Climate Change Impacts on Bushfire Risk in NSW

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Summary

This technical brief aims to review the state of knowledge about how climate change will affect bushfire risk in NSW. One way of approaching this topic is to consider the impacts of climate change on four major factors required for a bushfire: 1) the presence of sufficient fuel, i.e. vegetation; 2) the drying out of this fuel; 3) weather conditions conducive to the outbreak and spread of fire; and 4) an ignition source.

There is considerable uncertainty concerning the impacts of climate change on bushfire risk. This includes uncertainty over the trajectory of vegetation growth and hence fuel load, with potentially competing effects of climate and carbon dioxide fertilisation a major area of study. Impacts are also likely to vary in relation to vegetation type and climatic zone. Research on fire weather, and to a lesser extent fuel moisture, points to the potential for large increases in bushfire risk, including a longer fire season, but also the possibility of little change. More work needs to be done on climate change impacts on lightning, a major source of bushfire ignitions.

Summarising this research to determine the overall influence of climate change on bushfire risk in NSW is difficult. There is a clear need to integrate many diverse strands of evidence, including many interactions and feedbacks. However, broadly speaking the potential for significant increases in bushfire risk appears greater than the potential for equivalent decreases. Several lines of research point to increasing risk in temperate forested areas of NSW. The picture in moisture limited areas, such as arid grasslands in the state’s interior, is less clear, with some research suggesting that a decrease in fuel load will reduce overall risk despite strong increases in fire weather conditions. Bushfires are also intrinsically linked to human behaviour, including factors such as arson, planning regulations, community awareness and active bushfire suppression. This complexity and uncertainty heightens the need for fire managers in NSW to understand their exposure to and preparedness for a range of plausible climate futures.

1. Introduction

This technical brief[1] aims to review the state of knowledge about how climate change will affect bushfire risk. It considers the full range of national and international research and attempts to highlights the implications for NSW. Discussion is grouped along four major 'switches' that must be on for a bushfire to occur: fuel amount, fuel condition, weather conditions and ignition. Included in this brief is research conducted by and for the NSW Office of Environment and Heritage (OEH). Understanding and integrating research on this topic is critical to OEH delivering to the community as both a major land manager and the lead agency for building resilience to climate change and environmental hazards and risk in NSW.

2. Fire in context

Before considering the future, it is worth pausing briefly to consider the past. Fire has a long history on Earth, with evidence that fires occurred over 400 million years ago when terrestrial plants first appeared (Scott & Glasspool 2006). The evolution of humans marked a new period in the history of fire, as for the first time there was a species that could start fires, attempt to control or suppress them and change the flammability of the landscape (Marlon et al. 2008; Bowman et al. 2009; Pausas & Keeley 2009; Mooney et al. 2011; Bowman et al. 2013b). Satellite imagery reveals the ubiquity of bushfires today, while also hinting at the complexity of contemporary fire regimes (Figure 1; NASA FIRMS 2014). Understanding the possible future of modern fire regimes requires a relatively new context to be taken into account – the onset of an era in which humans have become the chief agent of global environmental change (Crutzen 2002; Rockstrom et al. 2009). Recent warming of the climate system is unequivocal, humans are extremely likely to have been the dominant cause and continued greenhouse gas (GHG) emissions will cause further warming and changes (IPCC 2013).

Bushfires are a worldwide phenomenon and an active area of scientific research[2]. A major reason for research interest in bushfires is the adverse effects they can have on environmental and other assets. In NSW, the *Living With Fire in NSW National Parks* strategy outlines OEH's strategy for protecting 'life, property and community assets from the adverse impacts of bushfires' (OEH 2012). The adverse effects of bushfires extend beyond the loss of lives and homes, to a wide range of environmental, social and economic and cultural assets, such as biodiversity, iconic and threatened flora and fauna, carbon stocks and clean air and water (McAneney et al. 2009; Gill et al. 2013).

