CLIMATE COUNCIL

BE PREPARED: CLIMATE CHANGE AND THE AUSTRALIAN BUSHFIRE THREAT

The Climate Council is an independent, crowd-funded organisation providing quality information on climate change to the Australian public.

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WARNING: This report may contain the images of Aboriginal and Torres Strait Islander people now deceased.

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Preface

This is the first major report of the Climate Council, established in September 2013 to replace the former Climate Commission. The Climate Council is an independent, non-profit organization, funded by donations from the public. Our mission is to provide authoritative, expert information to the Australian public on climate change.

Over the past year, record-breaking temperatures have been experienced across the country. More than 120 weather records were broken last summer, including the hottest summer, the hottest January, and the hottest day. 2013 is on track to become Australia's warmest year on record. These trends, together with below-average rainfall in many parts of the country including the southeast, indicated that the coming summer fire season was likely to be a serious one. We thus made the decision in September to focus our first report on bushfires and their link to climate change. This decision was, unfortunately, borne out by the events in NSW in early October, where intense and uncontrolled fires raged across parts of the Central Coast and the Blue Mountains.

The October bushfires focused the world's attention on Australia, with many questions being asked in the community about the link between these fires and climate change. We have aimed to provide an up-to-date and comprehensive summary of this link. We have drawn heavily on the peer-reviewed scientific literature, as well as on submissions to several recent enquiries and Royal Commissions into bushfires and their impacts. A reference list is provided at the end of this report for those that would like more information.

We are very grateful to our team of expert and community reviewers: Prof. David Bowman (University of Tasmania), Prof. Ross Bradstock (University of Wollongong), Mr Ron Collins, Dr Ryan Crompton (Risk Frontiers, Macquarie University), Mrs Jill Dumsday, Mr David Harper, Dr Fay Johnston (University of Tasmania), Assoc. Prof. Michelle Leishman (Macquarie University), and Dr Peter Smith. We are also grateful for the contribution of Climate Council staff, in particular Katherine Hall, in drafting the report.

The authors retain sole responsibility for the content of the report.

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Contents

Key findings

1. Climate change is already increasing the risk of bushfires.

- Extreme fire weather has increased over the last 30 years in southeast Australia.
- Hot, dry conditions have a major influence on bushfires. Climate change is making hot days hotter, and heatwaves longer and more frequent. Some parts of Australia are becoming drier. These conditions are driving up the likelihood of very high fire danger weather, especially in the southwest and southeast.
- Australia is a fire prone country and has always experienced bushfires. All extreme weather events are now being influenced by climate change because they are occurring in a climate system that is hotter and moister than it was 50 years ago.

2. In southeast Australia the fire season is becoming longer, reducing the opportunities for hazard reduction burning.

- These changes have been most marked in spring, with fire weather extending into October and March.
- The fire season will continue to lengthen into the future, further reducing the opportunities for safe hazard reduction burning.
- One analysis indicated that under a relatively modest warming scenario, the area of prescribed burning in the Sydney region would need to increase two- to three-fold to counteract the increased fire activity. Under a more realistic scenario, the amount of hazard reduction will need to increase five-fold.

3. Recent severe fires have been influenced by record hot, dry conditions.

- Australia has just experienced its hottest 12 months on record. NSW has experienced the hottest September on record, days well above average in October and exceptionally dry conditions. These conditions mean that fire risk has been extremely high and we have already seen severe bushfires in NSW in the Central Coast and the Blue Mountains.
- The Black Saturday fires in Victoria were preceded by a decade-long drought with a string of record hot years, coupled with a severe

heatwave in the preceding week. The previous record for the Forest Fire Danger Index was broken by such an extent that it was revised and the category “Catastrophic” or “Code Red” was added.

- Since 2009 there have been a number of subsequent declarations of Catastrophic conditions around southern Australia in step with the hotter and drier climate.

4. In the future, Australia is very likely to experience an increased number of days with extreme fire danger.

- Fire frequency and intensity is expected to increase substantially in coming decades, especially in those regions currently most affected by bushfires, and where a substantial proportion of the Australian population lives.

5. It is crucial that communities, emergency services, health services and other authorities prepare for the increasing severity and frequency of extreme fire conditions.

- As fire risk increases, disaster risk reduction and adaptation policies will play a critical role in reducing risks to people and their assets. Increased resources for our emergency services and fire management agencies will be required.
- One estimate of the future economic costs of bushfires indicates that with no adaptive change, increased damage to the agricultural industry in Victoria by 2050 could add $1.4 billion to existing costs.
- By 2030, it has been estimated that the number of professional firefighters will need to approximately double (compared to 2010) to keep pace with increased population, asset value, and fire danger weather.

6. This is the critical decade.

- Australia must strive to cut emissions rapidly and deeply to join global efforts to stabilise the world’s climate and to reduce the risk of even more extreme events, including bushfires.

Introduction

Australians have often experienced the serious consequences of bushfires.

Over the past decade alone, large and uncontrollable fires devastated several suburbs in Canberra (2003), took 173 lives and destroyed over 2,000 homes in Victoria and Western Australia (2009), and destroyed over 200 properties in Tasmania (2013), forcing the evacuation of hundreds of people from the Tasman Peninsula.

Together with the recent bushfire crisis in NSW that destroyed 200 houses, these events have drawn the world's attention to the risks that fires pose for Australia. Of course Australians have always lived with fire and its consequences. But climate change is increasing fire danger weather and thus the risk of fires.

We begin this report by describing the background context of fire in Australia. We then summarise the observed changes in climate over the past few decades as they relate to fire. We explore the impacts of fire on people, property, water supply, agriculture, biodiversity and the climate, and how the incidence of wildfire globally is changing. Finally, we summarise the latest projections of fire weather and activity for the future and outline the implications of these projections for fire managers, planners and emergency services.

1. THE NATURE OF BUSHFIRES IN AUSTRALIA

- Fire has been a feature of the Australian continent for millions of years.
- In the temperate forests of the southeast and southwest, fire activity is strongly determined by weather conditions and the moisture content of the fuel.
- A fire regime describes *a recurrent pattern of fire*, with the most important characteristics being the frequency, intensity, and seasonality of the fire. Significant changes in any of these features can have a very important influence on the ecological and economic impacts.

The nature of bushfires in Australia

Fire has been a feature of the Australian environment for at least 65 million years (Cary et al., 2012). Human management of fires also has a long history, starting with fire use by indigenous Australians ("fire-stick farming") up to 60,000 years ago. European settlement brought changes in fire activity with flow-on effects to Australian landscapes.

"At any time of the year it is fire season somewhere in Australia"

Sullivan et al., 2012, p51

Between 3% and 10% of Australia's land area burns every year (Western Australian Land Information Authority, 2013) (Figs. 1 and 2). In the north of the continent, extensive areas of the tropical savanna woodlands and grasslands are burnt every winter during the dry season. High rainfall during the summer followed by a dry warm winter, together with the presence of a highly combustible grass layer, creates a very flammable environment. Fire incidence peaks in the late winter dry season, with intensity increasing as the season progresses. In areas that receive more than 1000 mm of rainfall per year, about 35% of the land can be burnt in a typical year (Russell-Smith et al., 2007).

In the southeast and southwest, fires are common in the heathlands and dry sclerophyll forests, typically occurring about every 5 to 30 years, with spring and summer being peak fire season (Clarke

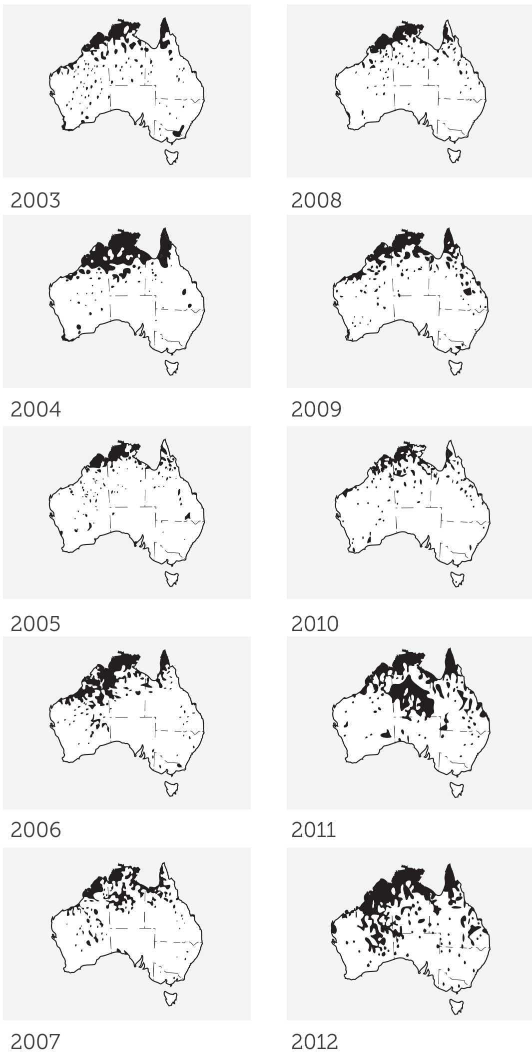


Figure 1: Fire burnt areas in Australia (2003-2012). Fire burnt areas are calculated by remote satellite sensing, where the smallest fires recorded are 4km^2. (Source: Western Australian Land Information Authority, 2013)

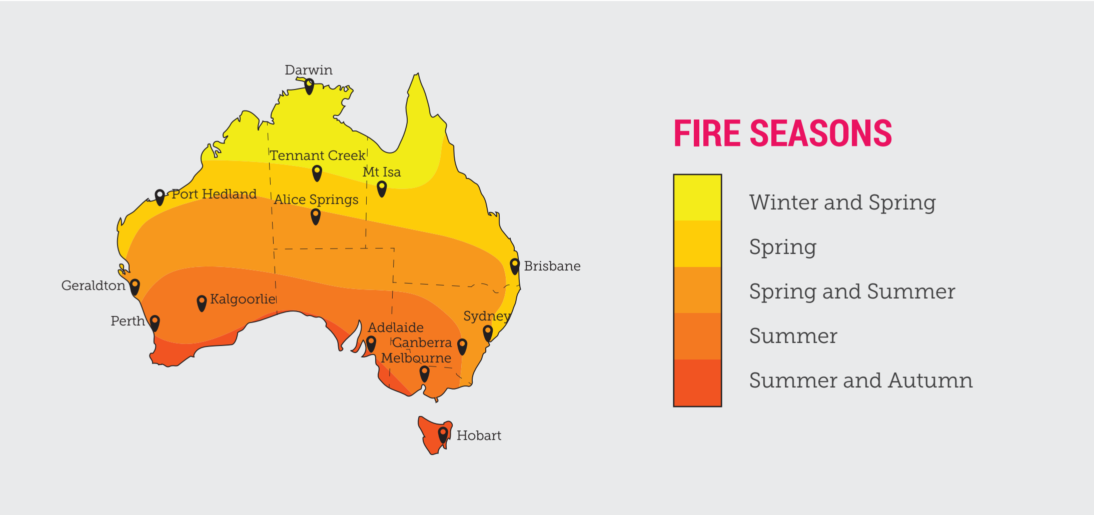


Figure 2: Bushfire seasons across Australia. (Source: BoM, 2009)

et al., 2011; Bradstock et al., 2012a). Fires in the southeast are often associated with periods of El Niño drought (Murphy et al., 2013) and may be extremely intense (El Niño is the phase of the El Niño-Southern Oscillation (ENSO) phenomenon characterised by warm dry conditions, while the La Niña phase is characterised by cool, wet conditions). Fires in wet sclerophyll forests, such as the mountain ash forests in Victoria, are less frequent but can be of very high intensity when they do occur (Gill, 1975). Fires are rare in rainforests in the absence of disturbances such as logging or cyclones because of the moist shaded local climate (Little et al., 2012). Arid central Australia experiences intermittent fires, typically following periods of extremely high rainfall associated with La Niña events because these events lead to increased fuel load (Murphy et al., 2013) (Fig. 3).

The concept of "fire regimes" is important for understanding the nature of bushfires in Australia, and for assessing changes in fire behaviour caused by both human and climatic factors. A fire regime describes a recurrent pattern of fire, with the most important characteristics being the frequency, intensity, and seasonality of the fire. Significant changes in any of these features can have a very important influence on the regime's ecological and economic impacts (Williams et al., 2009) (see section 2).

Fire is a complex process that is very variable in space and time. A fire needs to be started (ignition), it needs something to burn (fuel), and it needs conditions that favour its spread (weather and topography) (Fig. 4). The most important aspects of weather that affect fire and fuels are temperature, precipitation, wind and humidity. Once a fire is ignited, very hot days with low humidity and high winds are conducive to its spread. The type, amount, and moisture level of fuel available are also critical determinants of fire behaviour, extent and intensity. The relationship between rainfall and fuel is complex. Wet seasons can lead to increased plant growth and therefore increase fuel buildup in the months or

Figure 3: (a) Northern savanna woodlands, such as those in Kakadu National Park, NT, are burnt extensively each dry season. (Photo: Stephen Swayne) (b) Dry sclerophyll forests, which are found in many areas in southeast Australia, including the Blue Mountains, NSW, burn approximately every 5 to 30 years. (Photo: Sarah Wuttke) (c) Spinifex grasslands in the arid zone burn rarely but may do so after exceptionally large rainfall events in the previous season or year and resultant fuel buildup. (Photo: Irwin Reynolds)

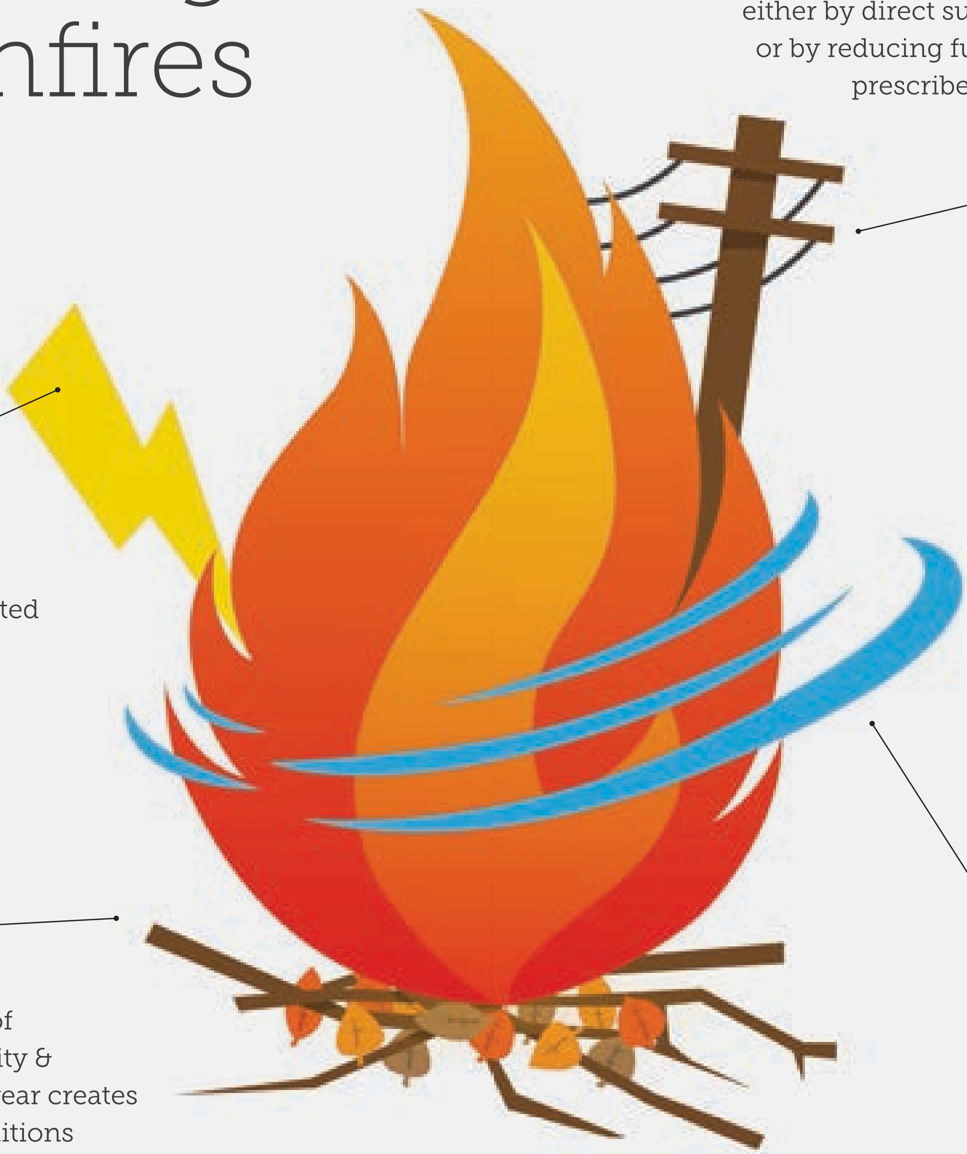
years before a fire is ignited (Bradstock et al., 2009). Warmer temperatures and low rainfall in the period immediately preceding an ignition, however, can lead to drier vegetation and soil, making the existing fuel more flammable. Warmer temperatures can also be associated with a higher incidence of lightning activity (Jayaratne and Kuleshov, 2006), increasing the risk of ignition.

The relative importance of weather and fuel varies between different ecosystems and regions. During the dry season in northern savannas, for example, fire activity is not limited by either the amount of fuel available or the weather in the dry season. In the temperate forests of the southeast and southwest, fire activity is strongly determined by weather conditions and the moisture content of the fuel. As fire weather conditions become more severe, fuel moisture content declines, making the fuel more flammable. In arid regions, vegetation and thus fuel in most years is sparsely distributed and fires, if ignited, rarely spread far. After heavy rainfall in La Niña seasons, however, increased grass cover can lead to a surge of fire activity (Gill et al., 2002; Clarke et al., 2013).

People are an important component of the fire equation. Many fires are either deliberately or accidentally lit, and in places where population density is high, the probability of a fire igniting increases close to roads and settlements (Willis, 2005; Penman et al., 2013). Some of Australia's most catastrophic bushfires have been ignited by powerline faults. But people also play an important role in reducing fire risk, by vegetation management including prescribed burning to reduce fuel load (see In Detail 2), and targeted fire suppression activities. Interventions such as total fire ban days also play a pivotal role in reducing ignitions under dangerous fire conditions.

