McCarthy 2016). Relationships between fire severity and time since fire are complex and do not necessarily increase linearly with time since fire (e.g. Taylor *et al.* 2014; Storey *et al.* 2016). These non-linear responses have been supported by empirical studies of flammability (McColl-Gausden and Penman 2019; McColl-Gausden *et al.* 2020).

- **Prescribed burning can limit the extent of future bushfires in some vegetation types, and under some weather conditions, thereby reducing risk to assets.** Studies on the effectiveness of prescribed burning for limiting the extent of future bushfire exist for a range of vegetation types in the fire-prone regions of the world, however results between regions differ considerably. The efficacy of hazard reduction burning in reducing the extent of bushfire can be considered as the probability of a bushfire encountering a prescribed burn area(s) while the fuel is in reduced state that moderates fire behaviour sufficient to stop a bushfire or allow successful suppression of that fire (Finney 2001; Agee and Skinner 2005). The scientific literature regarding the efficacy of prescribed burning for the protection of human and environmental assets is often contradictory. One predominant school of thought is that considerably more prescribed burning will be required to reduce the economic and ecological impact of major bushfires (Krusel and Petris 1992; McLeod 2003; Ellis *et al.* 2004; Cheney 2008; Morgan *et al.* 2020). An opposing view is that too much fire in certain systems will have negative ecological impacts, with many burnt landscapes being perceived as ecologically destroyed (Holloway 2000; Schultz 2008; Bradshaw *et al.* 2018). Furthermore, the increased health and wellbeing costs resulting from reduced air quality from smoke from major bushfires are another key issue that remain poorly understood (Brunson and Evans 2005; Bell and Oliveras 2006; Borchers *et al.* 2020).

- **Prescribed fire can reduce fuel load and structure, which is directly related to containment likelihood.** Fuel load and structure affects fire behaviour which has a strong influence on the ability of suppression crews to contain a fire (Ponto 1989; Hirsch and Martell

1996; Budd *et al.* 1997; Plucinski *et al.* 2012). Fire suppression models include both fire behaviour and fuel structure variables in acknowledgement of this (Bratten 1978; Mees *et al.* 1994; Fried and Fried 2010). According to these models, containment likelihood is higher in simple fuel structures (Hirsch and Martell 1996), i.e., little or no shrub cover and low grass heights. There are several studies that report recently burnt areas have enhanced suppression effectiveness (Billing 1981; Rawson *et al.* 1985; Grant and Wouters 1993; McCarthy and Tolhurst 2001; Tolhurst and McCarthy 2016). However, effectiveness has been found to diminish with time since fire and under more extreme fire weathers.

- **Prescribed burning can be used effectively to protect single/point-based assets.** Prescribed fire can be applied at fine spatial scales as well as more broadly across the landscape. Prescribed burning is commonly implemented at the wildland-urban interface (interface burns) or more broadly across the landscape (landscape burns). Interface burns are applied in close proximity to residential areas and important assets in an attempt to reduce the impacts of future unplanned fires to areas with high densities of people and/or assets. Simulation studies have found that fuel treatments in the area immediately around houses (500m - 2km) is more likely to reduce the risk of house loss than landscape treatments (Bradstock and Gill 2001; Cary *et al.* 2009; Ager *et al.* 2010; Bradstock *et al.* 2012; Penman *et al.* 2014; Florec *et al.* 2019; Cirulis *et al.* 2020).

- **Prescribed burning can be used to protect assets at a landscape scale, but this is highly context specific, with effectiveness diminishing as time-since-fire increases and fire weather worsens.** The goal of landscape fuel treatment is primarily to reduce the occurrence and extent of future bushfire, by slowing or impeding fire spread or moderating fire behaviour to gain a suppression advantage in a strategic location (Syphard *et al.* 2011; Penman *et al.* 2020a). Landscape burns are undertaken in strategic areas (commonly away from residential areas in contiguous forest). Landscape treatments can reduce the extent of bushfire (Finney *et al.* 2008), however the effect on the risk to assets such as property may be small for several reasons. Firstly, bushfires that ignite far from property generally only reach the property under severe or extreme fire weather conditions where fuel treatments are known to be less effective at altering fire behaviour. Risk to property is not purely a factor of fuel treatments. Suppression effort, fire development patterns and actions of communities and individual property owners (Blanchi and Leonard 2008; Stockmann *et al.* 2010; Gibbons *et al.* 2012; Macindoe and Leonard 2012; Syphard *et al.* 2013; Penman *et al.* 2015; Eriksen *et al.* 2016) all alter the probability of a house being impacted/destroyed by fire.

- **Modifying bark fuel through candling and prescribed burning can reduce risk to human and environmental assets by reducing spotting potential.** Bark fuel contributes the forward rate of spread of the fire through ember production (Gould *et al.* 2007; Cruz *et al.* 2012; Koo *et al.* 2012; Hall *et al.* 2015). There are few studies examining either bark consumption during hazard reduction burns or the rate of accumulation post fire (Chatto *et al.* 2003; Gould *et al.* 2011; Duff *et al.* 2012; Penman *et al.* 2017). Aerially suspended fuels like bark play an important role in fire behaviour, acting as a ladder for flames, increasing the chance of crown fires, or igniting and acting as firebrands. Bark fuels can be reduced by burning through candling (the deliberate ignition of bark and other dead fuels to reduce fuel loads in the canopy). There are few studies which assess the effectiveness of candling, however Duff *et al.* (2018a) provide details about the conditions when it can be safely undertaken. They found that between 2012 – 2016 conditions were suitable to undertake candling on a total of 124 days per year, compared to 76 days when planned burning could be safely undertaken (Duff *et al.* 2018a).

- **Prescribed burning may lower the likelihood of ignitions becoming active and resulting in bushfire.** Prescribed burning is unlikely to alter the rate of unplanned ignitions which are influenced by the natural and built environment (Prestemon and Butry 2008b; Syphard *et al.* 2008; Plucinski *et al.* 2014; Collins *et al.* 2015; Zhang *et al.* 2016; Clarke *et al.* 2019a). However, ignitions in recently treated areas may be expected to spread more slowly, occur at lower intensities and potentially more likely to self-extinguish due to reduced fuel loads.