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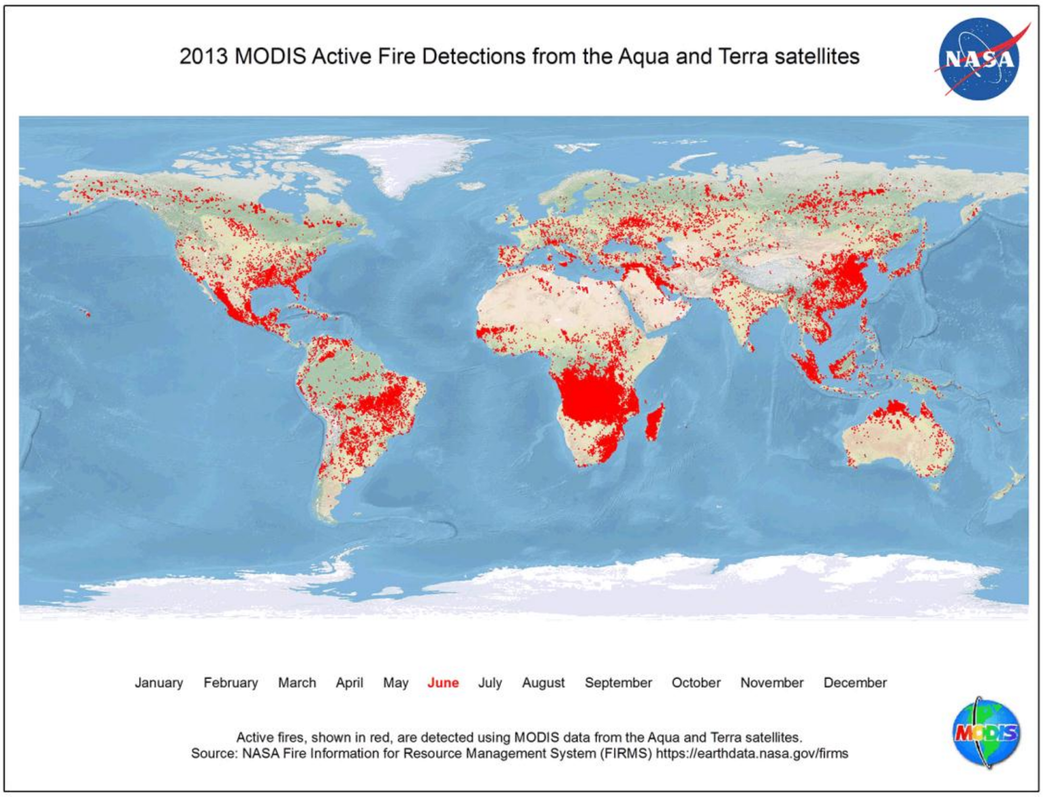
[1] Some material in this technical brief has been adapted from Clarke (2015).

[2] The term 'bushfire' is distinctly Australian. Those searching for literature on bushfires are advised to consider alternatives, including but not limited to: bush fire (note the space), wildfire, wildland fire, vegetation fire, unplanned fire, biomass burning and vegetation-specific terms such as grass fire and forest fire.



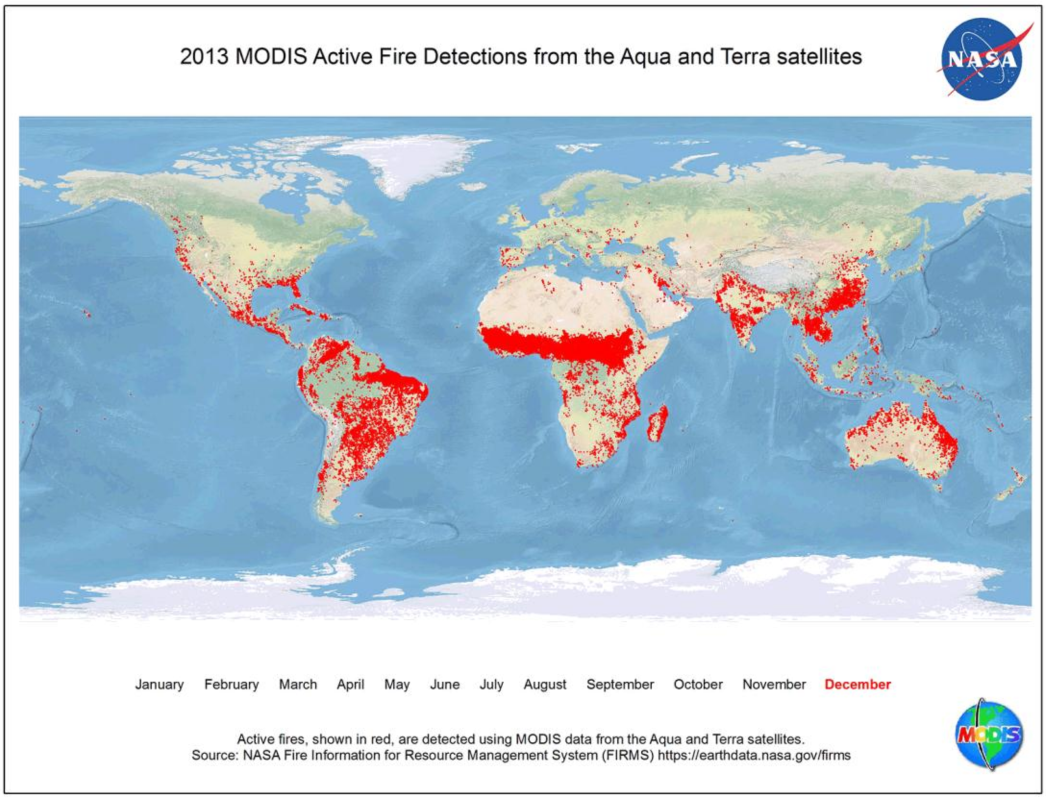


Figure 1: Fires detected by satellite in June 2013 and December 2013
Source: NASA FIRMS (2014)