Figure 4. Main factors affecting bushfires

Main factors affecting bushfires



3 | People
Fires may be deliberately started (arson) or be started by accident (e.g. by powerline fault). Human activities can also reduce fire, either by direct suppression or by reducing fuel load by prescribed burning

1 | Ignition
Fires can be started by lightning or people, either deliberately or accidentally

2 | Fuel
Fires need fuel of sufficient quantity & dryness. A wet year creates favourable conditions for vegetation growth. If this is followed by a dry season or year, fires are more likely to spread and become intense

4 | Weather
Fires are more likely to spread on hot, dry, windy days. Hot weather also dries out fuel, favouring fire spread and intensity

IN DETAIL 1

Forest Fire Danger Index

The Forest Fire Danger Index (FFDI) was developed in the 1960s by CSIRO scientist A.G. MacArthur to measure the degree of risk of fire in Australian forests (Luke and Macarthur, 1978). The Bureau of Meteorology and fire management agencies use the FFDI to assess fire risk and issue warnings.

The index is calculated in real time by combining a number of meteorological variables: preceding rainfall and evaporation; current wind speed; temperature; and humidity. A related index, the Grassland Fire Danger Index (GFDI), is also used in some regions and States, calibrated for more flammable grassland conditions.

The FFDI was originally designed on a scale from 0 to 100. MacArthur used the conditions of the catastrophic Black Friday fires of 1939 to set the maximum value of 100. These fires burned 5 million hectares and constituted, at the time, one of the largest fire events known globally. An index of 12 to 25 describes conditions with a "high" degree of danger. Days with ratings over 50 are considered to be "severe"—a fire ignited on such a day will likely burn so hot and fast that suppression becomes difficult. For forests, a rating over 75 is categorised as "Extreme".

The FFDI on 7th February 2009 in Victoria, known as "Black Saturday", ranged from 120 to 190, the highest FFDI values on record (Karoly, 2009). Following these fires the FFDI in Victoria was revised and the category "Catastrophic" or "Code Red" was added (FFDI>100). Consistent with the increasing incidence of hot and dry conditions, there have been a number of declarations of Catastrophic conditions around southern Australia since Black Saturday.

The FFDI is not only used by management agencies to calculate risk, it has also become an important tool for research. For example, the probability of destruction of property in the Sydney basin has been found to increase significantly with increasing FFDI (Bradstock and Gill, 2001). The FFDI has also been used extensively in projections of fire risk in the future (see section 7).

Category	Forest Fire Danger Index	Grassland Fire Danger Index
CATASTROPHIC (CODE RED)*	100 +	150 +
EXTREME	75–99	100–149
SEVERE	50–74	50–99
VERY HIGH	25–49	25–49
HIGH	12–24	12–24
LOW TO MODERATE	0–11	0–11

* In Tasmania, the "Catastrophic" category is indicated by the colour black

(Sources: CFA, 2009, Bureau of Meteorology http://www.bom.gov.au/weather-services/bushfire/)

2. IMPACTS OF BUSHFIRES

› Bushfires can have severe impacts on health, property, water, agriculture, livelihoods and biodiversity.

Impacts of bushfires

Bushfires have a very wide range of human and environmental impacts, including loss of life and severe health effects; damage to property; devastation of communities; and effects on water, air quality, agriculture, and natural ecosystems (Stephenson, 2010).

The risks to people are especially acute in southern Australia, where large populations live close to highly flammable native vegetation that is exposed to frequent severe fire weather. Many of the largest bushfires that have caused high mortalities and extensive property losses have triggered parliamentary and coronial enquiries, court cases and Royal Commissions. Several of the fire management agencies and activities initiated after the 1939 "Black Friday" fires in Victoria and New South Wales remain in force today (King et al., 2013b).

The economic cost of bushfires—including loss of life, livelihoods, property damage, and emergency services responses—is very high (Table 1). During the 47-year period from 1 July 1966 to 30 June 2013 the insured loss due to Australian bushfire totaled $5.6 billion in year 2011/12 values. This translates to an average annual loss of approximately $120 million over the period and represents about 10% of the insured loss of all natural disasters, and 11% of the insured loss of weather-related natural disasters. In the decade up to 30 June 2013 the insured losses due to bushfires in Australia totaled $1.6 billion. This translates to an average annual loss of approximately $160 million over the period[1].

These estimates of economic losses, however, do not account for the full range of costs associated with bushfires—few attempts have been made to account for loss of life, social disruption and trauma, opportunity costs for volunteer fire fighters, fixed costs for bushfire fighting services, government contributions for rebuilding and compensation, impacts on health, and ecosystem services (King et al., 2013b).

[1] These estimates are based on data from the Insurance Council of Australia (ICA 2013), and are normalised for 2011/12 values to account for trends in inflation and property values. (Crompton 2011, R. Crompton personal communication)

RECORDED LOSSES FROM MAJOR BUSHFIRE EVENTS IN AUSTRALIA SINCE 1939

FIRE EVENT	LOSSES (direct deaths due to fire)[1]	LOSSES (including residential property, stock)	SIGNIFICANT INSURED LOSSES (normalised to 2011 values)[2]
Black Friday, January 1939, Victoria	71 (AIC 2004, Reuters 2009)	1000+ homes (ABS 2004, AIC 2004)	N/A
Hobart, February 1967, Tasmania	62 (Reuters 2009, TBI 2013)	1300-1400 homes (McAneney et al., 2009; TBI 2013) 62,000 stock (TBI 2013)	$610 million (ICA 2013)
Ash Wednesday, February 1983, Victoria and South Australia	75 (AIC 2004; Reuters 2009, Stephenson et al., 2013)	> 2,300 homes (Ramsay et al., 1996; AIC 2004; McAneney et al., 2009; Stephenson et al., 2013) >200,000 stock (Ramsay et al. 1996; AIC 2004, CFA 2012; Stephenson, et al., 2013)	$1.796 billion (ICA 2013)
Sydney, NSW, January 1994	4 (Ramsay et al., 1996, ABS 2001, NSW Ministry for Police & Emergency Services 2007)	> 200 homes (Ramsay et al., 1996; NSW Ministry for Police & Emergency Services 2007)	$215 million (ICA 2013)
Canberra and alpine fires, 2003	4 in Canberra (McLeod 2003); 1 in alpine (Stephenson et al., 2013) Major injuries: 52; Minor injuries: 338 (Stephenson et al., 2013)	>500 properties (McLeod 2003; McAneney et al., 2009) including the Mt Stromlo Observatory (Pitman et al., 2007) >17,000 stock (Stephenson et al., 2013)	$660 million (ICA 2013)
Black Saturday, February 2009, Victoria	173 (Teague et al., 2010, Stephenson et al., 2013) Major injuries: 130 Minor injuries: 670 (Stephenson et al., 2013)	>2000 houses (CFA 2012; Stephenson et al., 2013) 8000-11,800 stock (Teague et al., 2010; (Stephenson et al., 2013)	$1.266 billion (ICA 2013)
Tasmania, Jan 2013	0	203 homes (TBI 2013) 10,000 stock (TBI 2013)	$89 million in 2013 values (ICA 2013)
Blue Mountains, October 2013	0	208 properties (Whyte 2013)	$183 million as of 19.11.13, in 2013 values (ICA 2013)

Table 1. Recorded losses from major bushfire events in Australia since 1939

1. Only deaths attributed directly to fires are included, but it should be noted that other deaths associated indirectly with fires have occurred (eg. deaths indirectly associated with NSW Blue Mountains fires in 2013 include one due to heart attack, and another due to a plane crash).

2. Insured losses shown have been normalised to 2011 values (taking inflation, and wealth changes into account) except for 2013 fires (Tasmania and NSW).

2.1 Human health

Fires pose a significant risk to human life and health (Johnston, 2009). In Australia, bushfires have accounted for more than 800 deaths since 1850 (Cameron et al., 2009; King et al., 2013b).

The majority of fatalities have occurred in Victoria, followed by NSW and Tasmania (Haynes et al., 2010). The Black Saturday bushfires in Victoria in February 2009 alone accounted for 173 deaths, ranking as one of the world's ten most deadly recorded bushfires (Teague et al., 2010). A large portion of the fatalities (44%) were children younger than 12 years old, people over 70 years and those with either chronic or acute disabilities (O'Neill and Handmer, 2012).

"...each year, smoke from bushfires and forest fires cause over 300,000 deaths globally"

Smoke from both planned and unplanned fires can have serious impacts on health. Smoke contains not only respiratory irritants, but also inflammatory and cancer-causing chemicals (Bernstein and Rice, 2013). Smoke can be transported in the atmosphere for hundreds or even thousands of kilometres from the fire front, exposing large populations to its impacts (Spracklen et al., 2009; Dennekamp and Abramson, 2011; Bernstein and Rice, 2013). Each year, smoke from wildfires causes the deaths of over 300,000 people globally (Johnston et al., 2012), with the largest proportion occurring in Africa and southeast Asia.

Smoke from bushfires has measurable impacts on human health in several of Australia's major cities. For example, smoke from bushfires in the Blue Mountains regularly affects Sydney's air quality. Days with severe pollution from bushfires around Sydney are associated with increases in all-cause mortality of around 5% (Johnston et al., 2011). Similar research in Melbourne found that cardiac arrests outside hospitals increased by almost 50% on bushfire smoke-affected days (Dennekamp et al., 2011).

The impacts of air pollution in the community are uneven. The elderly, infants, and those with chronic heart or lung diseases are at higher risk (Morgan et al., 2010). People with asthma can be harmed by smoke pollution at concentrations that are well tolerated by fit and healthy adults (Johnston et al., 2006), and hospital admissions of people with existing lung conditions such as chronic obstructive lung disease and asthma rise disproportionately during bushfire smoke episodes (Henderson and Johnston, 2012). Increases in hospital admissions for asthma and other respiratory diseases in Australian cities,

Figure 5: Smoke over Bondi beach, Sydney. "Smoke days" are associated with higher hospital admissions and mortality. (Photo: Andrew Quilty)

including Sydney, Brisbane and Darwin, have occurred on days where high levels of smoke from bushfires have been experienced (Chen et al., 2006; Johnston et al., 2007, 2011; Martin et al., 2013) (Fig. 5). From 1994-2007, asthma admissions in Sydney hospitals, for example, were reported to rise by 12% on days of "smoke events" compared to non-smoke days (Martin et al., 2013).

The trauma and stress of experiencing a bushfire can also increase depression, anxiety, and other mental health issues, both in the immediate aftermath of the trauma and for months or years afterwards (McFarlane and Raphael, 1984; Sim, 2002; Whittaker et al., 2012). A study of over 1500 people who experienced losses in the 1983 Ash Wednesday bushfires found that after 12 months, 42% were suffering a decline in mental health ("psychiatric morbidity") (McFarlane et al., 1997). These problems can be especially acute amongst those who have lost loved ones, property and/or livelihoods, and may be exacerbated by pre-existing stresses caused by droughts and associated financial hardship, especially in rural communities (Whittaker et al., 2012). Post-traumatic stress can also be manifest among firefighters, sometimes only becoming evident many months after an extreme event (McFarlane, 1988).

2.2 Built environment and infrastructure

An analysis of building damage from 1925-2009 shows that on average, the equivalent of around 300 houses per year (in 2008/09 values) were lost due to bushfires (Crompton et al., 2010).

Many Australians, including those in communities in outer Melbourne, Hobart, and Sydney, enjoy living close to, or on the fringes of, bushland, and this proximity is an important factor in increased bushfire vulnerability (Chen and McAneney, 2010; O'Neill and Handmer, 2012; Price and Bradstock, 2013) (Fig. 6). For example, many of the homes destroyed in Marysville and Kinglake, two communities devastated by the 2009 Victorian bushfires, were either surrounded by or located less than 10 metres from bushland (Chen and McAneney 2010; Crompton et al. 2010). In fact, the vast majority of buildings affected by major bushfires in Australia have been located at a distance of less than 100 metres from bushland (Chen and McAneney 2010). In the Blue Mountains, NSW, approximately 38,000 homes are within 200 metres of bushland, and 30,000 within 100 metres; many homes back directly onto bushland (McAneney 2013).

> "Living close to bushland increases risk to life and property from bushfires"

A significant portion of properties lost in bushfires are either uninsured or underinsured. An analysis by the Insurance Council of Australia published in 2007 indicated that approximately 23% of Australian households did not have a building or contents insurance policy (Tooth and Barker, 2007). The report also found that households with more limited financial reserves were less likely to have an insurance policy. CGU Insurance has estimated that the average level of deficiency in value of Business Interruption coverage is 84% (EB Economics, 2013). Approximately 13% of properties lost in the Black Saturday fires were uninsured (Teague et al., 2010), and between 27% and 81% of households affected by the 2003 Canberra fires were either uninsured or underinsured (by an average of 40% of replacement value) (ASIC, 2005). The lack of insurance is a particular issue in rural communities, where underinsurance of livelihood-associated assets such as livestock, farm buildings and fences is common (Whittaker et al., 2012).

Figure 6: Many homes and communities in Australia are situated in close proximity to flammable bushland, increasing their vulnerability to bushfires. (a) Blue Mountains, NSW. (Source: Google Maps, 2013. Springwood, NSW) (b) Destruction in Winmalee, NSW, caused by the October 2013 Blue Mountain fires. (Photo: AAP) (c) Shops in Marysville, VIC after the Black Saturday bushfires (Photo: Paul Watkins) and (d) remains of the old service station at Kinglake, VIC, after the Black Saturday bushfires. (Photo: Stephen Kinna photography)

Infrastructure such as powerlines and roads can also be damaged in bushfires. In the 2003 alpine fires in Victoria, for example, about 4500 km of roads were damaged and local businesses reported a 50-100% economic downturn in the fire aftermath (Stephenson, 2010).

Several studies have examined the question of whether risks of property loss in bushfires in Australia have changed over time. An analysis of insured property losses from 1900 to 2003 found no significant change in the annual probability of building destruction from bushfires once inflation, changes in population, and changes in wealth were taken into account (McAneney et al., 2009). A further analysis that included data from 1925 to 2009 (i.e. including the Black Saturday losses) similarly showed no statistically significant trend (Crompton et al., 2010, 2011).

These analyses could not, however, take into account several other factors that may have reduced vulnerability over the period (Nicholls, 2011, see also reply from Crompton et al., 2011). Significant improvements have been made in the management of emergency services, and the ability of these services to respond effectively to bushfires (Handmer et al., 2012; Senate Environment and Communications Committee, 2013). Weather forecasting has also improved in the past few decades, enabling emergency services to access more reliable information, to create weather warning systems and services, and to tailor their bushfire preparations and responses accordingly. It must be emphasised, however, that emergency services have limited capacity to reduce losses in catastrophic fires such as those that occurred on Black Saturday (Crompton et al., 2011).

Bushfires also affect livelihoods in a diverse range of industries, including farming (section 2.3), small business, and tourism (Stephenson, 2010; EB Economics, 2013). As noted above, however, many of the more intangible costs of bushfires are difficult, if not impossible, to estimate.

2.3 Agriculture

Figure 7: Livestock that survive bushfires may face starvation or attack from predators. (Photo: Jason Lam)

Uncontrolled bushfires can cause significant losses in farming areas.

Livestock losses were estimated at 13,000 in the 2003 alpine fires in Victoria, 65,000 in the 2005-6 Grampians fire, and more than 11,000 in the Black Saturday fires (Stephenson, 2010, Teague et al., 2010). Stock that survive direct effects of the fire can face starvation in the post-fire period (Fig. 7), as well as threats from predators due to loss of fences—over 8000 km of fences were lost in the Black Saturday fires (Stephenson, 2010). Smoke damage can also taint fruit and vegetable crops, with wine grapes particularly susceptible (Stephenson, 2010).

A study by Keating and Handmer (2013) provides one of the few full economic assessments of bushfire impacts on primary industry. This study conservatively estimated that bushfires directly cost the Victorian agricultural industry around $42 million per year. When business disruption was included more broadly, the costs to the entire Victorian economy from this impact were estimated to be $92 million per year. A similar analysis for the Victorian timber industry estimated direct costs at $74 million per year, and state-wide costs at $185 million (Keating and Handmer 2013).

2.4 Water

Fire can affect the quality and quantity of water in catchments, both immediately following the event and for many years after (Fig. 8).

Large-scale high intensity fires that remove vegetation expose topsoils to erosion and increased runoff after subsequent rainfall (Shakesby et al., 2007). This can increase sediment and nutrient concentrations in nearby waterways, potentially making water supplies unfit for human consumption (Smith et al., 2011). Following the 2003 Canberra fires, for example, there was severe disruption to supplies of drinking water from reservoirs within the Cotter River catchment (White et al., 2006).

Fire also has longer-term affects on water flow in forested catchments. Immediately after the fire there may be an increase in water flow. But as the forests regenerate, the new growth usually uses more water than the mature trees they have replaced (Langford 1976, Feikema et al., 2013). Seven years after the 2003 fires in the mountain ash forests of Victoria, for example, the regrowth was still using twice the water of adjacent mature forest (Buckley et al., 2012). This pattern, known as the "Kuczera effect", can last for several decades after a fire, with water yields from forested catchments being reduced by up to 50% (Kuczera, 1985; Brookhouse et al., 2013).

Fires can also effect water infrastructure. Fires in the Sydney region in 2002, for example, affected the Woronora pumping station and water filtration plants, resulting in a community alert to boil drinking water (WRF, 2013). Significant costs can be associated with these disruptions. The Black Saturday bushfires in 2009 affected about 30% of the catchments that supply Melbourne's drinking water. Melbourne Water estimated the post-fire recovery costs, including water-monitoring programs, to be over $2 billion (WRF, 2013).

Figure 8: The lower Cotter catchment area was burnt extensively in the 2003 ACT fires, affecting the availability of clean drinking water for Canberra. (Photo: Micheal Schultz)

2.5 Biodiversity

Fire is a regular occurrence in many Australian ecosystems, and many species have evolved strategies over millions of years to not only withstand fire, but to benefit from it (Crisp et al., 2011, Bowman et al., 2012).

Fire does not "destroy" bushland, as is often reported; rather, it acts as a major disturbance with a range of complex impacts on different species and communities.

Nevertheless, particular fire regimes (especially specific combinations of fire frequency and intensity) can favour some species and disadvantage others.

Even within a single fire, some parts of the landscape will be burnt more intensely than others, creating a mosaic of impacts (Bradstock, 2008). The complexity of the interactions between different species and aspects of fire regimes means that there is no "optimal" fire regime that conserves all biodiversity in a landscape. This is a particular challenge for fire managers (see In Detail 2 on Prescribed burning).