Mechanical fuel treatments

Mechanical fuel treatments involve the use of machinery to alter vegetation structure for the purpose of reducing bushfire fuel hazard. Mechanical treatments are predominantly undertaken as mulching (or masticating), slashing (or mowing), or thinning. Mechanical treatments such as ploughing and chain rolling are also used, but their application is less common. Mechanical approaches can be applied independently or as a precursor to prescribed burning. Mechanical treatments offer some advantages over fire treatments. They are not subject to a narrow range of weather conditions; can be designed to target individual plants or trees; do not produce smoke; and can be applied to fuel types that are difficult to safely burn (Parkins *et al.* 2021). Mechanical fuel treatments can be applied in patches across the landscape or in strategic locations as part of a fuel break network.

The primary objective for undertaking mechanical fuel treatments such as mastication is to modify fuel loads by relocating elevated fuel to the forest floor, in an attempt to reduce the intensity and rate of fire spread. In doing so, this better enables fire suppression, ultimately reducing the bushfire risk to people and property. Mastication is often used within fuel breaks or in urban-interface areas where prescribed burning cannot be conducted safely.

Here we summarise some key aspects regarding mechanical fuel treatments and briefly discuss the known evidence-base for the suitability of this approach for reducing risk to assets.

- **Mastication can effectively alter fuel structure (but not fuel load), resulting in larger gaps between key fuel strata which is expected to reduce the spread and intensity of bushfires.** The main objective of mastication is to reduce the intensity and rate of fire spread by relocating elevated and ladder fuels to the forest floor. In doing so, this better enables fire suppression, ultimately reducing the bushfire risk to people and property. Studies that measure changes in fuel structure as a result of mastication report reduced density of shrub fuels, increased surface fuel compaction and increase coarse fuel load on the forest floor (Kane *et al.* 2009; Battaglia *et al.* 2010; Keane *et al.* 2018). Changes to fuel moisture dynamics are also reported, with deep, masticated fuel beds retaining moisture for long periods (Schiks *et al.* 2015), however, this may be counterbalanced by reduced shrub cover increasing the exposure of the fuel bed to the drying effects of solar radiation.

- **Mastication reduces flame length which could aid fire suppression and reduce fire spread, thereby reducing risk to assets** (Kreye and Kobziar 2015). However, studies have also found long combustion times in masticated fuel (Brewer *et al.* 2013; Kreye *et al.* 2016; Heinsch *et al.* 2018). Residual flaming and smouldering after the main fire front has passed is caused by larger amounts of coarse fuel (woody fragments) in the fuel bed that burn for longer than finer needles and leaves. Long flaming and smouldering durations are an important consideration as this could make the task of 'blacking out' more difficult, cause more soil heating with potential negative ecological consequences and increase smoke production.

- **Forest thinning and pruning may reduce fuel loads in strategic areas, modifying fire behaviour through reduced fuel loads and improving suppression effectiveness.** The main objective of forest thinning and pruning in the context of fuel modification, is to alter forest structure to favour low intensity surface fires over high intensity crown fires (Agee and Skinner 2005). Ladder fuel (i.e., fuel that can carry the fire into the tree crown) is removed to increase the height to live crown by pruning branches and cutting small and intermediate trees. This prevents the initiation of a *passive* crown fire (torching). Crown bulk density is reduced by removing small and intermediate trees. This reduces the spread of fire between tree canopies (*active* crown fire).

- **Thinning and pruning improves the resistance of the trees to fire by reducing the likelihood of crown fire and helps protect people and property by reducing fire intensity.** Thinning may also be used as a precursor to safely returning low-intensity prescribed burning into forests subjected to long periods of fire exclusion or disturbance (e.g. logging) which have caused a build-up of elevated fuel hazard. The greatest reductions in bushfire intensity occur when thinning and pruning are combined with prescribed burning, as the thinning reduces canopy density while burning reduces the surface and ladder fuel loads (Graham *et al.* 1999; Stephens *et al.* 2009; Pique and Domenech 2018; Arellano-Perez *et al.* 2020).

Suppression

Fire suppression efforts are aimed at limiting the size and spread of bushfires and to reduce direct impacts on people and assets. The primary objective of suppression is to protect houses and lives from bushfires. However, suppression crews may attempt to reduce or control fire spread to protect a range of assets. Suppression efforts can involve a range of resources including on-ground firefighting crews, aerial suppression teams and remote monitoring of fires. The use of prescribed burning, mastication and strategic fuel breaks can improve suppression outcomes by increasing accessibility to ground crews and slowing the rate of spread of a flaming fire front.

Here we summarise some key aspects regarding suppression efforts and the known evidence-base for the suitability of this approach for reducing risk to assets.

- **The likelihood of a fire being contained by initial attack efforts or within the first 24-hours is influenced by weather, environment, and management.** Weather variables such as temperature, humidity, wind direction and wind speed can impact the probability of containment because they influence the speed and direction of a flaming fire front (Plucinski 2012; Collins *et al.* 2018; Marshall *et al.* 2022). The speed and direction of a fire front impacts the safety of ground crews and can make it more challenging for suppression teams to construct and maintain a safe control line (Plucinski 2019b). Environmental variables such as fuel hazard and vegetation type, as well as topographic conditions like elevation and slope influence both fire behaviour and control line construction (Arienti *et al.* 2006; Plucinski 2019a). Fuel hazard and elevation can influence suppression success by impacting ground crew accessibility and safety, particularly for large fires moving up slope.

- **Fire size when ground crews arrive is also an important predictor of whether a fire is likely to be contained in the first 24 hours.** Smaller fires result in more ground crew available per hectare and can result in faster control line construction which can be more easily maintained (McCarthy *et al.* 2012; Plucinski 2012). Maintaining a control line is critical because fires that escape control are less likely to be contained, become more costly and can cause more impacts to communities and assets.

- **Since smaller fire sizes have a higher likelihood of containment, response time and resource allocation are critical to suppression success.** Early detection and shorter response times result in smaller fires when ground crews arrive (Plucinski 2012; Collins *et al.* 2018). Ignition type can also play a role in response time. For example, lightning ignitions have longer response times on average because they tend to occur in more remote locations, at higher elevations which are less accessible and have lower detectability (Collins *et al.* 2018; Dorph *et al.* 2022; Marshall *et al.* 2022). Improving detection of remote ignitions and reducing response times could improve suppression success by reducing the fire size on arrival (Barmpoutis *et al.* 2020; Biddle *et al.* 2020). The number and type of ground resources allocated to suppression can influence the likelihood of success. Grass fires and forest fires may require different resources, which can result in variable rates of control line construction. The number of fire fighters, tankers and slip-on units deployed to a fire has been shown to influence initial attack success (McCarthy *et al.* 2012; Collins *et al.* 2018).