3. Australian fire regimes and the four switches of fire

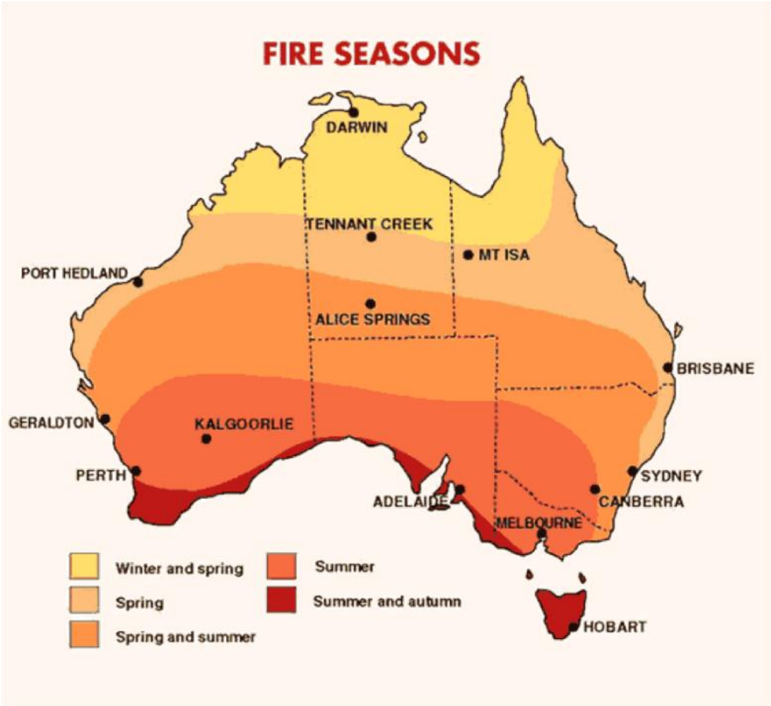
Our understanding of bushfire is frequently couched in the 'fire regime'[3] concept (Gill 1975). The concept has evolved since its introduction and now generally includes the prevailing timing (frequency and seasonality), size, severity and type (ground, surface, crown) of fires at a given location. Fire regimes vary greatly among ecosystems; it has been said that there are no fire adapted species *per se*, rather there are species adapted to specific fire regimes (Pausas & Keeley 2009). Variation in contemporary fire regimes can be traced to a large extent to variation in four drivers of bushfire incidence: the presence of sufficient vegetation, the availability of vegetation to burn, the presence of an ignition source and weather conditions conducive to the spread of fire (Archibald et al. 2009; Bradstock 2010). Given that each of these 'switches' must be on for a fire to occur, fire regimes can also be defined by the relative importance of each driver in limiting overall fire incidence. The 'four switches of fire' framework is a recurring theme in this technical brief.

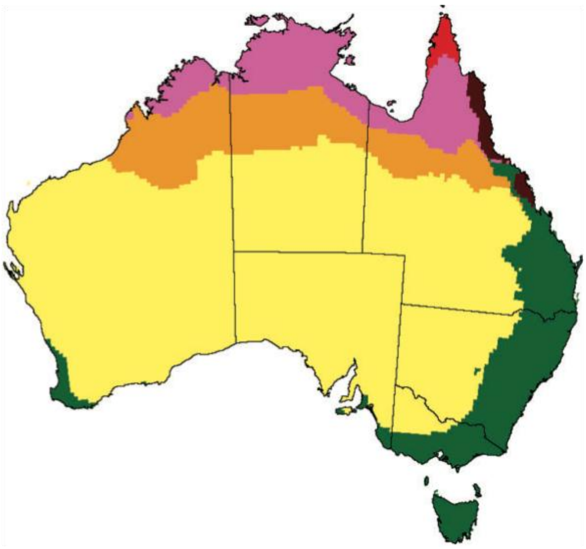
Recent studies have identified rainfall and fuel as particularly important in defining Australia's pattern of fire regimes. Russell-Smith et al. (2007) modelled the relationship between satellite-derived fire incidence data from 1997 to 2005 and a range of biophysical variables, finding rainfall seasonality to be the dominant influence, followed by vegetation (i.e. fuel) structure. Bradstock (2010) found that variation in available moisture and the dominance of either woody or herbaceous vegetation are the primary factors influencing fire regimes in much of Australia. In areas where a lack of moisture limits growth, rainfall leads to growth and fires follow. In areas where moisture does not limit growth, fire will only occur after a period of significant drying. Although herbaceous and forest fuels, respectively, are sometimes cited as typical of these two conditions, there are exceptions to this. In the tropics, monsoonal rainfall is predictably followed by 'the dry', leading to the build-up and subsequent drying out of fuel which often burns annually. Murphy et al. (2012) also identified the latitudinal gradient in summer monsoon rain activity as the major driver of Australia's fire regimes at a continental scale. The patterns of Australia's fire regimes developed by Russell-Smith et al. (2007; Figure 2) and Murphy et al. (2012; Figure 3) provide significant new detail compared to a frequently cited earlier version from Luke and McArthur (1978; Figure 2).