Some plant species in fire-prone environments are capable of resprouting from buds in their trunks, or from underground woody structures called lignotubers, even after very intense fire (Fig. 9). Many plant species, especially

A B C

Figure 9: Australian plant species display many different strategies to cope with fire. (a) Many plant species have seeds with hard seed coats that crack in the high heat of fires, letting in water and beginning the germination process. (Photo: Ron Oldfield) (b) Epicormic buds on tree trunks resprouting after a fire. (Photo: Lesley Hughes) (c) Stems sprouting from woody lignotubers. (Photo: Lesley Hughes)

Figure 10: Arboreal (tree-dwelling) mammals are particularly vulnerable in bushfires. (a) The Black Saturday 2009 bushfires devastated communities of the already endangered Leadbeater's possum. (Photo: D. Harley) (b) Koala. (Photo: Jemma Cripps) (c) Brushtail possum. (Photo: Mark Jekabsons)

those in eucalypt forests, have adults that are killed by fire but produce hard seeds that need fire to germinate or be released. These 'obligate seeder' plants require sufficient time between successive fires to become reproductively mature (Whelan et al., 2002). If fires are too frequent, species can become vulnerable to local extinction as the supply of seeds in the soil declines. Conversely, if the interval between fires is too long, plant species that rely on fire for reproduction may be eliminated from an ecological community.

Animals that are restricted to localised habitats, cannot move quickly, and/or reproduce slowly, may be at risk from intense large-scale fires that occur at short intervals (Yates et al., 2008). Invertebrates, reptiles, amphibians and birds tend to be more resilient to fire impacts. On the other hand, birds with poor flight capacity and tree-dwelling mammals can be particularly vulnerable (Bradstock, 2008) (Fig. 10).

Fire regimes are such important drivers of ecosystems that changes in their frequency or intensity can shift an ecosystem from one state to another—sometimes called a "tipping point". As one example, successive fires at short intervals can drive vegetation from one type to another because previously dominant plants do not have time to mature and set seed, thus becoming locally scarce or even eliminated. In the moist mountainous areas of the southeast, dense forests could be converted into open woodlands if the interval between severe fires is reduced due to a hotter and drier climate (Williams et al., 2009). Another example may be found in northern savannas where particular fire regimes, combined with establishment of invasive plant species (see below), can trigger shifts from vegetation dominated by trees to one dominated by grasses (Rossiter et al., 2003, Yates et al., 2008) (Fig. 11).

Ecosystems in which the natural fire interval is very long (>100 years) can undergo substantial change if the fire frequency increases. After successive fires in 2003 and 2006/7 in Victoria, *Acacia* shrublands have replaced some mountain and alpine ash forests because there was insufficient time between fires for the ash trees to become reproductively mature (Lindenmayer et al., 2011; Bowman et al., 2013b). This change in vegetation has important flow-on effects for other species, especially the ~40 vertebrate species that rely on the hollows of 120-150 year old mountain ash trees for habitat, such as the Leadbeater's possum (Fig. 10a).

Figure 11: Changes in fire regimes can shift vegetation from one type to another. For example, savannas in the Northern Territory can shift between vegetation dominated by trees (a) to one dominated by grasses (b). (Photos: Stephen Swayne)

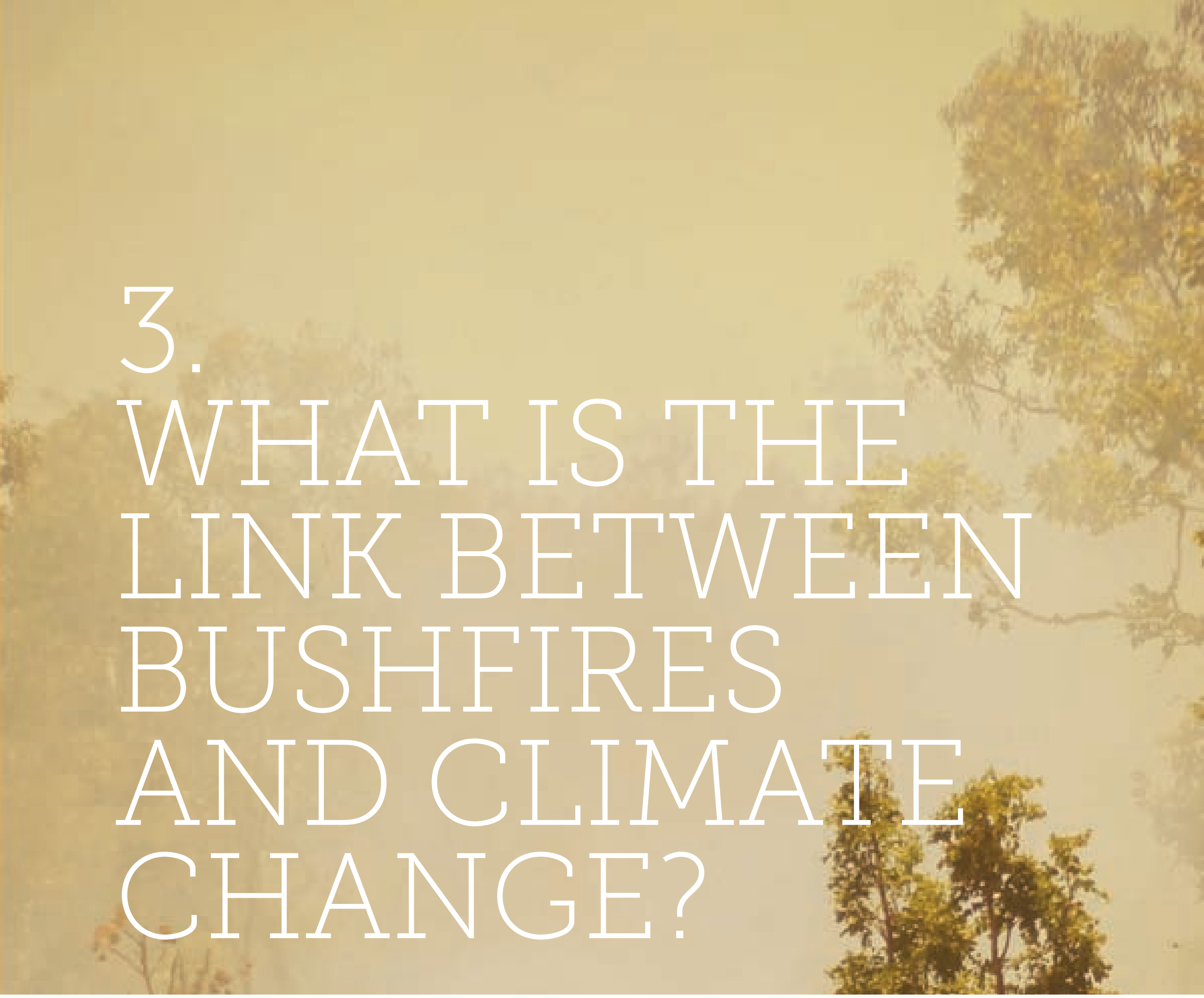
Changing fire regimes, due to a constellation of factors including climate change, are already affecting ecosystems in many parts of the world (see section 5) and will continue to do so. Indeed, changed fire regimes, driven by climatic changes, may have greater impacts on some species and ecosystems in the future than the direct impacts of warming and rainfall change (Battlori et al., 2013; Bowman et al., 2013c). Some of the world's most iconic ecosystems could change beyond all recognition within a few decades. One such example is the landscape of the Greater Yellowstone Region of the eastern United States. This region has been dominated by conifer species for over 11,000 years. Projected increases in fire frequency due to the changing climate could shift the vegetation substantially to either woodlands or "non-forest" vegetation by the middle of the century (Westerling et al., 2011b).

Figure 12: Gamba grass is an invasive grass from Africa that has colonised large areas in the Top End. It grows very rapidly, up to four metres in height in a single year, providing enormous amounts of flammable material that significantly increases fire risk and intensity. (a) (Photo: Russell Cumming) (b) (Photo: Invasive Species Council)

A

B

To complicate matters even further, changing fire regimes will interact with other pressures on ecosystems. One of the most important of these interactions is how fire and climate change will affect the impacts of invasive species, and vice versa. For example, the introduced African species gamba grass (*Andropogon gayanus*) has now colonised substantial areas in the Top End (Fig. 12). This grass grows extremely quickly, up to 4 metres in height in a single year, providing enormous quantities of highly flammable fuel in the dry season (up to 30 tonnes per ha). Fire intensity in gamba-invaded areas can be 16 times that of native grassland, and increase the number of days of severe fire risk by at least six times (Setterfield et al., 2013). The way in which climate change and invasive species like this will affect future fire regimes is an active area of research.



3. WHAT IS THE LINK BETWEEN BUSHFIRES AND CLIMATE CHANGE?

- The most direct link between bushfires and climate change comes from the long-term trend towards a hotter climate. Climate change is increasing the frequency and severity of very hot days and driving up the likelihood of very high fire danger weather.
- Changes in temperature and rainfall may also affect the amount and condition of fuel and the probability of lightning strikes.

As outlined in Section 1, a fire needs to be started (ignition), it needs something to burn (fuel) and it needs conditions that are conducive to its spread (weather). Climate change can affect all of these factors in both straightforward and more complex ways (Fig. 13).

Figure 13: Potential impacts of atmospheric and climatic change on factors that affect fire. Increased temperatures may increase the incidence of lightning and thus increase the probability of ignitions. Increased temperatures may either increase or decrease vegetation productivity, depending on the region. Changes in rainfall may also have complex impacts via changes in fuel load and fuel condition. Increases in extreme hot days will increase the probability that fires, once started, will spread and become more intense.

3.1 Ignition

The role of climate change in ignition is likely to be relatively small compared to the fuel and weather, but may still be significant.

The majority of fires are started by humans (Willis, 2005; Bradstock, 2010), although lightning is responsible for some ignitions. Lightning accounts for about 25% of ignitions in Victoria, but these fires account for ~50% of area burnt each year because they often burn uncontrolled in remote areas (Attiwill and Adams, 2011). Similarly, lightning accounts for ~27% of the ignitions in the Sydney region (Bradstock, 2008). The incidence of lightning is sensitive to weather conditions, including temperature (Jayaratne and Kuleshov 2006). It has been estimated that a 5-6% increase in global lightning activity could occur for every 1°C warming (Price and Rind, 1994). Analysis of a 16-year dataset (1995-2010) for continental USA shows significantly increased lightning activity in some regions over the period (Villarini and Smith, 2013).

Figure 14: The incidence of lightning may increase in a warmer climate and increase ignitions. (Photo: Louise Denton)

3.2 Fuel

The potential impacts of climate change on fuel are complex (Fig. 13) and it is not possible to determine how—or in what direction—a changing climate will affect the amount and condition of the fuel in a particular region.

The amount of fuel (fuel load) is affected by vegetation growth and decomposition (see also section 1). These processes are in turn influenced by several atmospheric and climate-related factors (Williams et al., 2009; Bradstock, 2010; Cary et al., 2012). Periods of high rainfall can spur growth in ecosystems that are water-limited, which is the case for much of Australia. Rising temperatures may also increase growth in vegetation in some regions, such as the mountainous forests of the southeast and Tasmania. Low rainfall can reduce decomposition, resulting in faster build up of fuel loads.

Conversely, periods of drought and excessively high temperatures can stunt vegetation growth, reducing fuel load. The increasing concentration of carbon dioxide in the air can also stimulate vegetation growth by promoting photosynthesis (the "CO_2 fertilisation effect") (Hovenden and Williams 2010), as well as potentially increasing flammability of plants and affecting resprouting ability (Hoffmann et al., 2000). Rising CO_2 may also alter the relative competitiveness of woody species over grasses, changing vegetation structure in ways that influence fire behavior (Hovenden and Williams 2010).

Weather also affects the condition of the fuel. Lack of rainfall can dry out the soil and vegetation, making the fuel more combustible, whereas periods of wet, cool weather make it less prone to burning.

"Bushfire threat is typically associated with high temperatures, low humidity, strong winds and high fuel load. Bushfires become catastrophic when all these things occur in combination"

Bureau of Meteorology submission to Senate Enquiry into
Recent trends in and preparedness for extreme weather events

3.3 Weather

"Climate change is increasing the frequency and severity of very hot days and driving up the likelihood of very high fire danger weather"

In many regions local weather conditions are the most important influence on fire activity (Fig. 13).

Very hot, dry and windy days create very high bushfire risk (see In Detail 1 Forest Fire Danger Index). The most direct link between bushfires and climate change therefore comes from the relationship between the long-term trend towards a warmer climate (see section 4) due to increasing greenhouse gas emissions—that is, the increasing amount of heat in the atmosphere—and the incidence of very hot days. Put simply, climate change is increasing the frequency and severity of very hot days (IPCC, 2012; 2013), and driving up the likelihood of very high fire danger weather. Any future changes in surface wind direction and strength will also be important, but unfortunately there are few reliable data or modeling projections available as yet.

The Black Saturday bushfires in 2009 and the recent fires in the Blue Mountains of NSW illustrate the role of weather conditions in affecting fire severity. In the case of Black Saturday, the fires were preceded by a decade-long drought with a string of record hot years, coupled with a severe heatwave in the preceding week. The weather conditions on February 7th broke temperature and humidity records, with the FFDI ranging from 120 to 190, the highest values ever recorded (Karoly 2009) (In Detail 1).

"There is a clear observed association between extreme heat and catastrophic bushfires"

Submission by the Australian Academy of Sciences to the Senate Enquiry into *Recent trends in and preparedness for extreme weather events*

The recent fires in NSW were preceded by the warmest September on record for that state, the warmest 12 months on record for Australia (Fig. 15), and below average rainfall in forested areas, leading to dry fuels (Bushfire CRC, 2013).

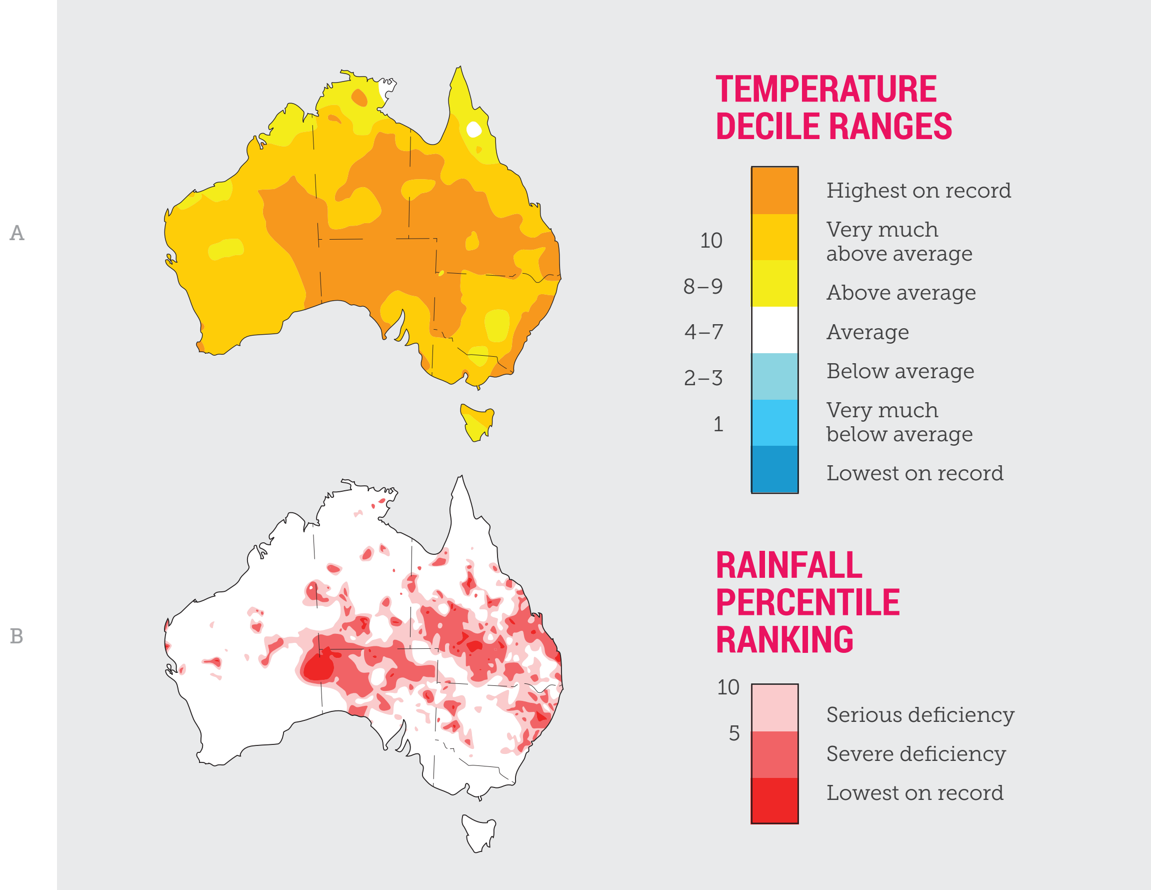


Figure 15: (a) Average temperature deciles and (b) rainfall deficiencies for the three months from 1 August to 31 October 2013. Mean temperature deciles represent 10 categories of average temperature across a range above and below the long-term average. Rainfall deficiency, or drought, is measured as areas when rainfall is in the lowest 10% or 5% of records for three months or more. High temperatures and dry vegetation and soil increase the bushfire risk. (Sources: Redrawn from BoM, 2013a and 2013b)

The relative influence of weather factors versus fuel factors on fire regimes varies between different vegetation types and different regions. In the northern savannas and the arid zone, fire activity is mainly limited by fuel dryness (Bradstock, 2010; King et al., 2013a, Murphy et al., 2013). Any future changes in fire activity will therefore be largely determined by changes in rainfall. Rainy years—such as those associated with strong La Niña periods—can result in enhanced fire danger in the following year(s) due to enhanced plant growth and resultant increased fuel loads (Harris et al., 2008).

In other regions and vegetation types, such as the dry sclerophyll woodlands and forests of the southeast and southwest, fire activity is strongly associated with weather, although fuel dryness remains important (Price and Bradstock, 2011). It is in these ecosystems that rising temperatures may have the most influence in the future (see section 7). Further, it is in these areas where the majority of the Australian population lives.

4. OBSERVATIONS OF CHANGING BUSHFIRE DANGER WEATHER IN AUSTRALIA

- *All* extreme weather events are now being influenced by climate change because they are occurring in a climate system that is warmer and moister than it was 50 years ago.
- While hot weather has always been common in Australia, it has become more severe over the past few decades. The annual number of record hot days across Australia has doubled since 1960.
- Parts of southeast Australia have already experienced a significant increase in extreme fire weather since the 1970s.
- The fire season has lengthened across southern Australia, with fire weather extending into October and March. The lengthening fire season means that opportunities for fuel reduction burning are reducing.

Observations of changing bushfire danger weather in Australia

Climate change is already increasing the intensity and frequency of some extreme events such as very hot days, heavy rainfall, droughts and floods.