- **If fires are not contained during initial attack or escape control lines, they can become very large and very costly (Gebert and Black 2012; Dunn *et al.* 2017; Simpson *et al.* 2019).** The factors influencing containment of fires which escape early suppression are mostly environmental and weather focused. For example, the prevailing wind direction and the fuel hazard influence rate of spread. Therefore, if initial attack efforts fail, managers face more challenging conditions with fewer options for controlling fire spread (McCarthy *et al.* 2012; Plucinski 2012; Wollstein *et al.* 2022). Aerial suppression is often utilised to aid in the containment of large campaign fires. However, these resources are expensive and on high fire danger days can be in high demand (McCarthy *et al.* 2003; Plucinski *et al.* 2012; Plucinski 2012). Early containment of high intensity fires through initial attack efforts, particularly on high fire danger days where multiple fires increase pressure on existing suppression resources, can reduce the risk to assets and increase suppression crew safety. Improving detection capability and reducing response time could improve the probability of containment.

Risk reduction research in the ACT

In this section we outline a range of published and unpublished studies undertaken by the FLARE Wildfire Research Group of relevance to the ACT, and provide a discussion of the key findings and implications on risk to human and environmental assets.

A study commissioned by the ACT Parks and Conservation used a cost framework to examine the risk reduction benefits of fuel treatments and fire suppression (Penman and Cirulis 2019). The study used five costs/asset types within their analysis, including: houses, lives, roads, powerlines, and environmental cost (Figure 1). These asset types all followed similar patterns of loss that appeared to be correlated with fire size i.e., larger fire size, greater costs. **Overall, the study found that extensive fuel treatments reduced landscape risk whereas the absence of fuel treatments for extended periods increased risk.** The most cost-effective fuel management program tested in the simulation framework included fuel treatments in both the ACT and neighbouring NSW. The study also found that **increasing the rate of suppression and decreasing the response time of suppression crews reduced bushfire damages** consistent with previous empirical analysis and simulation studies.

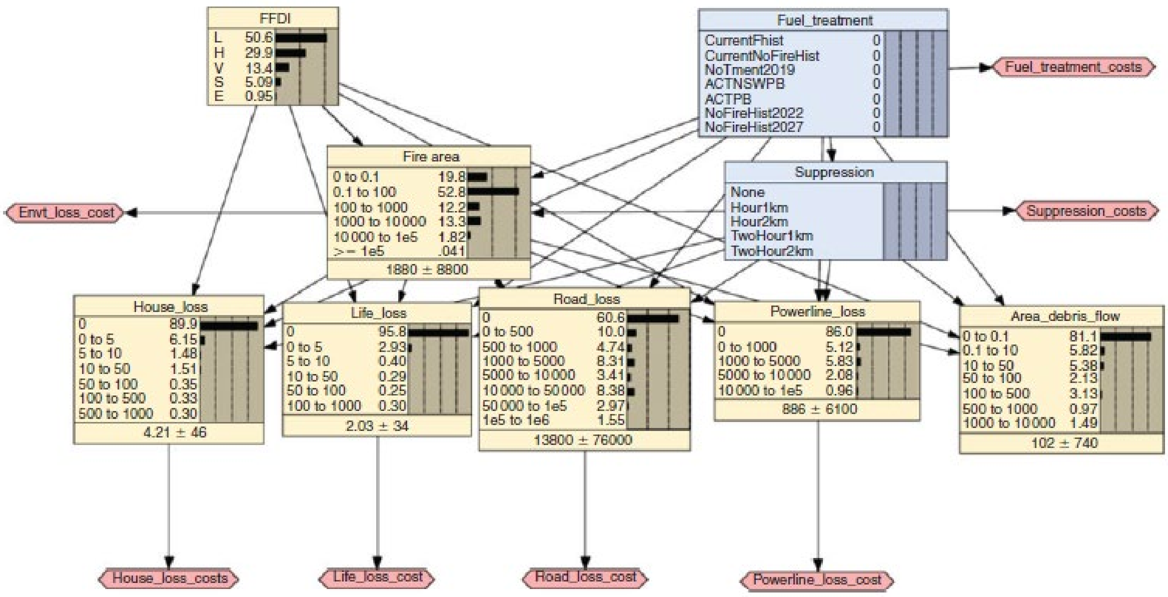


Figure 1 Bayesian Network influence diagram for the analysis of fire management decisions. From Penman and Cirulis (2019).

Two related papers, Cirulis *et al.* (2020) and Penman *et al.* (2020b), were outcomes from a Bushfire Natural Hazards CRC project which examined varying effort in fuel treatments and the effect on risk to people, property, carbon, powerlines, roads and the environment. These studies contrast risk reduction in absolute values and cost with treatments in many capital cities. Here we will focus on the drivers of risk and management effectiveness and the impacts on the ACT.

In the ACT, prescribed burning rates of 10% reduced annual area burnt and length of road damaged by more than 50%. However, house loss and life loss did not respond as strongly (Figure 2) (Cirulis *et al.* 2020). Higher levels of risk reduction on house and life loss could potentially be achieved if the 10% treatments were concentrated near the WUI. However, current prescribed burning rates are below 5% and are unlikely to get close to 10% given the constraints on budgets, resources limitations, and available days for suitable prescribed burning. An increase in prescribed burning also leads to a greater area being burnt below TFI (Tolerable Fire Interval) even if the prescribed burns do not occur in areas below TFI. This is because increased rates of treatment put more of the region into a younger age class, increasing the likelihood that a bushfire will interact with an area below its TFI. **Overall, weather had a consistently larger effect on area burnt and related risk compared to prescribed burning.**