These continental assessments highlight the significance of regular, widespread burning in Australia's north, for instance with regard to carbon accounting and the global carbon cycle (Meyer et al. 2012; Haverd et al. 2013; Poulter et al. 2014). Conversely, adopting the stance of fire as a problem to be dealt with (Gill et al. 2013) or a natural hazard to coexist with (Moritz et al. 2014) shifts attention to the infrequent but high intensity fire regimes associated with eucalypt forests of Australia's southern and eastern extremities, because it is there that the majority of the Australian population lives. The south-east of Australia has been identified as one of the highest risk areas in the world for bushfire (Chuvieco et al. 2014). Particular attention is given to communities at the so-called wildland–urban interface (WUI), which are at greatest risk of the direct impacts of bushfires[4]. A national forum in 2003 on fire research and policy priorities nominated 'a better understanding of current fire regimes' as a major goal (Dovers et al. 2004). Over ten years on from the forum, major steps have been taken towards addressing this goal.

[3] Krebs et al. (2010) give an interesting account of the history of the fire regime concept.

[4] The building and construction guidelines of NSW, Australia, reserve a vivid term for those at highest level of bushfire risk: the *flame zone*.





Generalised extent and seasonal distribution of fire occurrence in Australia 1997–2004

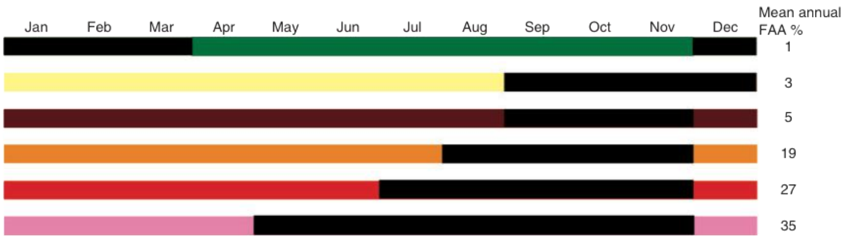


Figure 2: Models of different aspects of Australian fire regimes

Notes: Top is a widely cited schematic of bushfire seasonality (Luke & McArthur 1978). Bottom is a map and graph showing fire seasonality and extent derived by Russell-Smith et al. (2007). FAA stands for *fire affected areas* and corresponds to burned area. The black bar indicates the main season of burning.

4. Research on the impacts of climate change

The 2003 national forum identified another priority for both research and policy, which is the focus of this technical brief: how can we improve our ability to forecast the impacts of climate change on bushfires, in particular at scales relevant to fire management? Given the complexity of bushfire, and its strong coupling to human systems (e.g. land use and management), there are multiple pathways through which climate change may affect it (Hessl 2011; Bowman et al. 2013b). One approach is to consider the impact of climate change on the drivers of fire incidence discussed earlier: fuel amount, fuel dryness, fire weather and ignition.

4.1 Fuel amount

The first requirement for bushfire is having enough fuel in the landscape. Climate models produce meteorological variables which can be directly used for fire weather, fuel moisture and ignition risk assessment. In contrast, attempts to predict changes in vegetation growth or fuel load require a significant transformation of climate model data. In addition to influencing the climate, carbon dioxide increases plants' water-use efficiency and so could potentially counter the effects from any drying of the climate. Modelling climate change impacts on fuel load requires understanding the potential response of vegetation to changes in atmospheric carbon dioxide (CO_2) concentration and the climate (Karnosky 2003; Donohue et al. 2013). Reflecting this complexity, there are a number of different approaches to answering the question of how climate change affects wildfire fuel loads.

Field and laboratory studies have examined the response of plants to elevated CO_2 in controlled environments, for instance through free air CO_2 enrichment (Barton et al. 2010; Norby & Zak 2011). Statistical relationships have been developed between current vegetation patterns and meteorological variables (Matthews et al. 2012; Thomas et al. 2014; Williamson et al. 2014). These relationships allow vegetation changes to be derived from projected changes in meteorological variables, but do not account for CO_2 effects. For example, Thomas et al. (2014) found that fuel accumulation is likely to decrease in the future based on a statistical analysis of the relationship between climate and field observations of fuel.

In contrast to these empirical studies, there is an active research community devoted to process-based approaches to fuel load and vegetation more broadly. These approaches include dynamic global vegetation models (DGVMs), landscape fire succession models and biogeochemical models. These models may represent direct influences on fuel amount, such as litterfall, decomposition and fire incidence, as well as indirect causes like phenology, primary productivity, heat and moisture. Significantly, process-based models have the capacity to incorporate fertilisation effects of CO_2 on plant growth (e.g. Bala et al. 2013; Jiang et al. 2013; Kelley et al. 2014).