The strength of trends and the confidence in their attribution, however, varies between regions and between different types of event (IPCC, 2012; 2013). All extreme weather events are now being influenced, to some degree, by climate change because they are occurring in a climate system that is hotter and moister than it was 50 years ago (Trenberth, 2012).

While hot weather has always been common in Australia, it has become more severe over the past few decades. Australia's average air temperature has risen by 0.9°C since 1910, with most of that rise occurring in the post-1950 period (CSIRO and BoM, 2012). This is consistent with the increase in hot weather globally. A small increase in average temperature can have a disproportionately large effect on the number of hot days and record hot days (Fig. 16). When the average temperature increases, the hot and cold extremes shift too. There is a greater likelihood of very hot weather and a much lower likelihood of very cold weather.

The annual number of record hot days across Australia has doubled since 1960 and the number of record cold days has decreased (CSIRO and BoM, 2012; Fig. 17). In fact, the frequency of record hot days has been more than three times the frequency of record cold days during

"*All* extreme weather events are now being influenced by climate change because they are occurring in a climate system that is warmer and moister than it was 50 years ago"

Trenberth, 2012

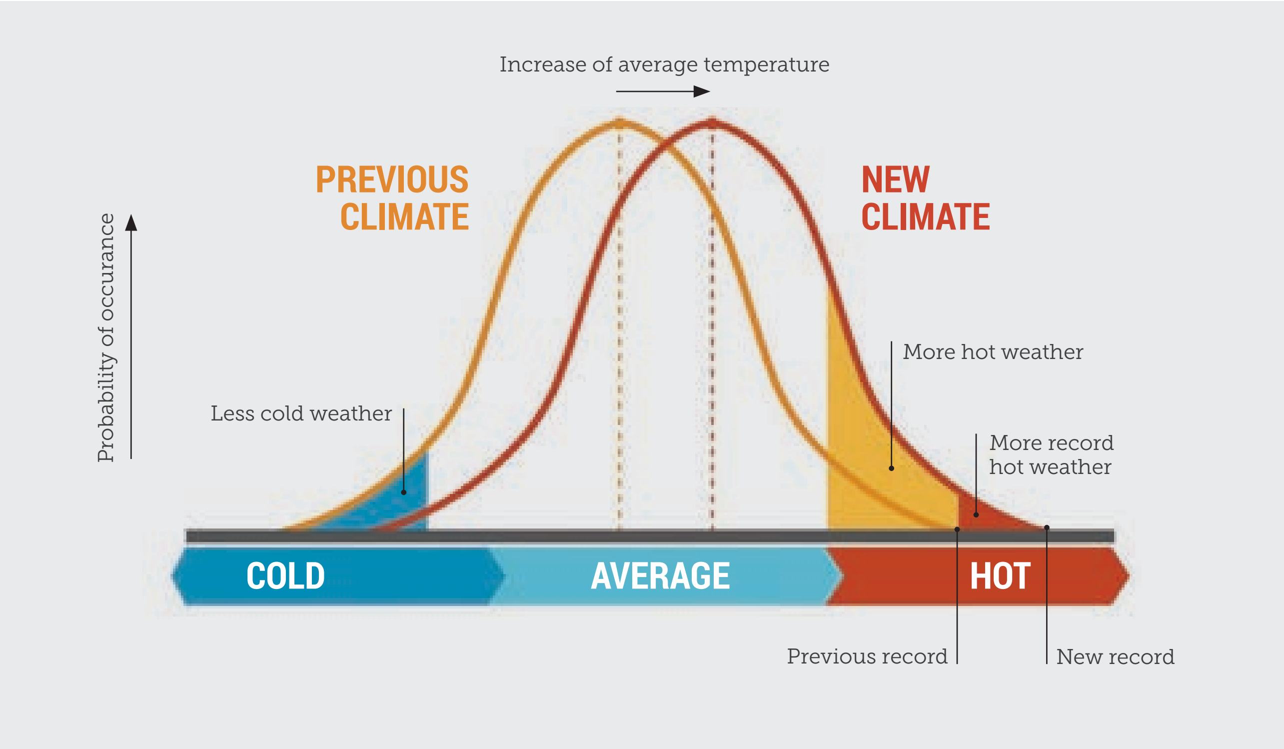


Figure 16: Relationship between average and extremes. Small increases in average temperature result in substantially greater numbers of extreme hot days. (Source: Climate Commission, 2013, redrawn from IPCC, 2007)

the past ten years (Trewin and Smalley, 2012). For example, in Canberra the long-term average (1961-1990) number of days per year above 35°C is 5.2 (BoM, 2013), but during the decade 2000–2009 the average number of such days nearly doubled to 9.4 (BoM, 2013).

The nature of heatwaves has also changed in many parts of Australia. Over the period 1971-2008, the duration and frequency of heatwaves has increased, and the hottest days during a heatwave have become even hotter (Perkins and Alexander, 2013).

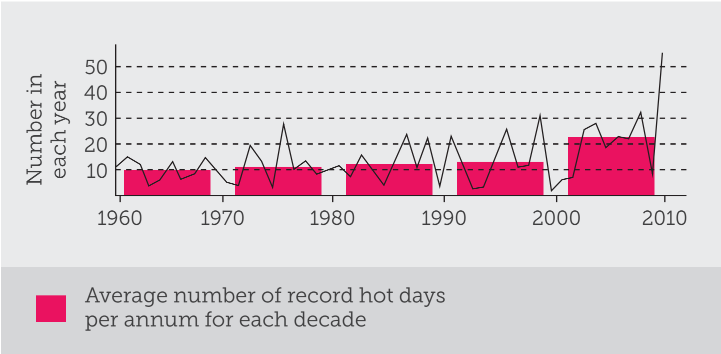


Figure 17: Number of record hot day maxima at Australian climate reference stations from 1960 to 2010. The annual number of record hot days across Australia has doubled since 1960. (Source: CSIRO and BoM, 2011)

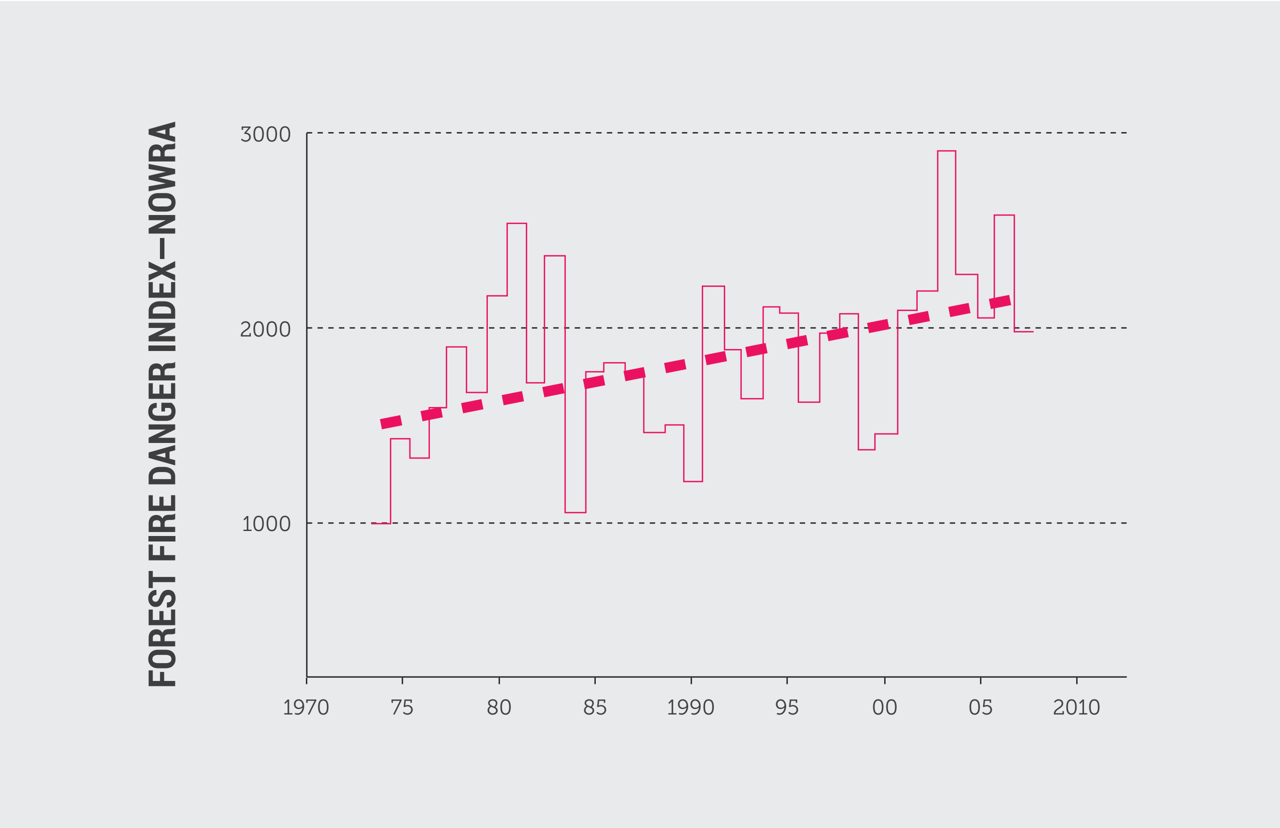


Figure 18: Change in Forest Fire Danger Index (FFDI) at Nowra on the south coast of NSW. (Source: Clarke et al., 2012)

The influence of these weather conditions on the likelihood of bushfire spread is captured in the Forest Fire Danger Index (FFDI) (In Detail 1), an indicator of extreme fire weather. Some regions of Australia, especially in the south and southeast (Victoria, South Australia and New South Wales) have already experienced a significant increase in extreme fire weather since the 1970s, as indicated by changes in the FFDI. The FFDI increased significantly at 16 of 38 weather stations across Australia between 1973 and 2010, with none of the stations recording a significant decrease (Clarke et al., 2013) (Fig. 18). These changes have been most marked in spring, indicating a lengthening fire season across southern Australia, with fire weather extending into October and March. The lengthening fire season means that opportunities for fuel reduction burning are reducing (Matthews et al., 2012) (In Detail 2 Prescribed burning). Overall, these trends mean that fire-prone conditions and vulnerability to fire are increasing, especially in heavily populated areas in the southeast.

IN DETAIL 2

Prescribed burning as a management tool

Prescribed, or hazard reduction, burning has been used in Australia to manage fuels and fire risk since the 1950s (Burrows and McCaw, 2013).

Fires are generally lit in cool weather to reduce the volume of leaf litter and reduce the intensity and rate of spread of subsequent bushfires. With the potential for more severe and frequent bushfires in the future (section 7), pressure is mounting on management agencies to increase the incidence of prescribed burning to reduce fuels. At the same time, the increasing length of fire seasons means that the window of opportunity to perform prescribed burning safely is shrinking.

Many Australians choose to live in close proximity to bushland. Prescribed burning in the urban-bushland interface is a contested issue, with managers faced with the challenge to balance the need to reduce risk to life and property whilst simultaneously conserving biodiversity and environmental amenity, and controlling air pollution near urban areas (Penman et al., 2011; Williams and Bowman, 2012; Adams 2013; Altangerel and Kull, 2013).

Several major fire events over the past decade have resulted in parliamentary, judicial, and coronial enquiries in the states of Victoria (Teague et al., 2010), Western Australia (Keelty, 2011) and Tasmania (TBI, 2013). These enquiries have highlighted community protection as the primary goal of fire management in populated, agricultural, and forested landscapes of southern Australia (Attiwill and Adams, 2011). Following major fire events there are frequent calls to increase prescribed burning (Penman et al., 2011). The Royal Commission into the Black Saturday fires received more submissions on hazard reduction burning than any other topic (Attiwill and Adams, 2011). The commission recommended treating at least 5% of Victorian public land per year (and up to 8%) by prescribed burning (Teague et al., 2010). The "5% solution" is being imported to some other states, even though fire ecologists stress that the frequency and amount of prescribed burning required to reduce risk varies greatly between different landscapes (Penman et al., 2011; Williams and Bowman, 2012). The recent Tasmania Bushfire Inquiry noted that a strategic approach to prescribed burning was "preferable to a quantitative target" (TBI, 2013, Vol 1 p. 223). In NSW, the 2021 Plan aims to increase the number of properties protected by hazard reduction across all bushfire prone areas by 20,000 per year by 2016, which would involve increasing the area treated by 45% on 2011 levels (NSW Government 2011).

A further challenge for fire managers is that the scientific evidence that fuel reduction can improve the safety, efficiency and effectiveness of fire suppression is both limited and contested (Attiwill and Adams, 2011; Penman et al., 2011; Bowman et al., 2013c), being highly variable between different studies and different regions, especially with regard to the impacts of severe bushfires. For example, although fuel reduction burning conducted within the three years prior to the Black Saturday fires reduced the severity of those fires, the reduction was not to →

IN DETAIL 2 PRESCRIBED BURNING AS A MANAGEMENT TOOL

a level that could facilitate suppression under catastrophic weather (Price and Bradstock 2012). Furthermore, most simulation studies also show that weather has a far greater impact than fuel management on the extent of unplanned fire (Cary et al., 2009; Penman et al., 2011).

In southwest Western Australia, the Department of Environment and Conservation protects an estate of approximately 2.5 million hectares. Prescribed fire is applied to treat approximately 6-7% per year. Wildfire costs, losses, and damages have been reduced since the program began (Sneeuwjagt, 2008; Boer et al., 2009; Williams et al., 2011), although 100 houses were lost in a wildfire in 2010/11 and 40 in a prescribed fire in late 2011.

The population of the Sydney region is surrounded by 19,000 km^2 of forests and woodlands (Penman et al., 2011). An average of 4.1% of the landscape was burned by bushfires between 1977 and 2007, with 0.5% treated by prescribed burning (Price and Bradstock, 2011). This program had only a modest effect on fire suppression, and was ineffective for high intensity fires (Price and Bradstock 2010). Five years after the prescribed burn had occurred, fuel had generally re-accumulated to pre-burn levels.

In the Sydney region, at least several hectares of prescribed burning are needed to achieve a one hectare reduction in bushfire size (Bradstock, 2008; Price and Bradstock, 2011). To halve the risk to people and property in this area, prescribed burning of an estimated 7%–10% of the landscape would be needed every year, considerably more than is currently achieved (Bradstock et al., 2012b). Targeting the hazard reduction to areas immediately adjacent to properties is likely to be more effective than treatments further away in the general landscape (Bradstock et al., 2012b; Gibbons et al., 2012). However, in the most severe fires, such as those on Black Saturday in Victoria, a fuel reduction zone of nearly 1 km from houses would have been needed due to the spotting of fires over long distances (Chen and McAneney 2010; Price and Bradstock, 2013).

The prospect of increasing fire risk as the climate warms (section 6) brings the prescribed burning issue into even sharper focus. One analysis indicated that even if warming were relatively modest, the area of prescribed burning in the Sydney region would need to increase two- to three-fold to counteract the increased fire activity; under a higher scenario, prescribed burning would need to increase five-fold (Bradstock et al., 2012b). Considering that in most years and in most states, existing-targets for hazard reduction are frequently not met because the window of opportunity during the year when weather conditions are suitable is often closed (e.g., Attiwill and Adams, 2011), the challenge for our fire management agencies becomes all the more daunting.

Figure 19: The opportunities for fuel reduction burning will decrease as fire seasons lengthen. (Photo: Alex Deura)

5. HAS INCREASED FIRE WEATHER LED TO INCREASED FIRE ACTIVITY?

- Fire activity has increased over the past few decades in many regions of the world, including Africa, Spain, Greece and North America. In many studies, these increases have specifically been attributed to the changing climate.

The previous section outlined the changes in fire danger weather observed over the past few decades in Australia. The next question is if these changes in weather have already had significant impacts on actual fire activity.

5.1 Global trends

Globally, about 350 million hectares are burned each year (Giglio et al., 2013)—an area roughly comparable to that of India (Flannigan et al., 2013).

Bushfires—also referred to as 'forest fires', 'wildfires' or 'brushfires'—are common in many regions of the world, including the vast boreal forests of Canada, Alaska and Siberia; Mediterranean ecosystems (e.g., the Mediterranean region, California, southern Africa); large savanna regions in Africa and parts of South America; and in the dry forests of the western USA. Over 80% of the area burned occurs in savannas and grasslands. Humans are responsible for the majority of ignitions although lightning is another common cause (Flannigan et al., 2013).

Recent analysis of the Global Fire Emissions Database (GFED) shows that in the period 1997 to 2011, the area burned globally decreased (Giglio et al., 2013); it should be noted that this database does not distinguish between areas burned by wildfires and those deliberately lit, for example to clear forests for agriculture. This global decrease masks significant differences in regional fire trends, with some regions experiencing increases and others decreases in fire activity. Increased fire activity in Mediterranean regions such as Portugal (Nunes, 2012) can be attributed to growing human populations, urban drift and land use change (reduced small holder burning and thickening of fields). In other regions, however, such as northeast Spain (Pausas 2004; Pausas and Fernandez-Munoz 2012), Greece (Koutsias et al., 2012), Africa (Hemp, 2005; Kraaij et al., 2013a,b), and parts of North America (Gillett et al., 2004, Westerling et al., 2006; Kasischke et al., 2010; Beck et al., 2011; Mann et al., 2012; Kelly et al., 2013), increased fire intensity and/or extent has been explicitly linked to climate change (Fig. 20). In some regions, not only has the area burned increased, but fire intensity—as measured by the depth of burning in the soil—has also increased, with significant implications for emissions of carbon to the atmosphere (see section 6) (Turetsky et al., 2011). It is also worth noting that the 2010 heatwave in Russia and the central USA was associated with extreme fire activity (Flannigan et al., 2013).

Figure 20: Fire activity has increased over the past few decades in many regions of the world, including Africa, Spain, Greece and North America.