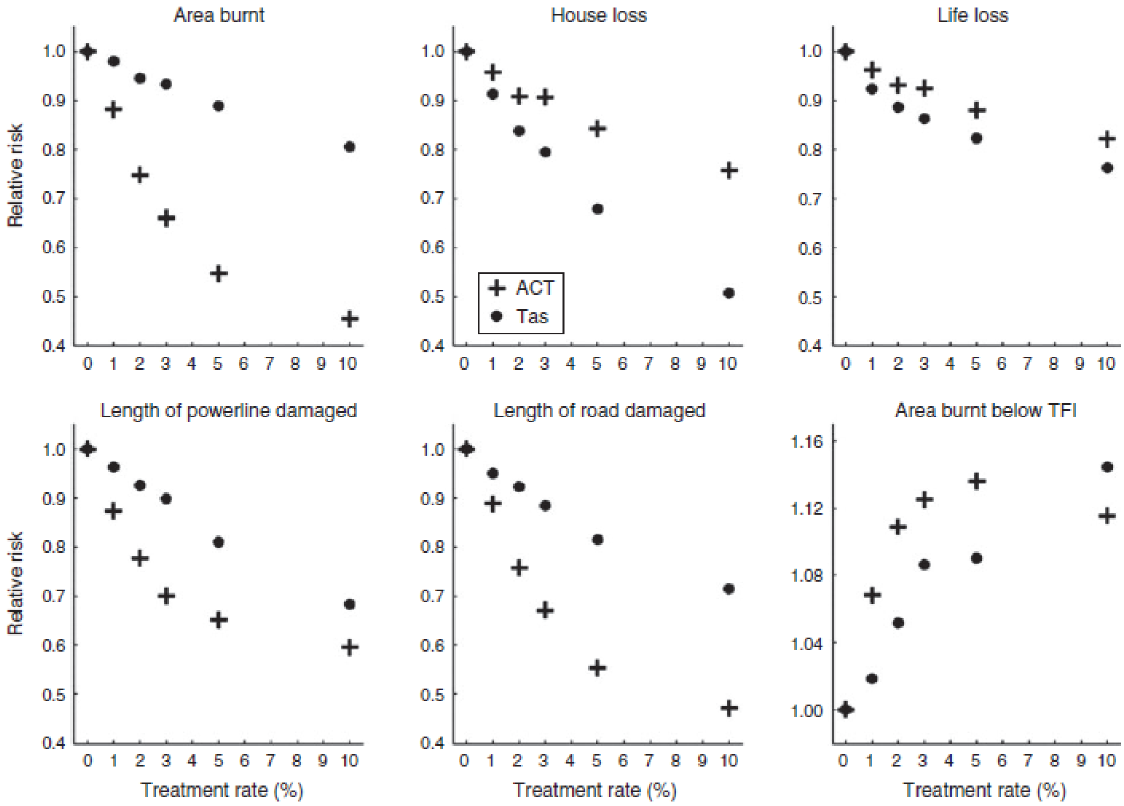


Figure 2 Influence of prescribed burning and weather on relative risk for area burnt and five key management values in the Australian Capital Territory (ACT) (cross), and Tasmania (circle) case study landscapes. For each treatment level, the Bayesian network incorporates all weather streams and adjusts impacts to reflect the proportional distribution of fire days within the five fire weather categories in each case study landscape. Relative risk is defined as the change in risk due to treatment, with a value of 1 representing no treatment. Note the y axis scale is different for area burnt below tolerable fire interval (TFI). From Cirulis *et al.* (2020).

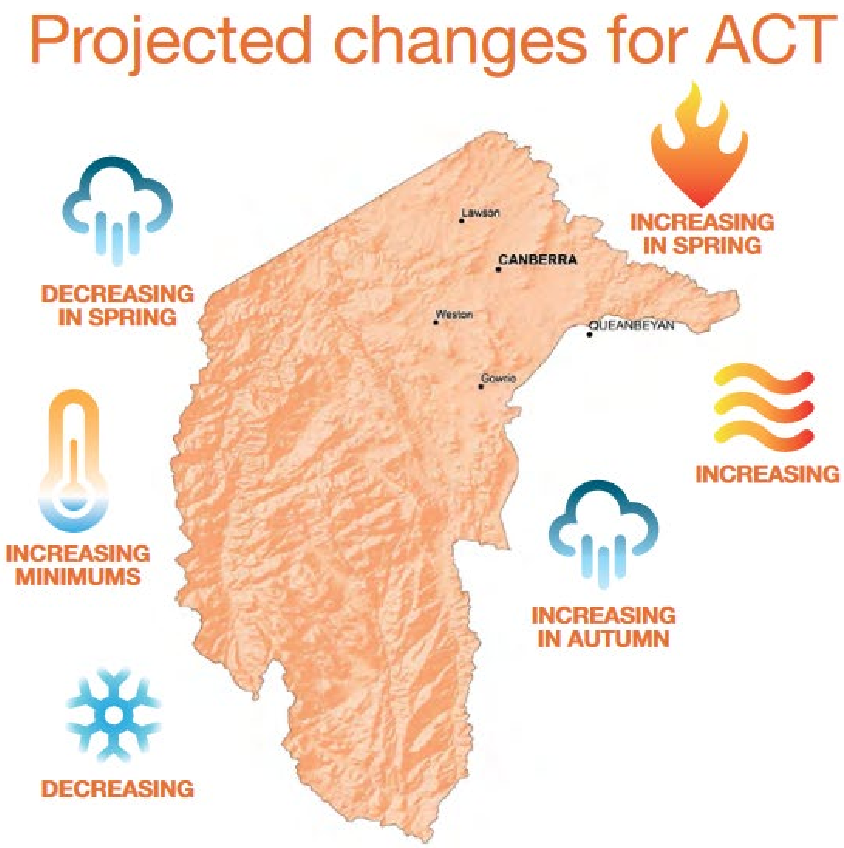
Penman *et al.* (2020b) examined the cost-effectiveness of fuel treatments in the vegetated area around five cities including Canberra, using multi-criteria decision analysis. There were three primary contributors to the total cost for all regions—treatments, houses and lives. Cost-effectiveness is likely to be driven by the spatial distribution of these assets within the landscape relative to the locations of treatments and the total value of assets within each case study landscape. This study found that **landscape treatments were more likely to extend benefits to assets that occur in native vegetation within the study areas**, e.g., powerlines, carbon and other environmental assets. **Edge treatments were generally more effective at reducing risk compared with landscape treatments.**

Forecast of future fire weather in the ACT

Weather is an important driver of bushfire risk (Bradstock 2010). Fire weather conditions are associated with drier fuels, greater chances of ignition, and more dangerous fire behaviour. When fires burn under extreme weather conditions, they can be virtually impossible to control and have devastating impacts on people, property and the environment. In recent decades fire weather conditions have been increasing in the ACT (Harris and Lucas 2019), along with many other parts of the country and indeed the world.