Clarke et al. (2015) found that fuel load in Australia is projected to increase substantially across both forested and grassy landscapes by the late 21st century. NSW is home to large areas of both of these major vegetation types. Fuel load was calculated using a land surface model, which uses known physical laws to model exchanges of heat, water and energy between the land and the atmosphere. The modelled fuel load is based on net primary production, which is a measure of the transfer of carbon from the atmosphere to land vegetation. This measure of fuel load requires validation and does not account for fine scaled local differences in vegetation or regrowth after fire; rather it provides a coarse estimate of the amount of vegetation growth under different climate conditions and, importantly, under different atmospheric CO_2 concentrations.

Although fuel load is one of the keys to understanding bushfire risk, there are no high quality, long-term, gridded observations of fuel load in Australia. This makes it difficult to understand how current fuel load varies across the landscape, and even more difficult to understand how it might respond to climate change and possible CO_2 fertilisation. One factor that could influence the CO_2 effect in Australia is the degree to which plant growth is nutrient-limited, rather than CO_2 limited. If the supply of nutrients is more important than CO_2, then increasing CO_2 will not lead to more growth unless nutrients are also increased.

4.2 Fuel condition

The second requirement for bushfire is that the fuel in the landscape is dry enough to burn. Climate models can be used to project climate change impacts on fuel dryness, given the possibility of relating it to standard meteorological variables such as relative humidity (Resco de Dios et al. 2015) and temperature[5]. Despite this, there are relatively few studies that focus exclusively on climate change impacts on fuel dryness as a driver of wildfire incidence. However, since several commonly used fire danger indices incorporate measures of fuel dryness, studies of these indices contain implicit projections of climate change impacts on fuel dryness, even if their conclusions do not always emphasise this aspect. One study found that, across five Australian cities (including Sydney and Canberra), an increase in warmer and drier climates will lead to more days with extremely dry fuel in eucalypt forests, narrowing the number of days suitable for prescribed burning (Matthews et al. 2011).

4.3 Fire weather

4.3.1 Background

The third requirement for bushfire is weather conducive to the outbreak and spread of fire. Given the central role played by coupled climate models in projecting future climate, it is unsurprising that fire weather has been heavily studied, as it can be calculated from meteorological variables obtained directly from global and regional climate models. There are also good scientific reasons for focusing on fire weather conditions, with evidence that weather can drive ignitions (Penman et al. 2013), fire severity (Bradstock et al. 2010), house loss (Blanchi et al. 2010) and fatalities (Blanchi et al. 2014).

Fire weather is typically expressed through some combination of surface air temperature, precipitation, relative humidity[6] and wind speed. There are a number of different indices that integrate these meteorological variables into a single fire danger measure, for example the McArthur Forest Fire Danger Index (FFDI; Luke & McArthur 1978), the Canadian Forest Fire Weather Index System (FWI; Van Wagner 1987) and the United States National Fire Danger Ratings System (Deeming et al. 1977). FFDI is often chosen in Australian studies because of its use in the fire management community. It is used operationally by weather forecasters and fire agencies in Australia to declare fire weather warnings and total fire bans and to determine fire danger (the difficulty of putting out fires which may occur).

Other metrics focus on the water and energy balance above the surface. The Haines Index (Haines 1988) and a variant adapted to Australia (Mills & McCaw 2010) link vertical atmospheric stability and humidity with erratic fire behaviour. The 850 hPa temperature gradient has also been linked to extreme fire weather events over south-east Australia (Mills 2005). There is a range of research focused on synoptic drivers of fire risk (e.g. Girardin et al. 2004; Crimmins 2006; Long 2006; Wastl et al. 2013; Papadopoulos et al. 2014 and references therein).

[5] Fuel dryness (i.e. fuel moisture) is of course commonly measured directly, e.g. through field sampling.

[6] Relative humidity is actually a proxy for vapour pressure deficit, which directly influences fuel moisture. This proxy works best at low dew points and worst at high dew points and temperatures (e.g. see Resco de Dios et al. 2015).

A natural reference point for any analysis or interpretation of projections of future fire weather is the existing or historical record of fire weather. Clarke et al. (2013) examined historical trends in FFDI. They found that the observational record of FFDI in Australia is marked by clear interannual variability with a large degree of spatial coherence, suggesting common drivers in its evolution. Against this backdrop of variability, 16 of 38 stations recorded a significant increase in average fire weather conditions between 1973 and 2010. No decreases were recorded at any station. Over the same period, 24 of 38 stations recorded a significant increase in high fire danger conditions. Again, no decreases were recorded. In NSW Cobar, Nowra and Wagga recorded increases in average FFDI, while many more recorded increases in 90th percentile FFDI: Cobar, Coffs Harbour, Moree, Nowra, Sydney, Wagga and Williamtown.