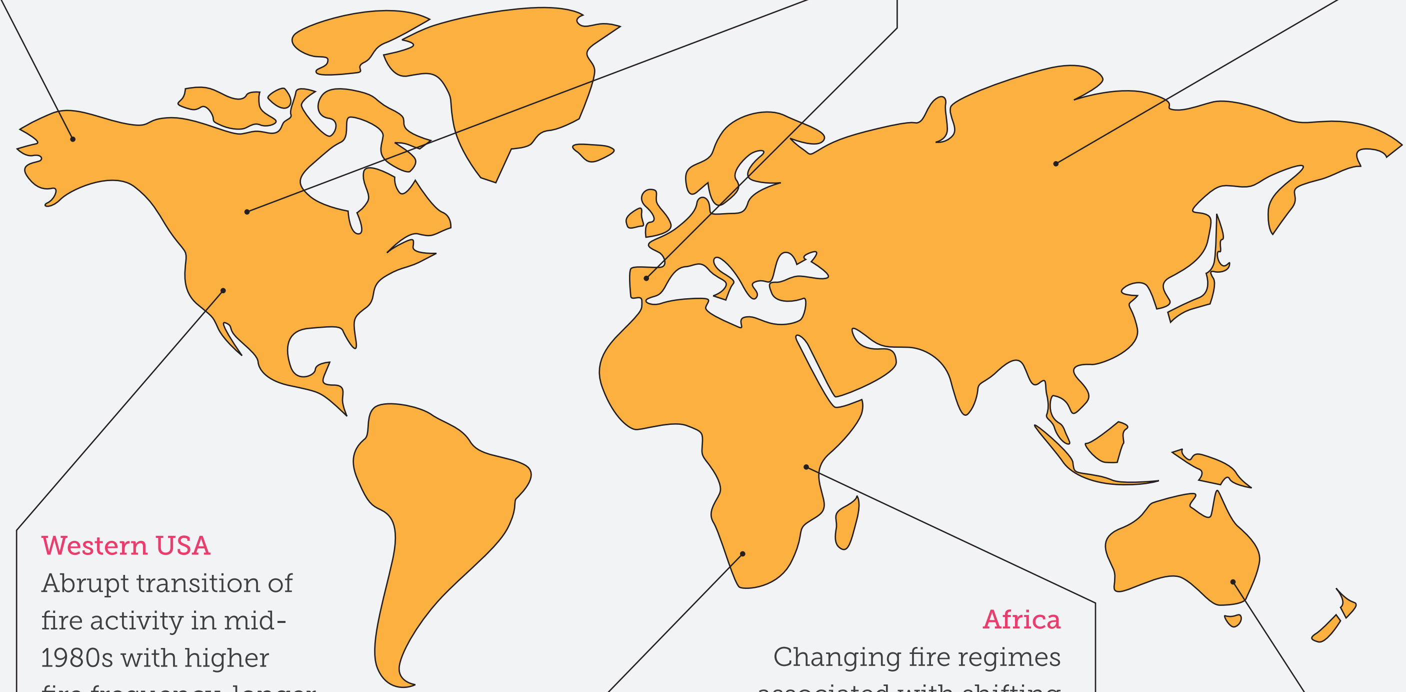
Fire activity has increased

Alaska
Incidence of late-season burning increased 4-fold in 2000–2009, compared to the previous 5 decades (Kasischke et al., 2010)

Canada
Increased area burned over the past four decades, associated with rising summer temperatures (Gillett et al., 2004)

Spain
Shift in fire regimes since 1970s, doubling of fire frequency and increase in area burnt by order of magnitude (Pausas and Fernandez-Munoz 2012)

Russia
2.3 million ha burned (>32,000 fires) associated with the 2010 heatwave (Williams et al., 2011)



Western USA
Abrupt transition of fire activity in mid-1980s with higher fire frequency, longer durations, and longer fire seasons. Fire frequency during 1987-2003 nearly 4 times the average for 1970–1986. Area burned 1987–2003 >6 times that from 1970–1986, length of the fire season increased by ~2 months (Westerling et al., 2006)

Africa
Changing fire regimes associated with shifting vegetation patterns on Mt Kilimanjaro (Hemp 2005)

South Africa
Increased fire activity in South African fynbos shrublands since 1980s, increased forest danger index (FDI) since late 1930s (Kraaij et al., 2013 a,b)

Australia
Increased area burned in 7 of 8 forested bioregions in south east Australia, little to no change in drier arid and woodland bioregions (Bradstock et al., 2013)

5.2 Australian trends

The high level of background variability in fire frequency and extent in Australia means that detecting significant trends in fire activity Australia-wide may not occur for at least many decades, regardless of the significant trends in fire danger weather (Clarke et al., 2011).

Furthermore, few datasets on fire activity spanning multiple decades are available in Australia (Cary et al., 2012), so our ability to measure long-term trends is limited. Analysis of the Global Fire Emissions Database over the period 1995-2011 showed that the amount of area burned in Australia decreased from 2001 to 2010 by about 5.5 million ha per year, but in 2011 there was a major upsurge in burning that exceeded the annual area burned in at least the previous 14 years. This was interpreted as being mainly a response to a previous La Niña event in the arid centre and north (Giglio et al., 2013).

At a regional level, the most comprehensive analysis of fire trends available points to a complex picture. Analysis of a 35-year dataset (1973-2009) for 32 bioregions in southeast Australia shows that for seven of the eight forest regions examined, the area burned has increased significantly (Bradstock et al., 2013). However, in the drier woodland and more arid regions, trends were far more variable, with either declines or no change shown. These results are consistent with predictions that in areas where water availability limits productivity, no trends or even decreases in fire activity might be expected during periods in which long-term drying has been observed.

6. THE IMPACTS OF FIRE ON THE CLIMATE SYSTEM

- Bushfires generate many feedbacks to the climate system, some of which can increase warming, while others decrease it.
- Emission of CO_2 from bushfires generally represents a *redistribution of existing carbon* in the active carbon cycle from vegetation to the atmosphere. As long as the vegetation is allowed to recover after a fire, it can reabsorb a very large fraction of the carbon released.
- By contrast, the burning of fossil fuels represents *additional carbon* inserted into the active land-atmosphere-ocean carbon cycle.
- Fires from deforestation can contribute to rising atmospheric CO_2 if the vegetation is not replaced.

The impacts of fire on the climate system

Bushfires generate many feedbacks to the climate system. Some impacts of fires can amplify the observed global warming trend (known as positive feedbacks), while others can have the opposite effect (negative feedbacks) (Bowman et al., 2009, 2013a).

These feedbacks operate over different time scales. The best-known impact is the production of long-lived carbon dioxide (CO_2) and other more transient greenhouse gases such as methane and nitrous oxide from the combustion of biomass during a fire. Emissions of CO_2 from fires can be very large, contributing as much as 10% of annual carbon emissions (van der Werf et al., 2010). The massive Indonesia fires of 1997 were estimated to have added 0.8–2.7 Petagrams of carbon (Pg C, a petagram is 10^{15} g) to the atmosphere (Page et al., 2002). To put this number in perspective, the carbon emissions from these fires were equivalent to 13%–40% of the mean annual global emissions from the burning of fossil fuels over that period, and contributed to a step increase in atmospheric CO_2 concentration (Page et al., 2002).

While estimates of carbon released by fires such as those in Indonesia can be very large, an important distinction must be made between these emissions and those from fossil fuels. Emission of CO_2 from bushfires generally represents a redistribution of existing carbon in the active carbon cycle from vegetation to the atmosphere. As long as the vegetation is allowed to recover after a fire, it can reabsorb a very large fraction of the carbon released. Indeed, the release and absorption of CO_2 from fire is often assumed to be in balance from landscape fires in flammable vegetation like savannas and eucalypt forests. By contrast, the burning of fossil fuels represents additional carbon inserted into the active land-atmosphere-ocean carbon cycle (Mackey et al., 2013). Fires from deforestation of tropical rainforests and peatlands can, however, also contribute to rising atmospheric CO_2 if the vegetation is not replaced.

Bushfires across Australia typically produce total emissions of CO_2 that are about a hundred times smaller than the largest tropical forest fires. The estimated annual carbon emissions from Australian bushfires for the period 1990–2011 was 26.4 Teragrams of carbon per year (Tg C, a teragram is 10^{12} g) (Haverd et al., 2013), compared to 18.7 Tg C emitted from land use change in Australia and 95.6 Tg C from our fossil fuel combustion. Tropical woodlands and savannas are a consistently high source of gross fire emissions, with desert areas making significant contributions after extremely wet years that enhance vegetation growth and hence accumulated fuel load. The cool temperate regions of the southeast are usually a small source of fire emissions, but can produce very large emissions in a severe bushfire season.

Climate is influenced by fire in ways other than the direct emission of CO_2. Aerosols (small particles) emitted in smoke play a significant, albeit complex and poorly understood, role in the climate system. Some compounds like SO_4 actually cool the climate through scattering incoming solar radiation (Charlson et al., 1992), thus acting in opposition to the emission of CO_2. However, other smoke particles, such as ash and soot (so-called "black carbon") absorb incoming solar radiation and therefore warm the lower atmosphere and the Earth's surface (Ramanathan and Carmichael, 2008). Aerosols from bushfires can also influence the climate through indirect effects, primarily through the role that the aerosols play in modifying clouds, precipitation patterns and atmospheric circulation.

Estimating the net impacts of all these effects has rarely been attempted although one study that integrated the long-term effects of changes in aerosols, greenhouse gas emissions, black carbon and albedo (reflectivity of the earth's surface) in Alaska, suggested that the net effect of wildfires with an 80-year cycle was initially a net warming, but was followed by a net cooling effect in the long term because the increase in surface albedo (due to the switch from dark forest cover to snow cover) had an overall larger impact than the release of greenhouse gases (Randerson et al., 2006).

The overall, long-term impacts of bushfires on the climate system cannot be understood by considering gross emissions from individual fire events, no matter how large they are. Rather, it is necessary to examine long-term changes in fire regimes (see section 5). If the fire regime—intensity, frequency, seasonality—is not changing, then the net emissions through multiple fire cycles (fire followed by regrowth) are approximately zero. That is, uptake of carbon via post-fire regrowth of the vegetation back to the pre-fire ecosystem state compensates for the pulse of carbon emissions from fires (Williams et al., 2012).

As described in section 5, some regions of the world are showing significant changes in fire activity, consistent with a climate change signal. Few studies have quantified the significance of these trends for the global carbon cycle. One exception is a study by Kurz and Apps (1999) that examined long-term data from the Canadian boreal forests. A shift in fire regimes around 1970 towards more frequent, very large fires, along with a similar shift in the frequency and extent of large insect attacks, has changed the carbon balance of these forests from being a carbon sink (a place that absorbs more carbon than it emits) prior to 1970, to being carbon-neutral, and even a source of carbon to the atmosphere in some years in the post-1970 period. This represents a net emission of carbon to the atmosphere, creating a reinforcing feedback to the climate system that enhances the warming trend.

Figure 21: The West Arnhem Land Fire Abatement (WALFA) project is the world's first savanna burning emissions reduction program. Since 2005, it has reduced CO_2 (eq) emissions by an estimated 100,000 tonnes per year. (Photo: Peter Eve, Monsoon Photographic Studio)

There is a great deal of interest in the possibility that fire regimes can be deliberately managed to increase carbon sinks (Bradshaw et al., 2013). Control of wildfires in North America and Europe via the modification of fuel may have the potential to produce a major reduction in emissions (e.g., Wiedinmyer and Hurteau, 2010). However, owing to differences in climate and fuel, and other environmental characteristics, this approach will not necessarily apply to all regions and all vegetation types (Campbell et al., 2011).

In Australia, Bradstock et al. (2012a) found that prescribed burning can potentially reduce carbon emissions from unplanned fires. This study nevertheless concluded that the capacity for this approach to reduce emissions in the southeast eucalypt forests was low. In contrast, the potential for net emission reductions via changes in northern savanna fire management may be considerably greater. The use of traditional indigenous burning techniques in these regions, for example by changing the seasonality of burning, can reduce emissions compared to the current fire regime (Russell-Smith et al., 2013). The world's first savanna burning emissions reduction program, the 23,000 km^2 West Arnhem Land Fire Abatement Project (WALFA), has been operational since 2005, reducing CO_2 (eq) emissions by an estimated 100,000 tonnes per year (Russell Smith et al., 2013) (Fig. 21).

7. FIRE IN THE FUTURE

- In the future, southeast Australia is very likely to experience an increased number of days with extreme fire danger.
- The largest increases in risk are projected in the regions where Australia's worst bushfires have occurred.
- The increasing length of the fire season will reduce the window of opportunity for hazard reduction at the same time that the need for hazard reduction becomes greater.
- The increasing bushfire risk will require additional resources, particularly in terms of increasing numbers of firefighters.

7.1 General and global projections

It is very difficult to project the future behaviour of bushfires themselves, as many non-climate and non-weather factors also influence the nature of the fires and their consequences (Fig. 13).

Perhaps the most important of these non-climate factors is the role of human management and decision-making, such as the resourcing of fire suppression activities, and changes in building codes and land-use planning.

However, as fire is highly sensitive to changes in weather conditions, such as high temperatures, duration of heat events, wind speed, and the condition of vegetation and soils, changes in these factors as the climate continues to shift can be combined to predict potential changes in dangerous fire weather in the future (Clarke et al., 2011) (Fig. 13).

As the climate warms, there is a general expectation that fire activity will increase in many flammable landscapes, with associated increases in severity and a lengthening of the fire season (IPCC, 2012; 2013). But changes in rainfall intensity and seasonality will also be crucial. In regions where vegetation productivity is limited by water availability, increased precipitation could increase fuel loads and lead to higher fire activity. But if these regions become drier, the opposite trend could occur (Moritz et al., 2012; Williams and Bowman, 2012; Bradstock et al., 2013). A further complication is the impact of rising atmospheric CO_2, which can increase plant growth as long as other factors such as water and soil nutrients are not limiting (Hovenden and Williams, 2010) (Fig. 13).

> "These paleoenvironmental records indicate that, all other things being equal, predicted increases in temperature across Australia during the 21st century... will lead to a rapid increase in biomass burning"

Mooney et al., 2012, p18

One technique to explore future fire regimes is to examine the relationship between fire activity and climate in the past. Reconstructions of past fire regimes in Australia have been based on the abundance of charcoal in sediments (e.g. Mooney et al., 2012). These reconstructions show a high degree of variability in fire activity on timescales from annual to multi-millennial. Despite this variation, the charcoal record shows clearly that warm periods were characterised by increased fire activity. The records also show that the response of fire to warmer climate was very rapid, with no discernible lag time between the climatic change and the change in charcoal abundance.

Many studies indicate that fire frequency, extent, and severity will increase significantly in many regions, including North and South America, central Asia, southern Europe, southern Africa and Australia (Flannigan et al., 2009; Spracklen et al., 2009; Liu et al., 2010; Pechony and Shindell, 2010; Westerling et al., 2011b; Moritz et al., 2012; Flannigan et al., 2013; Nitschke and Innes, 2013) due to warming in combination with drying. While different models produce different projections (including decreased fire activity in some regions), the level of disagreement, for both magnitude and direction of change, is reduced considerably in the second half of the century—that is, the models converge on the prediction of greater fire activity (Moritz et al., 2012).

In some regions, substantial increases in fire activity are projected even with relatively modest further warming. For example, a shift in just 0.5°C above the 1961–1990 average distinguishes extreme fire years in the northern Rocky Mountains from most others (Westerling et al., 2011b). The fire frequency in this area could increase from once every 100-300 years at a particular site to less than once every 30 years. Further years without any fire occurring would become increasingly rare (Westerling et al., 2011b). By 2050, temperature increases in the Pacific Northwest and Rocky Mountains regions in the US are projected to increase the area burned by 78% and 157% respectively (Spracklen et al., 2009). In California, increases of over 100% in fire activity are projected for many forested areas (Westerling et al., 2011a). In Alaska and western Canada the average area burned is projected to double by mid-century and increase five-fold by the end of the century (Balshi et al., 2009). In Mediterranean ecosystems, modelling results are mixed, with some areas projected to experience increases and others decreases (Battlori et al., 2013).

> “The bottom line is that we expect more fire in a warmer world” Flannigan et al., 2013

Potential impacts of increasing fire activity on air quality have also been modeled. For example, climate change could increase summertime organic carbon aerosol concentrations by 40% in western USA by 2050, compared to 2000 (Spracklen et al., 2009).

7.2 Projections for Australia

Research aimed at understanding future fire activity in Australia has a long history (Table 2).

While the detailed results of these studies vary due to the use of different global circulation models (GCMs) and different climate scenarios, the ultimate conclusion is clear—weather conditions conducive to fire in the southeast and southwest of the continent will increase.

Future changes in the El Niño-Southern Oscillation (ENSO) phenomenon are also likely to have an influence on fire activity. There is a strong positive relationship between El Niño events and fire weather conditions in southeast and central Australia (Williams and Karoly, 1999; Verdon et al., 2004; Lucas, 2005) and between El Niño events and actual fire activity (Harris et al., 2013).

"The driest regions of the mid-latitudes and the Australian continent are projected to experience consistent and extensive increases in fire probabilities"

Moritz et al., 2012

In northern and more arid regions, relatively little change in fire weather is expected due to climate change (Williams et al., 2009; Bradstock 2010; Clarke et al., 2011, Cary et al., 2012). As outlined in section 2.5, the future course of fires in these systems will be strongly influenced by invasive exotic grasses. However, in the southeast and southwest, it is very likely that an increased incidence of drought—coupled with consecutive hot and dry days—will in turn result in longer fire seasons and an ever larger number of days of extreme fire danger (e.g. Clarke et al., 2011, 2012).

Significant change has occurred in the nature of ENSO since the 1970s, with the phenomena being more active and intense during the 1979-2009 period that at any time in the past 600 years (Aiken et al., 2013). The most recent projections indicate increases in El Niño-driven drying in the western Pacific Ocean by mid- to late 21st century (Power et al., 2013); such a change would increase the incidence of drought, and potentially fire activity, in eastern Australia.

SUMMARY OF POTENTIAL CHANGES IN FIRE RISK

Study	Projections
Beer et al. (1988)	10%–20% increase in FFDI in southeast Australia
Beer and Williams (1995)	Increase in FFDI with doubling of atmospheric CO_2, commonly >10% across most of continent, especially in the southeast, with a few small areas showing decreases
Williams et al. (2001)	General trend towards decreasing frequency of low and moderate fire danger rating days, but an increasing frequency of very high and in some cases extreme fire danger days
Cary and Banks (2000), Cary (2002)	Direct effects of a 3–4°C temperature increase in the ACT would more than double fire frequency, increase average fire intensity by 20%, increase the area burned in autumn, and reduce areas burned in spring
Hennessy (2007)	Potential increase of very high and extreme FFDI days 4%–25% by 2020, 15%–70% by 2050
Lucas et al. (2007)	Increases in annual FFDI of up to 30% by 2050 over historical levels in southeast Australia and up to a trebling in the number of days per year where the uppermost values of the index are exceeded. The largest changes projected to occur in the arid and semi-arid interior of NSW and northern Victoria
Pitman et al. (2007)	Probability of extreme fire risk in 2050 increased by about 20% under both relatively low and relatively high scenarios, and increased dramatically (50%–100%) by 2100 under high scenario along the NSW coast and more than 100% along the QLD coast. In the Perth region, impact projected to be more limited (less than 25% in both 2050 and 2100
Bradstock et al. (2009)	20%–84% increase in potential ignition days for large (> 1000 ha) fires in the Blue Mountains and Central Coast regions by 2050
Hasson et al. (2009)	Analysed likelihood of increase in incidence of synoptic weather pattern in southeast Australia known to be associated with extreme fire events. Projected potential frequency of extreme events to increase from around 1 event every 2 years during the late 20th century to around 1 event per year in the middle of the 21st century, and to around 1 to 2 events per year by the end of the 21st century
Clarke et al. (2011)	FFDI projected to decrease or show little change in the tropical northeast. In the southeast, FFDI projected to increase strongly by end of the 21st century, with the fire season extending in length and starting earlier
Matthews et al. (2012)	Warming and drying climate projected to produce drier, more flammable fuel, and to increase rate of fire spread
Jones et al. (2013)	Projected increases in FFDI for Melbourne area (Fig. 22)
Cai et al. (2013)	Projected increases in positive Indian Ocean Dipole (IOD) events. Positive IOD events are linked to extreme drought and bushfires

Table 2: Summary of projections from modeling studies investigating potential changes in fire risk in Australia.