There is strong evidence that climate change will increase future bushfire risk in the ACT and surrounding regions by leading to an increase in fire weather conditions (Figure 3). Different studies use different methods, but overall they tell a consistent story of increasing fire danger with continued global warming (Hennessy et al. 2005; Clarke et al. 2011; Office of Environment and Heritage and ACT Government 2014; ACT Government 2016; Clarke et al. 2019b). Many studies use fire danger indices to represent the influence of weather on bushfire risk. These indices are calculated from weather variables like temperature, rainfall, wind speed and humidity. Some indices focus on the danger posed by surface weather conditions, while others incorporate upper atmospheric conditions, which can be important for the development of dangerous firestorms. **Within the ACT, multiple studies indicate increasing dangerous fire weather, with more days above an FFDI of 50** (forest fire danger index) (Figure 4) under a range of climate change weather models (Figure 5).

Increasing fire danger is likely to mean an earlier start to the fire season and a longer overall season. This will have implications for resource sharing between jurisdictions and will affect the availability of weather windows for conducting prescribed burning, although opportunities may open up during previously cooler and wetter months. Research is ongoing into climate change impacts on other aspects of the weather and climate system that are important for bushfire risk, such as the passage of strong frontal systems, and the fluctuations of El Niño and other climate drivers.



Projected temperature change	
Maximum temperatures are projected to increase in the near future by 0.6 – 0.9°C	Maximum temperatures are projected to increase in the far future by 1.4 – 2.3°C
Minimum temperatures are projected to increase in the near future by 0.4 – 0.7°C	Minimum temperatures are projected to increase in the far future by 1.4 – 2.3°C
The number of hot days will increase	The number of cold nights will decrease
Projected rainfall change	
Rainfall is projected to decrease in spring	Rainfall is projected to increase in summer and autumn
Projected Forest Fire Danger Index (FFDI) changes	
Average fire weather is projected to increase in spring, summer and winter	The number of severe fire weather days is projected to increase in summer and spring

Figure 3 Key climate impacts for the ACT identified by NARCliM. From ACT Government (2016).

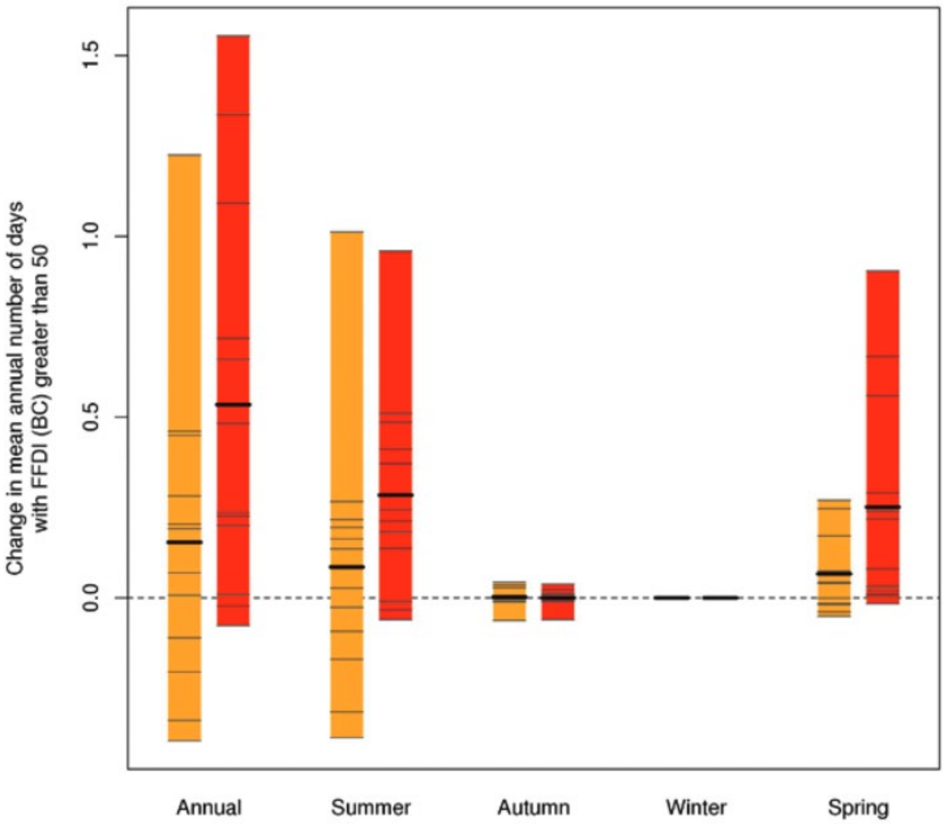


Figure 4 Projected changes in average annual number of days with a forest fire danger index (FFDI) greater than 50 for the ACT, annually and by season (2030 yellow; 2070 red)." The thin grey lines are the individual models. There are 12 thin lines for each bar. The thick line is the average of all 12 models for the region. The length of the bar shows the spread of the 12 model values for the region. Each line is the average for the region. They do not represent a single location in the region. From Office of Environment and Heritage and ACT Government (2014).