Numerous studies have projected changes in FFDI (e.g. Beer & Williams 1995; Cary & Banks 1999; Williams et al. 2001; Cary 2002; Lucas et al. 2007; Pitman et al. 2007; Bradstock et al. 2009; Fox-Hughes et al. 2014). Other elements of fire weather that have been related to climate change include atmospheric stability (Luo et al. 2013), synoptic patterns (Hasson et al. 2009; Grose et al. 2014) and modes of climate variability (Cai et al. 2009).. In southern Australia, the size distribution of bushfires is similar to the size distribution of fire weather events, based on FFDI (Boer et al. 2008). A selection of FFDI studies from global climate models (GCMs) and regional climate models (RCMs) will be discussed here.

4.3.2 GCM projections of FFDI

Clarke et al. (2011) used GCMs to project FFDI in eastern Australia, finding it varied along a clear latitudinal gradient. In summer rainfall-dominated tropical north-east Australia, mean and extreme FFDI were projected to decrease or remain close to 20th century levels. In the uniform and winter rainfall regions, which include south and southwest NSW, FFDI was projected to increase strongly by 2100. Projections fell between these two extremes for the summer rainfall region, which lies between the uniform and summer tropical rainfall zones and includes far northeast NSW. Based on these changes in fire weather, the fire season was projected to start earlier in the uniform and winter rainfall regions, potentially leading to a longer overall fire season.

More recently, CSIRO and Bureau of Meteorology developed FFDI projections for different natural resource management regions of Australia (www.climatechangeinaustralia.gov.au/en/climate-projections). NSW is home to five of these regions (also known as clusters): East Coast, Central Slopes, Southern Slopes, Murray Basin and Rangelands. Broadly speaking, average and extreme FFDI is projected to increase under climate change. However, there is variation amongst the GCMs used, with some projecting strong increases and others relatively little change. These projections also used two greenhouse gas emissions scenarios, with higher emissions leading to stronger increases in FFDI.

These and other results from GCMs point to the potential for significant increases in fire weather conditions in Australia. However, there is a strong demand from fire management agencies for finer resolution information than that available from GCMs. Such information is more suited to assessing impacts and planning adaptation at the scale at which such agencies operate.

4.3.3 RCM projections of FFDI

GCMs model the climate well at continental scales and above, but their ability to provide information about regional variations in climate is limited by their resolution and coarse representation of important regional climate drivers and offshore processes (e.g. the East Australian Current; Meehl et al. 2007; Randall et al. 2007; Flato et al. 2013). Dynamical downscaling with RCMs overcomes some of these limitations in providing information relevant to regional adaptation planning. They can operate at much finer spatial and temporal scales and contain additional information about a range of factors which are important in determining regional climate (such as more detailed topography). Since they are built on physical principles, dynamical RCMs allow for changes in the existing relationship between weather variables or climate drivers. A clear research direction therefore is to undertake high resolution modelling of fire weather.

The Weather Research and Forecasting (WRF; Skamarock et al. 2008) RCM has been used to generate an ensemble of projections for the NSW and ACT Regional Climate Modelling project (NARCliM; Evans et al. 2014). This ensemble was based on four GCMs and three RCMs[7], carefully selected for their skill, independence and to span the range of future climate change. FFDI calculated from the NARCliM ensemble is highly dependent on the GCM used. Two of the four global models (driving six of 12 ensemble members) project strong increases in mean and extreme FFDI, and the other two (driving the other six ensemble members) project relatively little change, including increases and decreases. Rainfall appears to be an important factor in this result. Where rainfall increases strongly, FFDI changes little. Where rainfall decreases, or only increases modestly, FFDI increases substantially. The largest increases in fire weather are projected to occur in spring and summer, suggesting a lengthening and intensification of the fire season. Results are available at www.climatechange.environment.nsw.gov.au.

4.3.4 Hazard reduction burning

The NSW Government is committed to conducting hazard reduction burns as part of its overall bushfire risk mitigation strategy. This strategy assumes the regular occurrence of periods during which weather is favourable for conducting prescribed burns.

Despite their centrality, there is little understanding of what constitutes 'normal' hazard reduction (HR) burn window conditions for any given part of the NSW landscape. It follows also that little can be said about how these windows might change in time or space under climate change. However, any lengthening of the fire season will lead to less favourable conditions in the shoulder seasons, shifting the burden towards winter.

OEH is examining the impacts of climate change on the seasonality and frequency of weather conditions conducive to conducting prescribed burns (Clarke & Kenny 2015). The research should improve the evidence base for planning and conducting hazard reduction burns in NSW now and into the future. This research is still underway.

The University of Wollongong is leading a project to deliver effective prescribed burning across southern Australian ecosystems. This project is also considering climate change impacts on the risk mitigation afforded by prescribed burning. The project is sponsored by the Bushfires and Natural Hazards Cooperative Research Centre (BNHCRC). Project partners include Melbourne University, Western Sydney University and OEH. Project details are available at: www.bnhcrc.com.au/research/1303.