"Thus, the clearest and largest increases in risk are projected in the regions where Australia's worst bushfires have occurred"

Clarke et al., 2011

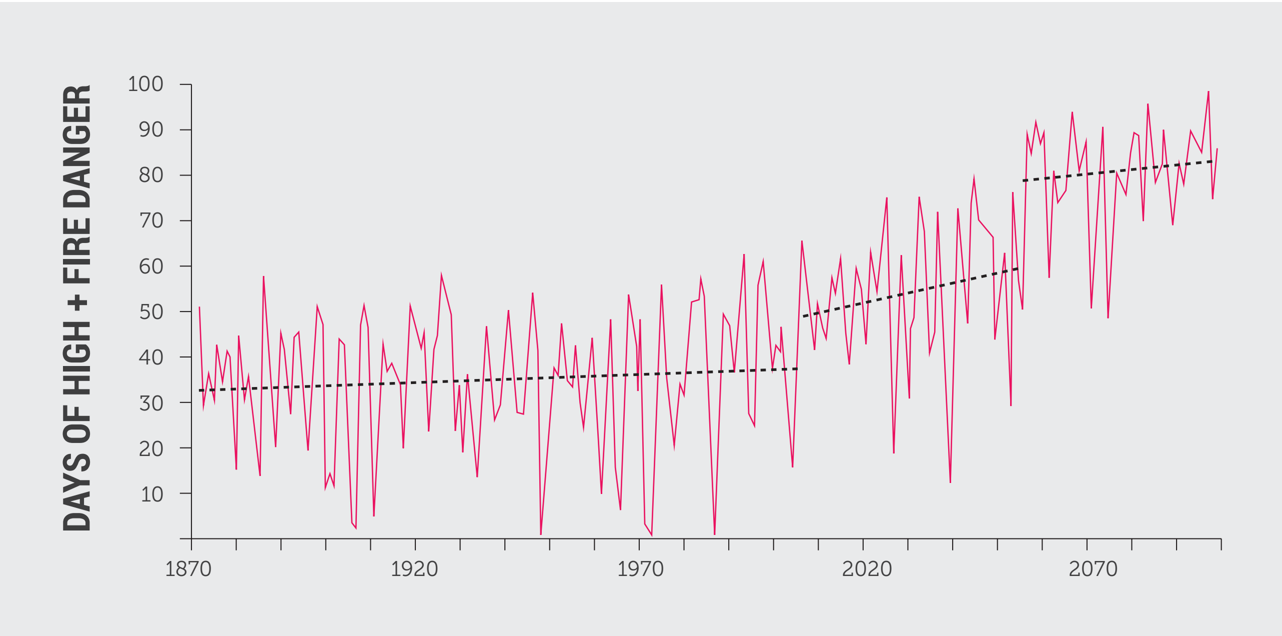


Figure 22: Estimated changes in days of high to catastrophic fire danger (based single model run of annual maximum temperature and total rainfall from a grid square over Melbourne from the CSIRO Mark3.5 A1B model, based on Laverton data). (Source: Jones et al., 2013)

7.3 Implications of increasing fire activity

Australia's population is expected to grow from 22.7 million in 2012 to 37–48 million in 2061, and to 42.4–70.1 million in 2101 (ABS, 2013).

Increasing development at the urban-bushland fringe, along with increasing fire danger weather, present significant and growing challenges.

The economic, social and environmental costs of increasing bushfire activity in Australia are potentially immense. One of the few studies to estimate economic costs of bushfires in the future indicates that with no adaptive change, increased damage to the agricultural industry in Victoria by 2050 could add $1.4 billion (or $46.6 million per year) to the existing costs of $92 million per year (Keating and Handmer, 2013). Similarly, the additional cost of bushfires to the Victorian timber industry is estimated to be $2.85 billion ($96.2 million per year), over and above the present day estimate of $185 million per year.

There is increasing interest in how adaptation to an increasingly bushfire-prone world may reduce vulnerability. Current initiatives centre on planning and regulations, building designs to reduce flammability, burying powerlines in high risk areas and retrofitting electricity systems, fuel management, fire detection and suppression, improved early warning systems, and community education (Handmer and Haynes, 2008; Preston et al., 2009; Buxton et al., 2011; O'Neill and Handmer, 2012, King et al., 2013b).

Australia's premier fire and emergency services agencies have recognised the implications of climate change for bushfire risk and thus fire-fighting resources for some time (AFAC, 2009; 2010). The increasing length of the fire season will reduce the window of opportunity for hazard reduction (In Detail 2) at the same time that the need for hazard reduction becomes greater. Longer fire seasons also have implications for the availability and costs of fire-fighting equipment that is leased from fire fighting agencies in the Northern Hemisphere. As fire seasons in the two hemispheres increasingly overlap, such arrangements may become increasingly impractical (Handmer et al., 2012). Substantially increased resources for fire suppression and control will

"In aggregate, the value of houses being protected has increased at about twice the rate as expenditure on fire services" EB Economics, 2013

"Improving the nation's preparedness for these events remains an important way to reduce risk and impact on people, property and economic stability"

Senate Environment and Communications Committee, 2013, p95

Figure 23: Lengthening bushfire seasons and increasing fire danger weather have serious implications for resourcing emergency management in Australia. (Photo: Dean Sewell)

"Current practices will not sustain [fire agencies] into 2020"

Mr Gary Morgan, CEO Bushfire CRC, Senate Committee Hansard, Senate Inquiry into *Recent trends in and preparedness for extreme weather events.*

be required. Most importantly, a substantial increase in the number of both professional and volunteer firefighters will be needed. To keep pace with asset growth and population, it has been estimated that the number of professional firefighters will need to increase from approximately 11,000 in 2010 to 14,000 by 2020 and 17,000 by 2030 (NIEIR, 2013). When the increased incidence of extreme fire weather under a realistic warming scenario is also taken into account, a further 2000 firefighters will be needed by 2020, and 5000 by 2030 (NIEIR, 2013). Overall, this represents a doubling of professional firefighter numbers needed by 2030, compared to 2010. These estimates are likely to be conservative because they do not account for the potential lengthening of the fire season, in addition to increased fire weather. Further, they do not account for the increased pressures on the professional firefighting services due to declining numbers of volunteer firefighters (NIEIR, 2013).

8. THIS IS THE CRITICAL DECADE

This is the Critical Decade

The impacts of climate change are already being observed.

Sea levels are rising, oceans are becoming more acidic, and heatwaves have become longer and hotter. Heavy rainfall events are increasing, while the southeast and southwest corners of Australia have become drier. As detailed earlier in this report, increasing fire activity in several regions of the world has been attributed to the influence of climate change, and high fire danger weather is increasing in southeast Australia. We are now more confident than ever that the emission of greenhouse gases by human activities, mainly carbon dioxide from the combustion of fossil fuels, is the primary cause for the changes in climate over the past half-century (IPCC 2013).

Projections of future climate change and its impacts have convinced nations that the global average temperature, now at 0.8°C above the pre-industrial level, must not be allowed to rise beyond 2°C above pre-industrial—the so-called '2°C guardrail'. Societies will have to adapt to even more serious impacts as the temperature rises towards the 2°C guardrail, and for southeast Australia, that means increased fire danger weather and longer bushfire seasons. Ensuring that this guardrail is not exceeded will prevent even worse impacts from occurring, including the crossing of tipping points that could drive the warming trend beyond human control.

"Increasing fire activity in several regions of the world has been attributed to the influence of climate change"

To have only a two out of three (66%) chance of staying within the 2°C guardrail, we can emit no more than about 1,000 billion tonnes of CO_2 from 2012 until global emissions must be reduced to zero (IPCC 2013). Unfortunately, the rate at which we are spending this 'carbon budget' is still growing rather than slowing down. For example, from 2003 to 2012, global CO_2 emissions from fossil fuel combustion and cement production rose by 2.7% per year (Global Carbon Project, 2013), and the trend over the past decade is consistent with the IPCC's highest emission scenario.

There are some promising signs that the first steps are being taken towards decarbonising the global economy. Renewable energy technologies are being installed at increasing rates in many nations. The world's largest emitters—China and the USA—are beginning to take meaningful action to limit and reduce emissions. In these countries, the rate of increase in fossil fuel emissions for 2012 and that projected for 2013 are lower than the 2003-2012 average. However, in absolute terms, emissions continue to rise. The rapid consumption of the carbon budget, not to mention the discovery of many new fossil fuel reserves, highlights the enormity of the task. Much more needs to be done to reduce emissions… and quickly.

The evidence is clear and compelling. The trend of increasing global emissions must be slowed and halted in the next few years and emissions must be trending downwards by 2020 at the latest if the 2°C guardrail is to be observed. Investments in and installations of renewable energy must therefore increase rapidly. And, critically, most of the known fossil fuel reserves must remain in the ground.

Australia must strive to cut its emissions rapidly and deeply to join global efforts to stabilise the world's climate and to reduce the risk of even more extreme events, including bushfires.

This is the critical decade to get on with the job.

"Australia must strive to cut its emissions rapidly and deeply to join global efforts to stabilise the world's climate"

References

ABS (Australian Bureau of Statistics) (2001) 1301.0 Year Book Australia 2001. Accessed 25.10.13 at http://www.abs.gov.au/AUSSTATS/abs@.nsf/Previousproducts/1301.0Feature%20Article32001

ABS (Australian Bureau of Statistics) (2004) 1301.0 Year Book Australia 2004. Accessed 25.10.13 at http://www.abs.gov.au/AUSSTATS/abs@.nsf/Previousproducts/CCB3F2E90BA779D3CA256DEA00053977

ABS (Australian Bureau of Statistics) (2013) *Population Projections Australia,* 2012 (base) to 2101. Accessed 27.11.13 at http://www.abs.gov.au/ausstats/abs@.nsfLookup/3222.0main+features52012%20(base)%20to%202101

AFAC (2009) *Climate Change and the Fire and Emergency Services Sector.* Position paper prepared for the Australasian Fire and Emergency Service Authorities Council, accessed 10.11.13 at http://www.afac.com.au/positions/Climate_Change_and_the_Fire_and_Emergency_Services_Sector

AFAC (Australasian Fire and Emergency Services Council) (2010) *Climate Change and the Fire and Emergency Services Sector.* Discussion paper prepared for the Australasian Fire and Emergency Service Authorities Council. Accessed 10.11.13 at http://www.afac.com.au/positions/Climate_Change_and_the_Fire_and_Emergency_Services_Sector

AIC (Australian Institute of Criminology) (2004) Cost of Bushfires. *Bushfire arson bulletin no. 2.* ISSN 1832-2743. Canberra, November 2004.

AIC (Australian Institute of Criminology) (2009) Cost of Bushfires. *Bushfire arson bulletin no. 60.* ISSN 1832-2743 Canberra, December 2009 http://www.aic.gov.au/publications/current%20series/bfab/41-60/bfab060.html

Adams, M (2013) Mega-fires, tipping points and ecosystem services: managing forests and woodlands in an uncertain future. *Forest Ecology and Management* 294: 250-261.

Aiken CM, Santoso A, McGregor S, England MH (2013) The 1970's shift in ENSO dynamics: A linear inverse model perspective. *Geophysical Research Letters* 40: 1612-1617.

Altangerel K, Kull CA (2013) The prescribed burning debate in Australia: conflicts and compatibilities. *Journal of Environmental Planning and Management* 56:103-120.

ASIC (2005) Getting Home Insurance Right: A Report on Home Building Underinsurance. Australian Securities and Investment Commission, Gippsland, Victoria.

Attiwill PM, Adams MA (2011) Mega-fires, inquiries and politics in the eucalypt forests of Victoria, south-eastern Australia. *Forest Ecology and Management* 294: 45-53

Balshi MS, McGuire AD, Duffy P, Flannigan M, Walsh J, Melillo J (2009) Assessing the response of area burned to changing climate in western boreal North America using a Multivariate Adaptive Regression Splines (MARS) approach. *Global Change Biology* 15: 578-600.

Batllori B, Parisien M-A, Krawchuk MA, Moritz MA (2013) Climate change-induced shifts in fire for Mediterranean ecosystems. *Global Ecology and Biogeography* 22: 1118-1129

Beck PSA, Goetz SJ, Mack MC, Alexander HD, Jin Y, Randerson JT, Loranty MM (2011) The impacts and implications of an intensifying fire regime on Alaskan boreal forest composition and albedo. *Global Change Biology* 17: 2853-2866.

Beer T, Gill AM, Moore RHR (1988) Australian bushfire danger under changing climatic regimes. In Pearman GI (ed.), *Greenhouse: Planning for Climatic Change,* CSIRO, pp. 421-427.

Beer T, Williams A (1995) Estimating Australian forest fire danger under conditions of doubled carbon dioxide concentrations. *Climatic Change* 29: 169-188.

Bernstein AS, Rice MB. (2013) Lungs in a warming world: climate change and respiratory health. *CHEST Journal* 143:1455-59.

Boer MM, Sadler RJ, Wittkuhn R, McCaw L, Grierson PF (2009) Long term impacts of prescribed burning on regional extent and incidence of wildfires—evidence from 50 years of active fire management in SW Australian forests. *Forest Ecology and Management 259*: 132-142.

Bureau of Meteorology (2009) Bushfire Weather. Accessed 29.11.13 at http://www.bom.gov.au/weather-services/bushfire/about-bushfire-weather.shtml

Bowman DMJS, Balch JK, Artaxo P, Bond WJ, Carlson JM, Cochrane MA, D'Antonio CM, DeFries RS, Doyle JC, Harrison SP, Johnston FH, Keeley JE, Krawchuk MA, Kull CA, Marston JB, Moritz MA, Prentice IC, Roos CI, Scott AC, TW Swetnam, van der Werf GR, Pyne SJ (2009) Fire in the Earth system. *Science* 324: 481–484.

Bowman DMJS, Murphy BP, Boer MM, Bradstock RA, Cary GJ, Cochrane MA, Fensham RJ, Krawchuk MA, Price OF, Williams RJ (2013a) Forest fire management, climate change, and the risk of catastrophic carbon losses. *Frontiers in Ecology and the Environment* 11: 66-68.

Bowman DMJS, Murphy BP, Burrows GE, Crisp MD (2012) Fire regimes and the ecvolution of the Austrlaian biota. In *Flammable Australia: Fire regimes, biodiversity and ecosystems in a changing world.* Bradstock RA, Gill AM, Williams RJ (eds), CSIRO Publishing, Collingwood, VIC, pp 27-48

Bowman DMJS, Murphy BP, Neyland DLJ, Williamson GJ, Prior LD (2013b) Abrupt fire regime change may cause landscape-wide loss of mature obligate seeder forests. *Global Change Biology* DOI: 10.1111/gcb.12433

Bowman DMJS, O'Brien J, Goldammer J (2013c) Pyrogeography and the global quest for sustainable fire management. *Annual Review of Environment and Resources* 38: 57-80.

Bradshaw CJA, Bowman DMJS, Bond NR, Murphy BP, Moore AD, Fordham DA, Thackway R, Lawes MJ, McCallum H, Gregory SD, Dalal RC, Boer MM, Lynch AJJ, Bradstock RA, Brook BW, Henry BK, Hunt LP, Fisher DO, Hunter D, Johnson CN, Keith DA, Lefroy EC, Penman TD, Meyer W, Thomson JR, Thornton CM, Van Der Wal J, Williams D, Keniger L, Specht A (2013) Brave new green world—consequences of a carbon economy for the conservation of Australian biodiversity. *Biological Conservation* 161: 71-90.

Bradstock RA (2008) Effects of large fires on biodiversity in south-eastern Australia: disaster or template for diversity? *International Journal of Wildland Fire* 17:809-822.

Bradstock RA (2010) A biogeographic model of fire regimes in Australia: current and future implications. *Global Ecology and Biogeography* 19: 145-158.

Bradstock RA, Boer MM, Cary GJ, Price OF, Williams RJ, Barrett D et al. (2012a) Modelling the potential for prescribed burning to mitigate carbon emissions from wildfires in fire-prone forests of Australia. *International Journal of Wildland Fire* 21:629-639.

Bradstock RA, Cary GJ, Davies I, Lindenmayer DB, Price OF, Williams RJ (2012b) Wildfires, fuel ignition and risk mitigation in Australian eucalypt forests: insights from landscape-scale simulation. *Journal of Environmental Management* 105:66-75.

Bradstock RA, Cohn JS, Gill AM, Bedward M, Lucas C (2009) Prediction of the probability of large fires in the Sydney region of south-eastern Australia using fire weather. *International Journal of Wildland Fire* 18: 932-943.

Bradstock RA, Gill AM (2001) Living with fire and biodiversity at the urban edge: in search of a sustainable solution to the human protection problem in southern Australia. *Journal of Mediterranean Ecology* 2:179–195.

Bradstock RA, Penman T, Boer M, Price O, Clarke H (2013) Divergent responses of fire to recent warming and drying across south-eastern Australia. *Global Change Biology* doi: 10.1111/gcb.12449

Brookhouse MT, Farquar GD, Roderick ML (2013) The impact of bushfires on water yield from south-east Australia's ash forests. *Water Resources Research* 49: 4493-4505.

Buckley TN, Turnbull TL, Pfautsch S, Gharun M, Adams MA (2012) Differences in water use between mature and post-fire regrowth stands of subalpine *Eucalyptus delegatensis* R. Baker. *Forest Ecology and Management* 270: 1-10.

Burrows N, McCaw L (2013) Prescribed burning in southwestern Australian forests. *Frontiers in Ecology and Environment* 11: e25-e34.

Bushfire CRC (2013) Southern Australia seasonal bushfire outlook 2013-14. *Fire Note Issue 116.* September 2013.