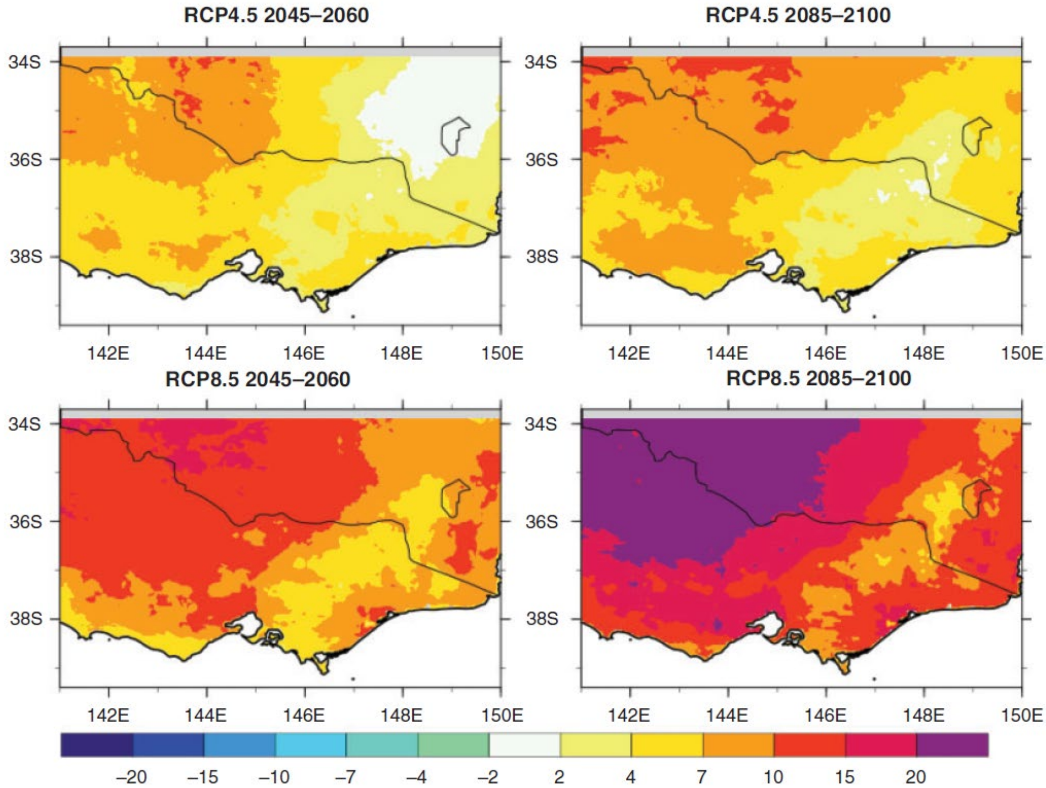


Figure 5 Change in the mean of the highest yearly FFDI values in future climate scenarios averaged across the models used for each scenario for 2045-2060 (left) and 2085-2100 (right) relative to 1973-2016. The top row is RCP4.5 and bottom row RCP8.5" [ACT can be seen in the northeastern corner] From Clark *et al.* (2021)

Predicted changes to the fire regime in the ACT

McColl-Gausden *et al.* (2022) predicted changes in the fire regime across south-eastern Australia. Here we summarise the findings relevant to the ACT and examine key implications on risk to human and environmental assets.

Within the original study we used five fire regime attributes (i) annual area burnt, (ii) annual area burnt at high intensity, (iii) fire interval, (iv) fire interval of high-intensity fires, and (v) season midpoint. The attributes relate only to native vegetation, that is all other cell types are masked out of the analysis, except for season midpoint which incorporates all cells. These represent key components of the fire regime—namely, fire frequency, intensity, seasonality, and extent (Gill 1975; Bond and Keeley 2005; Gill and Allan 2008) and are important determinants of ecosystem processes in fire-adapted systems. Six climate models were used within the original study. CSIRO Mk3 and ECHAM5 are global climate models. Global climate models have cell grids that can be hundreds of kilometers wide and are not useful for projecting regional differences. Thus, three regional climate models (RCMs) are used to downscale the two GCMs to a grid size of 10 km, which better represents features important for local and regional weather and fire behaviour such as topography and coastlines. Here we present a subset of the results, showing two RCMs per GCM with two time periods, current (1990-2009) and future (2060-2079). The difference between the time periods gives us an indication of how fire regimes might change over the next 50 to 60 years.

The simulation results relevant to the ACT cover 87% of the ACT as well as important surrounding vegetation (Figure 6). Here we focus on area burnt by bushfire and changes in the frequency of fire within the simulation area. Annual area burnt within the simulation area increased under all climate models tested (Figure 7A). The magnitude of change between the two time periods varies depending on the climate model selected. This emphasises the uncertainty in aspects of future predictions. However, given the universal nature of the direction of change, we can be more certain that annual area burnt will increase.

The number of fires an area experiences within a particular time frame is an important component of the fire regime. Figure 7B shows how much of the landscape experienced multiple fires across the 100-year simulation period. Both ECHAM and CSIRO models show an increase in the area experiencing many fires i.e., 3+ bushfires. We can also map these results spatially for each climate model (Figure 8). **While the highest fire frequency areas are outside the ACT, these areas may provide ignition sources for fires that spread into the ACT, particularly around the complex WUI around Canberra.** Some areas within the west of the ACT such as within the Namadgi National Park, are predicted to experience an increase in fire frequency.

Overall, the ACT is predicted to have an increased risk of fire over the next 50-60 years. High fire frequency is expected within native forests of the ACT but this does not rule out increasing impacts on people and property within the WUI. More research identifying key assets and the role management may have on risk reduction could improve our understanding of where the greatest risks within the landscape sit, and if and how we can reduce those risks.