4.4 Ignition

The fourth and final requirement for bushfire is an ignition source. The major natural ignition source is lightning, while human caused bushfires may be accidental (e.g. from arcing power lines or escaped camp fires) or on purpose i.e. arson. Lightning tends to be the dominant ignition source in remote areas, while arson can be a significant factor in more densely populated areas. One study in the Sydney Basin found that, when considering only fires caused by lightning and arson, 58% were caused by arson and 42% by lightning (Penman et al. 2013). Few studies have addressed climate change impacts on ignition, although this is

[2] The three RCMs are based on three different configurations of the WRF model.

starting to change. Climate change impacts on lightning have been explored directly by modelling the drivers of lightning (Price & Rind 1994; Goldammer & Price 1998; Krause et al. 2014) and indirectly by linking lightning with other weather patterns (Krawchuk et al. 2009; Penman et al. 2013). Although climate change is not expected to affect human-caused ignitions directly, a number of studies have looked at the drivers of human ignitions, such as population density and land use (Bistinas et al. 2013; Penman et al. 2013; Knorr et al. 2014; Price & Bradstock 2014).

4.5 Other areas of bushfire research

Because bushfires involve so many different natural processes and are affected by humans in different ways, they are studied by many different scientists and organisations here in NSW and around the world. The complexity of bushfires also means that under climate change, different factors will interact with each other and there may be feedback effects. Although most research tends to focus on a few key aspects of bushfire risk, many have noted the potential for feedbacks and interactions, and the need to study them (e.g. Cary et al. 2012; Gill et al. 2013; Clark et al. 2014; Hurteau et al. 2014a, 2014c; Mitchell et al. 2014).

Although it is often assumed that an increase in a risk factor will lead to more fire, this might not always be the case. For instance, it is commonly projected that climate change could lead to a doubling or more in the occurrence of extreme fire weather conditions or area burned in some areas (Guyette et al. 2014; Hurteau et al. 2014b; Stavros et al. 2014). However, an increase in fires may reduce the fuel available for future fires, acting as a negative feedback (e.g. Heon et al. 2014). Conversely, it is likely that suppression has had some influence on historical fires, which form the basis of correlative models used in projections (Turco et al. 2014). If increases in fire weather conditions are large enough to overwhelm humans' ability to suppress them and lead to increases in the number of uncontrollable fires (de Groot et al. 2013), then projections of future fire based on correlative models may be underestimates.

The following is a small sample of systems affected by fire that have the potential for feedback effects including and up to transition to entirely different fire regimes (Zinck et al. 2011; Batllori et al. 2013; Pausas & Keeley 2014):

- the age of vegetation and fuel load (Raymond & McKenzie 2012; Taylor et al. 2014) and overall biomass carbon stock (Keith et al. 2014). In the Mountain Ash of the Victorian Central Highlands, for example, the age of the stand influences the severity of the fire (Taylor et al. 2014). High severity fires are uncommon in the youngest and oldest stands, but widespread in stands of more intermediate age. This could create a negative feedback, as increases in severely burned area could create new areas at lower risk of such burning.
- litter properties (Papanikolaou et al. 2010; Aponte et al. 2014; Toberman et al. 2014). For instance, in a study of wet sclerophyll forest in southeast Queensland, it was found that litter decomposition was significantly slower in recently burned areas (Toberman et al. 2014). A slowdown in decomposition leads to an increase in litter amount, which could potentially act as a positive feedback after fire.
- soil properties, hydrology and water supply (Dunbar et al. 2012; Bladon et al. 2014). One example is a long term study of soil bacteria exposed to elevated CO2 in different United States ecosystems, which found a wide range of significant effects (Dunbar et al., 2012). It is unknown just how these changes in bacterial biomass, richness and composition might influence soil properties relevant to bushfire risk, such as decomposition of deep litter layers.
- a wide range of impacts on animals and plants – for instance on weeds and invasive species vis-à-vis fuel load – beyond that explored by DGVMs (Driscoll et al. 2010; Vivian et al. 2010; Banks et al. 2014; Dolanc et al. 2014). A notorious example is invasive grasses that can trigger a “grass-fire cycle” (Bowman et al. 2013a). This is a feedback

loop where the exotic grasses are not only more fire prone than native vegetation, but are better able to survive and thrive after fire. This has the potential to lead to major changes in the prevailing vegetation type and structure.

- GHG emissions (Keith et al. 2014; Loehman et al. 2014). Bushfires are often assumed to represent a net neutral impact on greenhouse gas emissions, because the CO_2 emitted on burning is then taken up as vegetation grows back after fire. This balance has the potential to be upset by a range of factors, such as a transition to vegetation types which store different amounts of carbon, or the active management of vegetation - for instance by fire suppression – to promote carbon uptake and storage.
- fire management including prescribed burning (Bradstock et al. 2012; Tarancón et al. 2014) and land management (Gibbons et al. 2012). Increased investment in fire suppression and land management could act as a negative feedback on increased fire risk. But if climate change were to reduce the resources available for bushfire risk mitigation, this could reinforce any increasing trends in risk.
- a range of social and health impacts, e.g. land use (Bryant & Westerling 2014), smoke (Price et al. 2012), national park visitation (Duffield et al. 2013) and employment (Nielsen-Pincus et al. 2014).One study in Yellowstone National Park in the Unite States found that bushfires had a measurable effect on park visitation and associated recreation and tourism in surrounding areas (Duffield et al. 2013). They estimated the combined effects over several decades at over $250m (USD). This issue is of particular relevance in NSW, with its large areas of National Parks.