Buxton M, Haynes R, Mercer D, Butt A (2011) Vulnerability to bushfire risk at Melbourne's urban fringe: The failure of regulatory land use planning. *Geographical Research* 49: 1-12.

Cai W, Zheng X-T, Weller E, Collins M, Cowan T, Lengaigne M, Yu W, Yamagata T (2013) Projected response of the Indian Ocean Dipole to greenhouse warming. *Nature Geoscience* 6: 999-1007.

Cameron PA, Mitra B, Fitzgerald M, Scheinkestel CD, Stripp A, Batey C, Niggemeyer L, Truesdale M, Holman P, Mehra R, Wasiak J, Cleland H (2009) Black Saturday: the immediate impact of the February 2009 bushfires in Victoria, Australia. *Medical Journal of Australia* 191: 11-16.

Campbell LJ, Harmon ME, Mitchell SR (2011) Can fuel-reduction treatments really increase forest carbon storage in the western US by reducing future fire emissions? *Frontiers in Ecology and Environment* doi:10.1890/110057.

Cary GJ (2002) Importance of a changing climate for fire regimes in Australia. In *Flammable Australia: The Fire Regimes and Biodiversity of a Continent,* Bradstock RA, Gill AM and Williams JE (eds), Cambridge University Press, Cambridge, pp 26-46.

Cary GJ, Banks JCG (2000) Fire regime sensitivity to global climate change: an Australian perspective. In *Advances in Global Change Research,* Innes JL, Verstraete MM, Beniston M (eds), Kluwer Academic Publishers, Dordrecht and Boston.

Cary GJ, Bradstock RA, Gill AM, Williams RJ (2012) Global change and fire regimes in Australia pp149-170 in *Flammable Australia: Fire regimes, biodiversity and ecosystems in a changing world.* (Eds Bradstock RA, Gill AM, Williams RJ). CSIRO Publishing, Collingwood, VIC

Cary GJ, Flannigan MD, Keane RE, Bradstock RA, Davies ID, Lenihan JM et al. (2009) Relative importance of fuel management, ignition management and weather for area burned: evidence from five landscape-level succession models. *International Journal of Wildland Fire* 18: 147-156.

Charlson RJ, Schwartz SE, Hales JM, Cess RD, Coakley Jr JA, Hansen JE, Hoffman DJ (1992) Climate forcing by anthropogenic sulfate aerosols. *Science* 255: 423–430.

Chen K, McAneney J (2010) Bushfire Penetration into Urban Areas in Australia: A Spatial Analysis. *Report for the Bushfire CRC* Accessed 18.11.13 at http://www.bushfirecrc.com/managed/resource/bushfire_penetration_into_urban_areas_in_australia_crc-304-001-0001.pdf

Chen L, Verrall K, Tong S (2006) Air particulate pollution due to bushfires and respiratory hospital admissions in Brisbane, Australia. *International Journal of Environmental Health Research* 16:181-191.

Clarke H, Smith PL, Pitman, AJ (2011) Regional signatures of future fire weather over eastern Australia from global climate models. *International Journal of Wildland Fire* 20: 550-562.

Clarke H, Lucas C, Smith P (2013) Changes in Australian fire weather between 1973 and 2010. *International Journal of Climatology* 33: 931-944.

Climate Commission (2013) The Critical Decade: Extreme Weather. http://pandora.nla.gov.au/pan/136923/20130919-1415/climatecommission.gov.au/report/extreme-weather/index.html

CFA (Country Fire Authority) (2009) New warning system explained. Accessed 23.10.13 at http://www.cfaconnect.net.au/index.php?option=com_k2&view=item&id=873

(CFA) (Country Fire Authority) (2012). Major fires. Accessed 19.11.13 at http://www.cfa.vic.gov.au/about/major-fires/

Crisp MD, Burrows GE, Cook LG, Thornhill AH, Bowman DMJS (2011) Flammable biomes dominated by eucalypts originated at the Cretaceous-Palaeogene boundary. *Nature Communications* 2: 1-8.

Crompton RP (2011) Normalising the Insurance Council of Australia Natural Disaster Event List: 1967-2011. *Report prepared for the Insurance Council of Australia,* Risk Frontiers. http://www.insurancecouncil.com.au/assets/files/normalising%20the%20insurance%20council%20of%20australia%20natural%20disaster%20event%20list.pdf

Crompton RP, McAneney KJ, Chen K, Pielke Jr RA, Haynes K (2010) Influence of location, population, and climate on building damage and fatalities due to Australian bushfire: 1925-2009. *Weather, Climate, and Society* 2: 300-310.

Crompton RP, McAneney KJ, Chen K, Pielke Jr RA, Haynes K (2011) Reply to 'Comments on Influence of location, population, and climate on building damage and fatalities due to Australian bushfire: 1925-2009'. *Weather, Climate, and Society* 3: 63-66.

CSIRO and BoM (2011) State of the climate 2010. Accessed 17.11.13 at http://www.csiro.au/en/Outcomes/Climate/Understanding/State-of-the-Climate-2010/ Temperature.aspx

CSIRO and BoM (2012) State of the Climate 2012. Accessed 17.11.13 at http://www.csiro.au/Outcomes/Climate/Understanding/~/media/8E59FBA4F8A94FE4B84F01E271226316.pdf

Dennekamp M, Abramson MJ (2011) The effects of bushfire smoke on respiratory health. *Respirology* 16: 198-209.

Dennekamp M, Erbas B, Sim M, Glass D, Keywood M, Abramson M, et al. (2011) Air pollution from bushfires and out of hospital cardiac arrests in Melbourne Australia. *Epidemiology* 22: S53

EB Economics (2013) The economic cost of fire. *Report for the United Firefighters Union of Australia.* Submission to the Senate Inquiry into *Recent trends in and preparedness for extreme weather events*. Accessed 17.11.13 at https://senate.aph.gov.au/submissions/comittees/viewdocument.aspx?id=e932d3b1-599f-4df0-b9c7-ef0b8e32364f

Feikema PM, Sherwin CB, Lane PNJ (2013) Influence of climate, fire severity and forest mortality on predictions of long term streamflow: potential effect of the 2009 wildfire on Melbourne's water supply catchments. *Journal of Hydrology* 488: 1-16.

Flannigan M, Cantin AS, de Groot WJ, Wotton M, Newbery A, Gowman LM (2013) Global wildland fire season severity in the 21st century. *Forest Ecology and Management* 294:54-61.

Flannigan MD, Krawchuk MA, de Groot WJ, Wotton M, Gowman LM (2009) Implications of changing climate for global wildland fire. *International Journal of Wildland Fire* 18: 483-507.

Gibbons P, van Bommel1 L, Gill AM, Cary GJ, Driscoll DA, Bradstock RA, Knight E, Moritz MA, Stephens SL, Lindenmayer DB (2012) Land Management Practices Associated with House Loss in Wildfires. *PLOS One* 7: e29212.

Giglio L, Randerson JT, van der Werf GR (2013) Analysis of daily, monthly, and annual burned area using the fourth generation global fire emissions database (GFED4). *Journal of Geophysical Research-Biogeosciences* 118: 317-328.

Gill AM (1975) Fire and the Australian flora: a review. *Australian Forestry* 38: 4-25.

Gill AM, Bradstock RA, Williams JE (2002) Fire regimes and biodiversity: a legacy and vision. In *Flammable Australia: the Fire Regimes and Biodiversity of a Continent.* Bradstock RA, Williams JE, Gill AM (eds), Cambridge University Press, Cambridge, pp. 429–446.

Gillett NP, Weaver AJ, Zwiers FW, Flannigan MD (2004) Detecting the effect of climate change on Canadian forest fires. *Geophysical Research Letters* 31: L18211.

Global Carbon Project (2013) *Carbon budget* 2013. Accessed 21.11.13 at http://www.globalcarbonproject.org/carbonbudget/

Handmer J, Haynes K (2008) Interface (urban-rural fringe) bushfire community safety. In: *Community Bushfire Safety,* CSIRO, Collingwood, pp. 3-7.

Handmer J, McKellar R, McLennan B, Whittaker J, Towers B, Duggie J, Woolf M, (2012) *National Climate Change Adaptation Research Plan: Emergency Management—Revised 2012 Edition,* National Climate Change Adaptation Research Facility, Gold Coast, 60pp.

Harris, S, Tapper, N, Packham D, Orlove B, Nicholls, N (2008) The relationship between monsoonal summer rain and dry-season fire activity of northern Australia International. *Journal of Wildland Fire* 17: 674-684.

Harris S, Nicholls N, Tapper N (2013) Forecasting fire activity in Victoria, Australia, using antecedent climate variables and ENSO indices. *International Journal of Wildland Fire* http://dx.doi.org/10.1071/WF13024

Hasson AEA, Mills GA, Timbal B, Walsh K (2009) Assessing the impact of climate change on extreme fire weather event over southeastern Australia. *Climate Research* 39: 159-172.

Haverd V, Raupach MR, Briggs PR, Canadell JG, Davis SJ, Law RM et al. (2013) The Australian terrestrial carbon budget. *Biogeosciences* 10: 851-869.

Haynes K, Handmer J, McAneney J, Tibbits A, Coates L (2010) Australian bushfire fatalities 1900–2008: exploring trends in relation to the 'Prepare, stay and defend or leave early' policy. *Environmental Science and Policy* 13:185-194.

Hemp A (2005) Climate change-driven forest fires marginalise the impact of ice cap wasting on Kilimanjaro. *Global Change Biology* 11: 1013-1023.

Henderson SB, Johnston FH (2012) Measures of forest fire smoke exposure and their associations with respiratory health outcomes. *Current Opinion in Allergy and Clinical Immunology* 12: 221-227.

Hennessy KJ (2007) Fire weather. In *Climate change in Australia: technical report 2007,* Pearce KB, Holper PN, Hopkins M, Bouma WJ, Whetton PH, Hennessy KJ, Power SB (eds), CSIRO Marine and Atmospheric Research, Aspendale, Victoria, pp 90-91.

Hoffmann WA, Bazzaz FA, Chatterton NJ, Harrison PA, Jackson RB (2000) Elevated CO_2 enhances resprouting of a tropical savanna tree. *Oecologia* 123: 312-317.

Hovenden MJ, Williams AL (2010) The impacts of rising CO_2 concentrations on Australian terrestrial species and ecosystems. *Austral Ecology* 35: 665-684.

ICA (Insurance Council of Australia) (2013) Historical Disaster Statistics. Accessed 28.10.13 at http://www.insurancecouncil.com.au/industry-statistics-data/disaster-statistics/historical-disaster-statistics

IPCC (Intergovernmental Panel on Climate Change) (2007) *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt K.B, Tignor M, Miller HL (eds), Cambridge University Press, Cambridge, United Kingdom and New York.

IPCC (Intergovernmental Panel on Climate Change) (2012) *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation.* A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner G-K, Allen SK, Tignor M, Midgley PM (eds), Cambridge University Press, Cambridge and New York, 582 pp.

IPCC (2013) *Climate Change 2013: The Physical Science Basis.* Working Group I Contribution to the IPCC 5th Assessment Report—Changes to the underlying Scientific/Technical Assessment. http://www.ipcc.ch/report/ar5/wg1/

Jayaratne R, Kuleshov E (2006) The relationship between lightning activity and surface wet bulb temperature and its variation with latitude in Australia. *Meteorology and Atmospheric Physics* 91:17-24.

Johnston FH (2009) Bushfires and human health in a changing environment. *Australian Family Physician* 38: 720–725.

Johnston FH, Bailie RS, Pilotto LS, Hanigan IC (2007) Ambient biomass smoke and cardio-respiratory hospital admissions in Darwin, Australia. *BMC Public Health* 7:240.

Johnston FH, Hanigan IC, Henderson SB, Morgan GG, Bowman DMJS (2011) Extreme air pollution events from bushfires and dust storms and their association with mortality in Sydney, Australia 1994-2007. *Environmental Research* 111: 811-16.

Johnston FH, Henderson SB, Chen Y, Randerson JT, Marlier M, DeFries RS, Kinney P, Bowman DMJS, Brauer M (2012) Estimated global mortality attributable to smoke from landscape fires. *Environmental Health Perspectives* 120:695-701.

Johnston FH, Webby RJ, Pilotto L, Bailie R, Parry D, Halpin S (2006) Vegetation fires, particulate air pollution and asthma: a panel study in the Australian monsoon tropics. *International Journal of Environmental Health Research* 16: 391-404.

Jones RN, Young CK, Handmer J, Keating A, Mekala, GD, Sheehan P (2013) *Valuing adaptation under rapid change.* National Climate Change Adaptation Research Facility, Gold Coast, 184 pp.

Karoly D (2009) The recent bushfires and extreme heat wave in southeast Australia. *Bulletin of the Australian Meteorological and Oceanographic Society* 22: 10-13.

Kasischke ES, Verbyla DL, Rupp TS, McGuire AD, Murphy KA, Jandt R, et al. (2010) Alaska's changing fire regime: implications for the vulnerability of boreal forests. *Canadian Journal of Forest Research* 40: 1360-1370.

Keating A, Handmer J (2013) Future potential losses from extremes under climate change: the case of Victoria, Australia. *VCCCAR Project: Framing Adaptation in the Victorian Context, Working Paper,* Victorian Centre for Climate Change Adaptation Research, Melbourne.

Keelty M (2011) *A shared responsibility: the report of the Perth Hills bushfire February 2011 review.* A report for the Western Australian Government. Accessed 21.11.13 at http://www.publicsector.wa.gov.au/sites/default/files/documents/inquiry_-_perth_hills_bushfire_2011_-_a_shared_responsibility_report.pdf

Kelly R, Chipman ML, Higuera PE, Stefanova I, Brubaker LB, Hu, FS (2013) Recent burning of boreal forests exceeds fire regime limits of the past 10,000 years. *Proceedings of the National Academy of Sciences* 110: 13055-13060.

King KJ, Cary GJ, Bradstock RA, Marsden-Smedley JB (2013a) Contrasting fire responses to climate and management: insights from two Australian ecosystems. *Global Change Biology* 19: 1223-1235.

King D, Ginger J, Williams S, Cottrell A, Gurtner Y, Leitch C et al. (2013b) *Planning, building and insuring: Adaptation of built environment to climate change induced increased intensity of natural hazards.* National Climate Change Adaptation Research Facility, Gold Coast, 361 pp.

Koutsias N, Arianoutsou M, Kallimanis, A Athanasios S, Mallinis G, Halley JM, Dimopoulos P (2012) Where did the fires burn in Peloponnisos, Greece the summer of 2007? Evidence for a synergy of fuel and weather. *Agricultural and Forest Meteorology* 156: 41-53.

Kraaij T, Baard JA, Cowling RM, van Wilgen BW (2013a) Historical fire regimes in a poorly understood, fire-prone ecosystem: eastern coastal fynbos. *International Journal of Wildland Fire* 3: 277-287.

Kraaij T, Cowling RM, van Wilgen BW (2013b) Lightning and fire weather in eastern coastal fynbos shrublands: seasonality and long-term trends. *International Journal of Wildland Fire* 22: 288–295.

Kuczera GA (1985) Prediction of water yield reduction following a bushfire in Ash-mixed species eucalypt forest. *Water Supply Catchment Hydrology Research Report* MMBW-W-0014, Melbourne and Metropolitan Board of Works, Melbourne.

Kurz WA, Apps MJ (1999) A 70-year retrospective analysis of carbon fluxes in the Canadian forest sector. *Ecological Applications* 9: 526-547.

Langford KJ (1976) Change in yield of water following a bushfire in a forest of Eucalyptus regnans. *Journal of Hydrology* 29:87-114.

Lindenmayer DB, Hobbs RJ, Likens GE, Krebs CJ, Banks SC (2011) Newly discovered landscape traps produce regime shifts in wet forests. *Proceedings of the National Academy of Sciences* 108: 15887-15891.

Little JK, Prior LD, Williamson GJ, Williams SE, Bowman DMJS (2012) Fire weather risk differs across rain forest—savanna boundaries in the humid tropics of northeastern Australia. *Austral Ecology* 37: 915–925.

Liu Y, Stanturf J, Goodrick S (2010) Trends in global wildfire potential in a changing climate. *Forest Ecology and Management* 259: 686–697.

Lucas C (2005) *Fire weather history of south-east Australia.* (Bushfire CRC) Accessed 29.10.13 at http://www.bushfirecrc.com/managed/resource/fireweatherhistory.pdf

Lucas C, Hennessy K, Mills G, Bathols J (2007). *Bushfire weather in southeast Australia: recent trends and projected climate change impacts.* Bushfire CRC and Australian Bureau of Meteorology. September 2007, Consultancy Report prepared for The Climate Institute of Australia.

Luke RH, McArthur AG (1978) *Bushfires in Australia.* Australian Government Publishing Service, Canberra.

Mackey B, Prentice IC, Steffen W, Lindenmayer D, Keith H, Berry S, House J (2013) Untangling the confusion around land carbon science and climate change mitigation policy. *Nature Climate Change* 3: 552-557.

McAneney J (2013) Climate change and bushfires: you're missing the point! Accessed 18th November 2013 from http://theconversation.com/climate-change-and-bushfires-youre-missing-the-point-19649

McAneney J, Chen K, Pitman A (2009) 100-years of Australian bushfire property losses: Is the risk significant and is it increasing? *Journal of Environmental Management* 90: 2819-2822.

McFarlane AC (1988) The longitudinal course of post-traumatic morbidity: the range of outcomes and their predictors. J*ournal of Nervous and Mental Diseases* 176: 30–9.

McFarlane AC, Clayer JR, Bookless CL (1997) Psychiatric morbidity following a natural disaster: an Australian bushfire. *Society of Psychiatry and Psychiatric Epidemiology* 32: 261-268.

McFarlane AC, Raphael B (1984) Ash Wednesday: the effect of a fire. Australian and New Zealand *Journal of Psychiatry* 18: 341–51.

McLeod R (2003) Inquiry into the Operational Response to the January 2003 Bushfires in the ACT. Canberra, ACT Government.

Martin KL, Hanigan IC, Morgan GG, Henderson SB, Johnston FH (2013) Air pollution from bushfires and their association with hospital admissions in Sydney, Newcastle and Wollongong, Australia 1994–2007. *Australian and New Zealand Journal of Public Health* 37: 238-243.

Mann DH, Rupp TS, Olson MA, Duffy PA (2012) Is Alaska's boreal forest now crossing a major ecological threshold? *Arctic, Antarctic and Alpine Research* 44: 319-331.

Matthews S, Sullivan AL, Watson P, Williams RJ (2013) Climate change, fuel and fire behaviour in a eucalypt forest. *Global Change Biology* 18: 3212-3223.