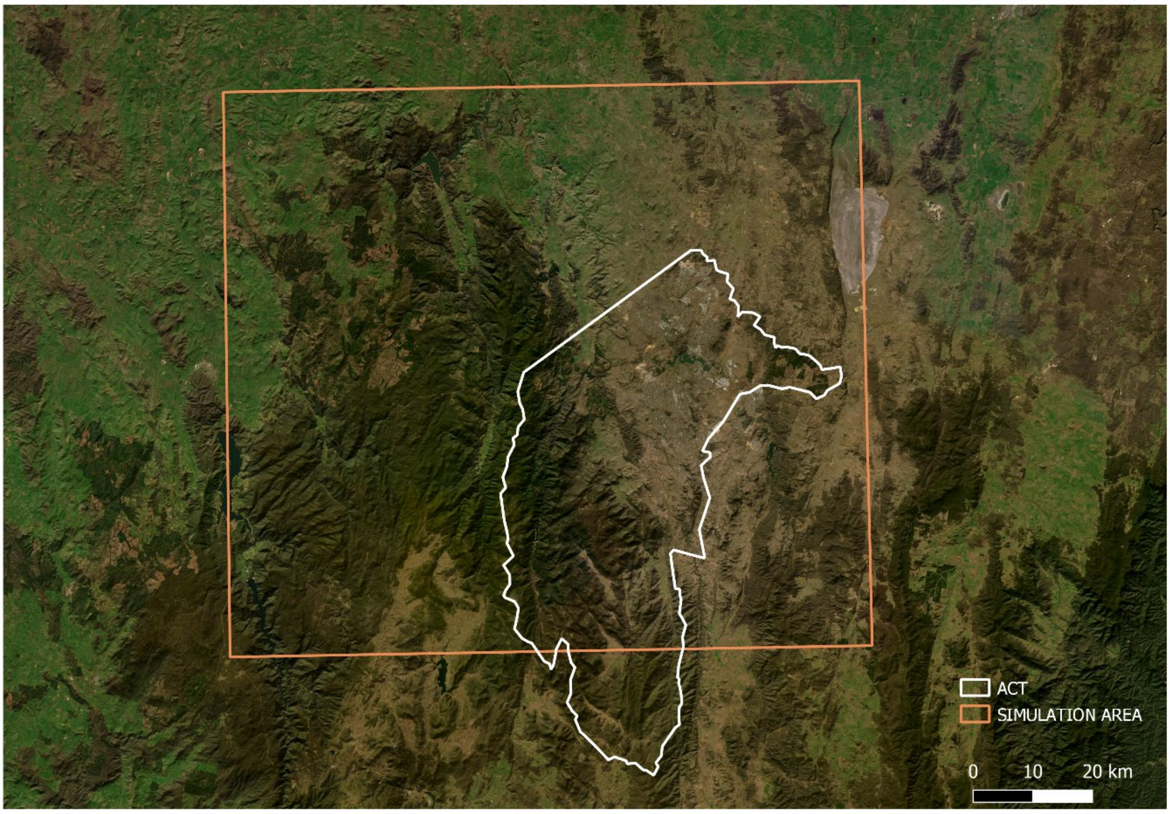


Figure 6 Satellite image of the simulation area (orange) and the ACT (white).

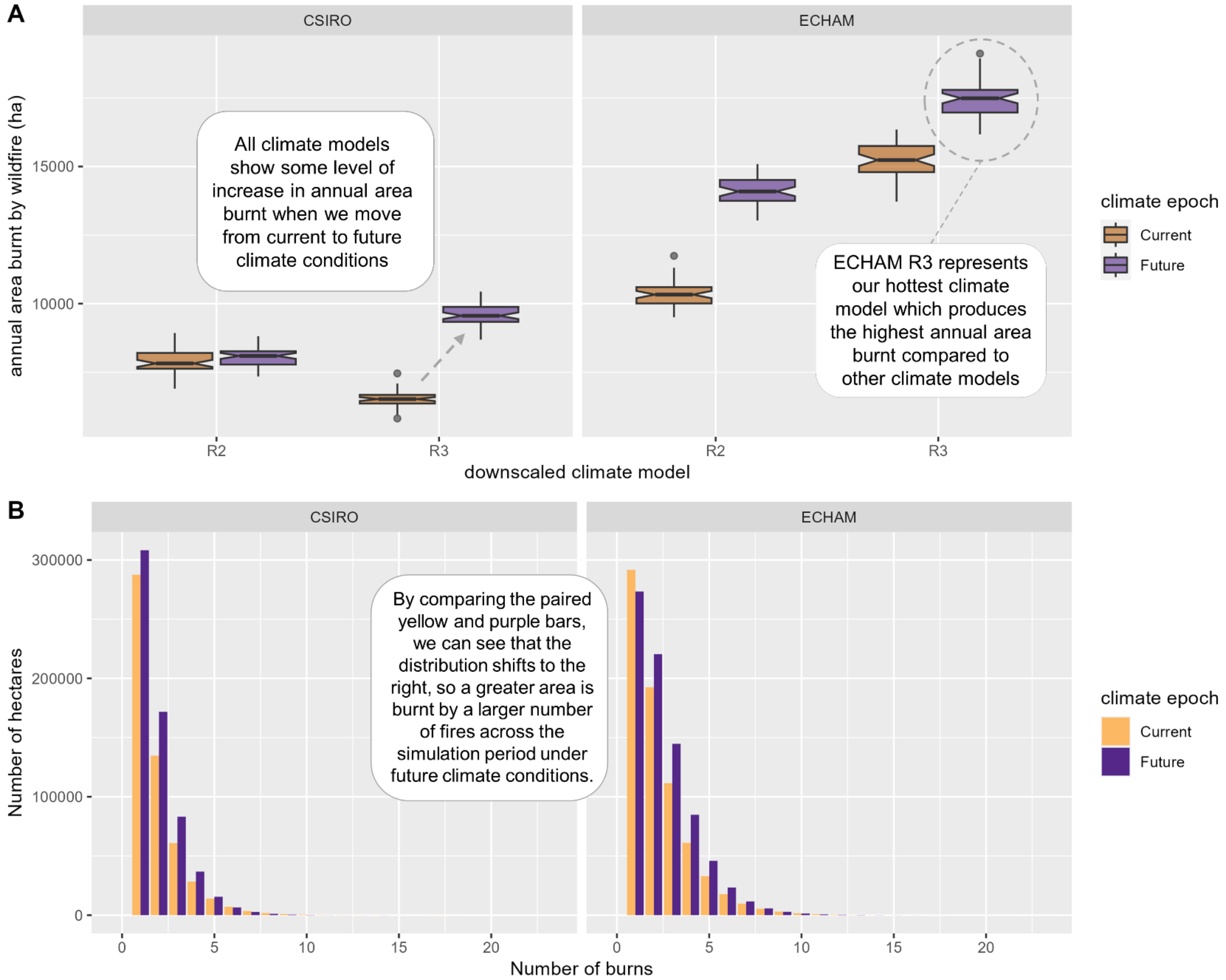


Figure 7 A) Annual area burnt in the simulation area under the different climate models: CSIRO R2, CSIRO R3, ECHAM R2 and ECHAM R3. The boxplots display the range of area burnt across the simulation replicates. Orange box plots are results under current climates (1990-2009) and purple boxplots are results under future climates (2060-2079). B) Number of hectares burnt by multiple fires across the 100 year simulation timeframe. These results are averaged across the RCMs within each GCM, i.e., CSIRO R2 and CSIRO R3 are averaged for the results under the CSIRO heading. Yellow bars show the results under current climates, and purple bars show the results under future climates.