4.6 Integrated assessments

A number of studies have attempted to characterise potential responses of bushfire regimes to climate change, with significant impacts expected (Flannigan et al. 2009; Krawchuk et al. 2009; Bradstock 2010; Macias Fauria et al. 2011; Cary et al. 2012; Moritz et al. 2012; Bowman et al. 2014). Compared to the total number of studies of the impact of climate change on wildfire, relatively few attempt quantitative, integrated assessments of the impact of climate change on multiple fire drivers (Pechony & Shindell 2010; Kloster et al. 2012; Loepfe et al. 2012; Eliseev et al. 2014).

In Australia, Bradstock (2010) provides a qualitative assessment of each of the four drivers, based on case studies of five fire regimes using quantitative and qualitative data. Bradstock (2010) concludes that increasing temperatures and dryness may lead to divergent impacts on fire activity across Australia, with potential increases in temperate forests, but decreases in areas where fires are currently limited by fuel amount rather than fire weather conditions. Both trends would affect NSW, which is home to both temperate forest along the eastern seaboard and grassy fuel-dominated areas in the arid inland of the state. This study also noted that these trends could be confounded or reinforced by elevated CO_2 effects. There is some empirical support for these projections from the recent observational record (Bradstock et al. 2014).

In a study in Western Sydney, Matthews et al. (2012) projected increased fire weather and fuel moisture but decreased fuel amount. Understanding the combined effect of such changes will require a better understanding of things like the effect of climate change on vegetation structure. Using simulation modelling, King et al. (2011, 2012) examined climate change impacts on multiple wildfire drivers in the Snowy Mountains and in grassland regions of Sydney, Canberra and Melbourne. While each study examined potential changes in fire weather and fuel load, only the grassland study included fuel moisture (curing) as well as fertilisation effects of CO_2 (King et al. 2012). Both studies projected increases in fire weather conditions and overall decreases in fuel load, which translated to increases in fire incidence and area burned in forests, but minimal changes in fire risk in grasslands.

5. Conclusions

There is great interest in understanding the impacts of climate change on bushfire risk, given its impacts on natural and human systems. However, fire is also a complex phenomenon, influenced by processes operating at a wide range of spatial and temporal scales. Many projections of climate change impacts on bushfire risks attempt to simplify this complexity by focusing on one of the major drivers of bushfire incidence: fuel amount, fuel moisture, fire weather or ignition.

Research on fire weather, and to a lesser extent fuel moisture, points to the potential for large increases in bushfire risk, but also the possibility of little change. There is greater uncertainty over the trajectory of vegetation growth and hence fuel load, with potentially competing effects of climate and carbon dioxide fertilisation a major area of study, and the likelihood of considerable regional variation. More work needs to be done on climate change impacts on lightning, a major source of bushfire ignitions.

Summarising this research to determine the overall influence of climate change on bushfire risk in NSW is difficult. There is a clear need to integrate many diverse strands of evidence, including many interactions and feedbacks. However, broadly speaking the potential for significant increases in bushfire risk appears greater than the potential for equivalent decreases. Several lines of research point to increasing risk in temperate forested areas of NSW. The picture in moisture limited areas, such as arid grasslands in the state's interior, is less clear, with some research suggesting that a decrease in fuel load will reduce overall risk despite strong increases in fire weather conditions. Bushfires are also intrinsically linked to human behaviour, including factors such as arson, planning regulations, community awareness and active bushfire suppression. This complexity and uncertainty heightens the need for fire managers in NSW to understand their exposure to and preparedness for a range of plausible climate futures.

6. Useful references

- CSIRO and Bureau of Meteorology FFDI are available at: www.climatechangeinaustralia.gov.au/en
- Climate Council report summarising research into climate change impacts on bushfire risk in NSW www.climatecouncil.org.au/be-prepared-climate-change-and-the-nsw-bushfire-threat
- A number of major research conferences include speakers and posters addressing aspects of climate change and bushfire risk:
  - Research proceedings from the 2015 Bushfire and Natural Hazards CRC & AFAC conference www.bnhcrc.com.au/publications/researchproceedings2015
  - Abstracts from the Australian Meteorological and Oceanographic Society 2015 conference www.amos.org.au/documents/item/737
  - Abstracts from the Climate Adaptation 2014 conference www.nccarf.edu.au/conference2014/wp-content/uploads/2014/09/ClimateAdaptation2014_Program_and_Abstracts_book.pdf.

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