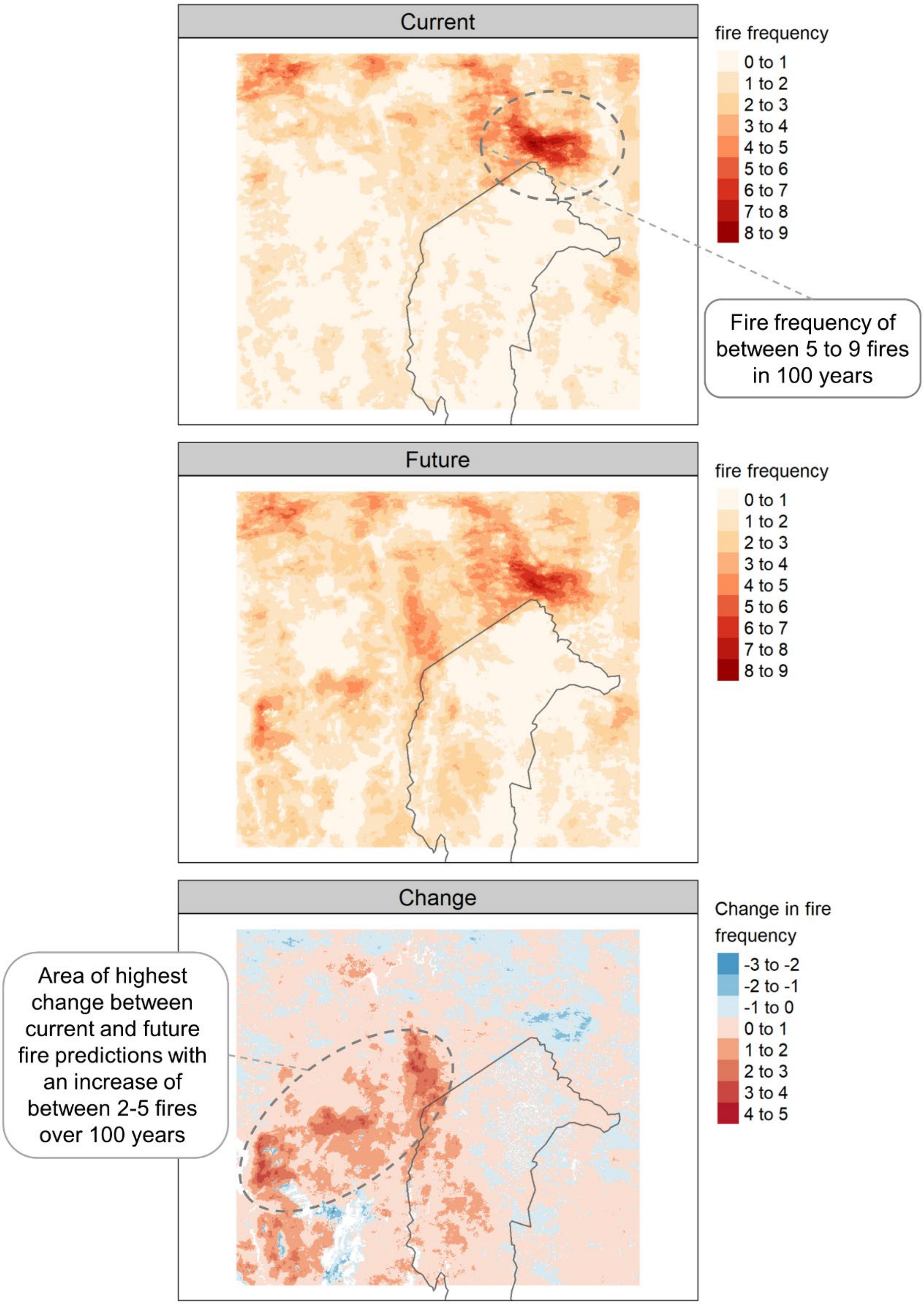


Figure 8 Fire frequency maps (number of fires over the 100 year simulation) for ECHAM R2 climate model under current and future climates. And the change in fire frequency between current and future simulations.

Summary

The ACT, like much of Australia, is predicted to experience an increased risk from fire over the coming century. As evidenced above, shifting climates will result in an increased extent and intensity of fire across the region, although there is still some within region variability. Changes in fire regimes are likely to result in an increased risk to human life, property, human physical and mental health, water quality and other environmental values. Climatic changes are likely to overwhelm any reduction in fuel loads or shifting vegetation communities.

A diverse array of preventative and responsive fire management actions will continue to be relevant in reducing risk to values in the landscape for this region. Most research to date has focused on the risk reduction achieved through individual actions, however it is the interaction of various management actions that yield the greatest reduction in risk to human and environmental values. There is no one-size-fits-all approach across different landscapes and therefore attention needs to be focused on what works best for the ACT (and elsewhere).

Land planning over the coming decades will determine the extent to which fire management can reduce risk. Complex wildland urban interfaces (WUI) created by urban expansion into native vegetation, present the greatest risk of house loss. Preventing new developments in high-risk locations such as the WUI will be paramount where the focus is on fire risk reduction, although we acknowledge increasing social pressure to create lifestyle blocks may overpower fire risk considerations in some contexts.

Agencies will need to remain agile to adapt to changing fire regimes. Risk reduction strategies will reduce in their efficacy under changing climates due to the overwhelming effects of weather on fire risk. Identification and adoption of new methods or technology that may prevent the occurrence of fires, reduce the intensity of future fires or aid in suppression effectiveness is important. It remains to be seen whether these new approaches will be outpaced by shifting regimes and if traditional approaches remain the best.

General principles of current fire management are likely to remain relevant under these new regimes. **Early detection and rapid response to fires** gives agencies the best chance of containing most fires. In doing so, agencies may be able to reduce impacts on the worst weather days when the greatest losses are likely to occur. **Strategic fuel treatments** adjacent to assets of concern, in areas known to contribute to the acceleration of bushfire or high-risk ignition zones will continue to be important. Finally, **active engagement with the community** about their risk from fire, as well as how they can prepare their property and respond to fire is extremely important. The role of fire/fuel management on private land will be increasingly important under changing climates.

Conservation land management is going to provide the greatest challenge for ACT under shifting climates and fire regimes. Currently the predicted rate of climatic change far exceeds the migration potential of many species, particularly those with long generation times. Intensification of fire regimes will increase the pressure on many species and communities, potentially resulting in shifting ecological formations. Conservation management will need to consider a range of *in situ* and *ex situ* conservation actions to reduce the risk of species extinctions.

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