Mooney SD, Harrison SP, Bartlein PJ, Stevenson J (2012) The prehistory of fire in Australasia. In *Flammable Australia: Fire regimes, biodiversity and ecosystems in a changing world.* Bradstock RA, Gill AM, Williams RJ (eds), CSIRO Publishing, Collingwood, Victoria, pp 3-26.

Morgan G, Sheppeard V, Khalaj B, Ayyar A, Lincoln D, Jalaludin B et al. (2010) The effects of bushfire smoke on daily mortality and hospital admissions in Sydney, Australia, 1994 to 2002. *Epidemiology* 21: 47-55.

Moritz MA, Parisien M-A, Batllori E, Krawchuk MA, van Dorn J, Ganz DJ, Hayhoe K (2012) Climate change and disruptions to global fire activity. Ecosphere 3: Article 49 http://dx.doi.org/10.1890/ES11-00345.1

Murphy BP, Bradstock RA, Boer MM, Carter J, Cary GJ, Cochrane MA, Fensham RJ, Russell-Smith J, Williamson GJ, Bowman DMJS (2013) Fire regimes of Australia: a pyrogeographic model system. *Journal of Biogeography* 40: 1048-1058.

Nicholls N (2011) Comments on influence of location, population, and climate on building damage and fatalities due to Australian bushfire: 1925-2009. *Weather, Climate, and Society* 3: 61-62.

NIEIR (2013) *Firefighters and climate change: The human resources dimension of adapting to climate change.* Final and consolidated report prepared by the National Institute of Economic and Industry Research for the United Firefighters Union of Australia. Submission to the Senate Standing Committee on Environment and Communications' Inquiry into recent trends and preparedness for extreme weather events. February 2013.

Nitschke CR, Innes JL (2013) Potential effect of climate change on observed fire regimes in the Cordillera forests of South-Central Interior, British Columbia. *Climatic Change* 116: 579-591.

NSW Government (2011) NSW 2021: *A plan to make NSW number one.* NSW Government. Accessed 19.11.13 at http://www.2021.nsw.gov.au/sites/default/files/NSW2021_WEB%20VERSION.pdf

NSW Ministry for Police & Emergency Services (2007) 1993–1994, December–January, North Coast, Hunter and Sydney bushfire. Accessed 19.11.13 at http://www.emergency.nsw.gov.au/content.php/598.html

Nunes AN (2012) Regional variability and driving forces behind forest fires in Portugal: an overview of the last three decades (1980-2009). *Applied Geography* 34: 576-586.

O'Neill SJ, Handmer J (2012) Responding to bushfire risk: the need for transformative adaptation. *Environmental Research Letters* 7: 014018.

Page SE, Siegert F, Rieley JO, Boehm H-D.V, Jaya A, Limin S (2002) The amount of carbon released from peat and forest fires in Indonesia during 1977. *Nature* 420: 61–65.

Pausas JG (2004) Changes in fire and climate in the eastern Iberian Peninsula (Mediterranean basin). *Climatic Change* 63: 337-350.

Pausas JG, Fernandez-Munoz S (2012) Fire regime changes in the Western Mediterranean Basin: from fuel-limited to drought-driven fire regime. *Climatic Change* 110: 215-216

Pechony O, Shindell DT (2010) Driving forces of global wildfires over the past millennium and the forthcoming century. *Proceedings of the National Academy of Sciences* 107: 19167-19170.

Penman TD, Bradstock RA, Price O (2013) Modelling the implications of ignition in the Sydney Basin, Australia: implications for future management. *International Journal of Wildland Fire* 22: 469-478.

Penman TD, Christie FJ, Andersen AN, Bradstock RA, Cary GJ, Henderson MK, Price O, Tran C, Wardle GM, Williams RJ, York A (2011) Prescribed burning: how can it work to conserve the things we value? *International Journal of Wildland Fire* 20:721-733.

Perkins S, Alexander L (2013) On the measurement of heatwaves. *Journal of Climate* 26: 4500-4517.

Pitman AJ, Narisma GT, McAneney, J (2007) The impact of climate change on the risk of forest and grassland fires in Australia. *Climatic Change* 84:383-401.

Power S, Delage F, Chung C, Kociuba G, Keay K (2013) Robust twenty-first-century projections of El Niño and related precipitation variability. *Nature* 502: 541-545

Preston B, Brooke C, Measham T, Smith T, Gorddard R (2009) Igniting change in local government: lessons learned from a bushfire vulnerability assessment. *Mitigation and Adaptation Strategies for Global Change* 14: 251-283.

Price C, Rind D (1994) Possible implications of global climate change on global lightning distributions and frequencies. *Journal of Geophysical Research* 99 (D5): 10,823–10,831.

Price OF, Bradstock RA (2010) The effect of fuel age on the spread of fire in sclerophyll forest in the Sydney region of Australia. *International Journal of Wildland Fire* 19: 35–45.

Price OF, Bradstock RA (2011) Quantifying the influence of fuel age and weather on the annual extent of unplanned fires in the Sydney region of Australia. *International Journal of Wildland Fire* 20:142-151.

Price OF, Bradstock RA (2012) The efficacy of fuel treatment in mitigating property loss during wildfires: insights from analysis of the severity of the catastrophic fires in 2009 in Victoria, Australia. *Journal of Environmental Management* 113: 146-157.

Price O, Bradstock R (2013) Landscape Scale Influences of forest area and housing density on house loss in the 2009 Victorian bushfires. *PLOS ONE* 8: e73421. doi:10.1371/journal.pone.0073421.

Ramanathan V, Carmichael G (2008) Global and regional climate changes due to black carbon. *Nature Geosciences* 1: 221–227.

Ramsay GC, McArthur NA, Dowling VP (1996) Building in a fire-prone environment: research on building survival in two major bush fires. *Proceedings of the Linnean Society of NSW* 116: 133-140.

Randerson JT, Liu H, Flanner MG, Chambers SD, Jin Y, Hess PG et al. (2006) The impact of boreal forest fire on climate warming. *Science* 314: 1130–1132.

Reuters (2009) 'Factbox—Australia's worst natural disasters' published February 8, 2009. Accessed 25.10.13 at http://www.reuters.com/article/2009/02/08/idUSSYD99754

Rossiter NA, Setterfield SA, Douglas MM, Hutley LB (2003) Testing the grass-fire cycle: alien invasion in the tropical savannas of northern Australia. *Diversity and Distributions* 9: 169-176.

Russell-Smith J, Yates CP, Whitehead PJ, Smith R, Craig R (2007) Bushfires 'Down Under': patterns and implications of contemporary Australian landscape burning. *International Journal of Wildland Fire* 16: 361–377.

Russell-Smith J Cook GD, Cooke PM, Edwards AC, LendrumM, Meyer CP, Whitehead PJ (2013) Managing fire regimes in north Australian savannas: applying Aboriginal approaches to contemporary global problems. *Frontiers in Ecology and Environment* (Online Issue 1): e55–e63, doi:10.1890/120251.

Senate Environment and Communications Committee (2013) *Recent trends in and preparedness for extreme weather events*. Accessed 12.11.13 at http://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Environment_and_Communications/Completed_inquiries/2010-13/extremeweather/report/index

Setterfield SA, Rossiter-Rachor NA, Douglas MM, Wainger L, Petty AM, Barrow P, Shepherd IJ, Ferdinands KB (2013) Adding fuel to the fire: the impacts of non-native grass invasion on fire management at a regional scale. *PLOS One* 8:e59144.

Shakesby RA,Wallbrink PJ, Doerr SH, English PM, Chafer CJ, Humphreys GS, Blake WH, Tomkins KM (2007) Distinctiveness of wildfire effects on soil erosion in south-east Australian eucalypt forests assessed in a global context. *Forest Ecology and Management* 238: 347–364.

Sim, M (2002) Bushfires: are we doing enough to reduce the human impact? *Occupational and Environmental Medicine* 59: 215-216.

Smith HG, Sheridan GJ, Lane PNJ, Nyman P, Haydon S (2011) Wildfire effects on water quality in forest catchments: A review with implications for water supply. *Journal of Hydrology* 396: 170-192.

Sneeuwjagt RJ (2008) Prescribed burning: how effective is it in the control of large bushfires? In: *Fire, Environment and Society: From Research to Practice.* Bushfire Co-operative Research Centre and The Australasian Fire and Emergency Service Authorities Council, Adelaide, South Australia. pp 419–35.

Spracklen DV, Mickley LJ, Logan JA, Hudman RC, Yevich R, Flannigan MD, Westerling AL (2009) Impacts of climate change from 2000 to 2050 on wildfire activity and carbonaceous aerosol concentrations in the western United States. *Journal of Geophysical Research* 114: D20301.

Stephenson C (2010) A literature review on the economic, social and environmental impacts of severe bushfires in south-eastern Australia. F*ire and Adaptive Management Report No. 87.* Bushfire CRC.

Stephenson C, Handmer J (2012) Estimating the net cost of the 2009 Victorian Black Saturday fires to the affected regions. *Fire Australia*, Summer 2011/12.

Stephenson C, Handmer J, Betts R (2013) Estimating the economic, social and environmental impacts of wildfires in Australia. *Environmental Hazards* 12: 93-111.

Sullivan AL, McCaw WL, Cruz MG, Matthews S, Ellis PF (2012) Fuel, fire weather and fire behaviour in Australian ecosystems. In *Flammable Australia: Fire regimes, biodiversity and ecosystems in a changing world.* Bradstock RA, Gill AM, Williams RJ (eds). CSIRO Publishing, Collingwood, Victoria, pp 51-78.

TBI (Tasmania Bushfires Enquiry) (2013) Vol .1 ISBN 978-0-9923581-0-5. Published October 2013. Department of Premier and Cabinet, Tasmanian Government. ISBN 978-0-9923581-0-5 http://www.justice.tas.gov.au/bushfiresinquiry

Teague B, McLeod R, Pascoe S (2010) Victoria Bushfires Royal Commission. *2009 Victorian Bushfires Royal Commission: Final Report:* Government Printer, South Africa, 2010.

Tooth R, Barker G (2007) The non-insured: who, why and trends. Report for the Insurance Council of Australia. Accessed 11.11.13 at http://www.insurancecouncil.com.au/assets/report/the%20non%20insured%20-%20report.pdf

Trenberth KE (2012) Framing the way to relate climate extremes to climate change. *Climatic Change* 115: 283-290.

Trewin B, Smalley R (2012) Changes in extreme temperatures in Australia, 1910 to 2011. 19th AMOS National Conference, Melbourne, 11-13 February 2013.

Turetsky MR, Kane ES, Harden JW, Ottmar RD, Manies KL, Hoy E, Kasischke ES (2010) Recent acceleration of biomass burning and carbon losses in Alaskan forests and peatlands. *Nature Geosciences* 4:27–31.

van der Werf GR, Randerson JT, Giglio L, et al. (2010) Global fire emissions and the contribution of deforestation, savanna, forest, agricultural, and peat fires (1997–2009). *Atmospheric Chemistry and Physics* 10: 11707–11735.

Verdon DC, Kiem AS, Franks SW (2004) Multi-decadal variability of forest fire risk—eastern Australia. *International Journal of Wildfire Fire* 13: 165–171.

Villarini G, Smith JA (2013) Spatial and temporal variability of cloud-to-ground lightning over the continental U.S. during the period 1995–2010. *Atmospheric Research* 124: 137-148.

Westerling AL, Bryant BP, Priesler HK, Holmes TP, Hidalgo HG, Das T, Shresha SR (2011a) Climate change and growth scenarios for California wildfire. *Climatic Change* 109 (Suppl. 1): S445-S463.

Westerling AL, Hidalgo HG, Cayan DR, Swetnam TW (2006) Warming and earlier spring increase Western U.S. forest wildfire activity. *Science* 313: 940-943.

Westerling AL, Turner MG, Smithwick EAH, Romme WH, Ryan MG (2011b) Continued warming could transform the Greater Yellowstone fire regimes by mid-21st century. *Proceedings of the National Academy of Sciences* 108:13165-13170.

Western Australian Land Information Authority (2013) Landgate FireWatch. Accessed on 30.10.13 at http://firewatch.landgate.wa.gov.au/landgate_firewatch_public.asp

Whelan RJ, Rodgerson L, Dickman CR, Sutherland EF (2002) Critical life cycles of plants and animals: developing a process-based understanding of population changes in fire-prone landscapes. In *Flammable Australia: the fire regimes and biodiversity of a continent,* Bradstock RA, Williams JE, Gill AM (eds), Cambridge University Press, Cambridge UK.

White I, Wade A, Worthy M, Mueller N, Daniell T, Wasson R. (2006). The vulnerability of water supply catchments to bushfires: impacts of the January 2003 wildfires on the Australian Capital Territory. *Australian Journal of Water Resources* 10: 1–16.

Whittaker J, Handmer J, Mercer D (2012) Vulnerability to bushfires in rural Australia: A case study from East Gippsland, Victoria. *Journal of Rural Studies* 28: 161-73.

Whyte, S. (2013). NSW bushfires: live updates October 23. Sydney Morning Herald. 23.10.13.

Wiedinmyer C, Hurteau MD (2010) Prescribed fire as a means of reducing forest carbon emissions in the western United States. *Environmental Science & Technology* 44: 1926–1932.

Williams AAJ, Karoly DJ (1999) Extreme fire weather in Australia and the impact of the El Niño–Southern Oscillation. *Australian Meteorological Magazine* 48: 15–22.

Williams AAJ, Karoly DJ, Tapper N (2001) The sensitivity of Australian fire danger to climate change. *Climatic Change* 49: 171-191.

Williams RJ, Bradstock RA, Barrett D, Beringer J, Boer MM, Cary GJ et al. (2012) Fire regimes and carbon in Australian vegetation. In *Flammable Australia: Fire regimes, biodiversity and ecosystems in a changing world.* Bradstock RA, Gill AM, Williams RJ (eds). CSIRO Publishing, Collingwood, Victoria, pp 273-292.

Williams RJ, Bradstock RA, Cary GJ, Enright NJ, Gill AM, Liedloff AC, et al. (2009) *Interactions between climate change, fire regimes and biodiversity in Australia—a preliminary assessment.* Report to the Department of Climate Change and Department of the Environment, Water, Heritage and the Arts, Canberra. 214 p.

Williams J, Albright D, Hoffman AA, Eritsov A, Moore PF, de Morais JCM, Leonard M, San Miguel-Ayanz J, Xanthopoulos G, van Lierop P (2011 Findings and implications from a coarse-scale global assessment of recent selected mega-fires. Paper presented to *5th International Wildland Fire Conference,* Sun City, South Africa. http://foris.fao.org/static/pdf/fm/5thIWFConference2011.pdf (9–13 May 2011)

Williams RJ, Bowman DMJS (2012) Fire futures for a megadiverse continent. *New Phytologist* 196: 337-340.

Willis M (2005) Bushfire arson: a review of the literature. *Research and Public Policy Series No. 61.* Bushfire CRC, Melbourne. 166 pp.

WRF (Water Research Foundation) (2013) Water quality impacts of extreme weather events. Water Research Foundation, Denver, Colorado.

Yates CP, Edwards AC, Russell-Smith J (2008) Big fires and their ecological impacts in Australian savannas: size and frequency matters. I*nternational Journal of Wildland Fire* 17: 768–781.

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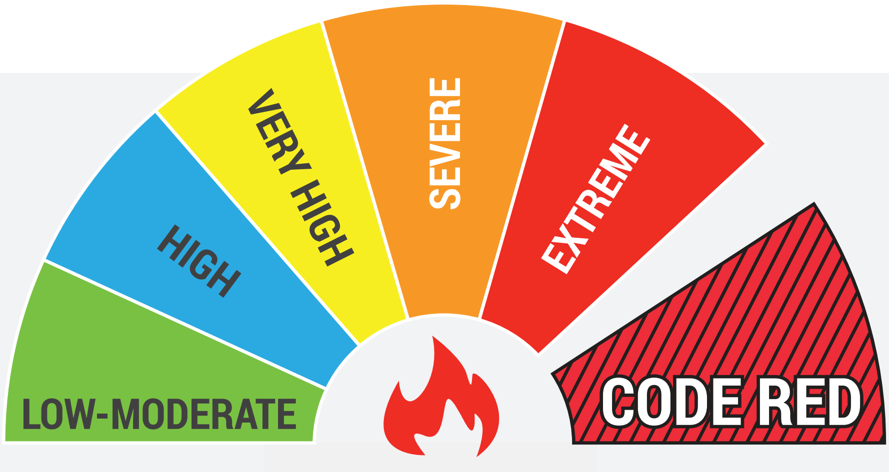
Fire danger rating



FIRE DANGER RATING	ACTION
CATASTROPHIC (CODE RED) Fires in these conditions are uncontrollable, unpredictable, and fast moving. People in the path of fire will very likely be killed, and it is highly likely that a very great number of properties will be damaged.	**LEAVE EARLY—DO NOT STAY.** Keep up to date with the situation.
EXTREME Fires in these conditions are uncontrollable, unpredictable, and fast moving. People in the path of the fire may die, and it is likely that many properties will be destroyed.	**LEAVE EARLY.** Only stay and defend if your house has been built specifically to withstand bushfires, and if you are physically able, and your property has been prepared to the very highest level. Keep up to date with the situation.
SEVERE Fires in these conditions will be uncontrollable and will move quickly. There is a chance that lives will be lost, and that property will be destroyed.	**IF YOU PLAN TO LEAVE, LEAVE EARLY.** If you plan to stay and defend property, only do so if your property is well prepared and you are able. Keep up to date with the situation.
VERY HIGH Conditions in which fires are likely to be difficult to control. Property may be damaged or destroyed but it is unlikely that there will be any loss of life.	Monitor the situation, and be prepared to implement your bushfire survival plan.
HIGH Conditions in which fires can most likely be controlled, with loss of life unlikely and damage to property to be limited.	Know your bushfire survival plan, and monitor the situation.
LOW TO MODERATE Fires in these conditions can most likely be easily controlled, with little risk to life or property.	Ensure you have a bushfire survival plan, know where to access up-to-date information.

Sources: Country FIre Authority, 2013 http://www.cfa.vic.gov.au/warnings-restrictions/about-fire-danger-ratings/
NSW RFS, 2013 http://www.rfs.nsw.gov.au/file_system/attachments/Attachment_FireDangerRating.pdf
SA Country Fire Service, 2013 http://webcache.googleusercontent.com/search?q=cache:xqhKmcXSmmQJ:www.cfs.sa.gov.au/public/download.jsp%3Fid%3D5090+&cd=2&hl=ky&ct=clnk

Preparing for a bushfire

IN AN EMERGENCY, CALL TRIPLE ZERO (106 FOR PEOPLE WITH A HEARING OR SPEECH IMPAIRMENT) 000

INFORM YOURSELF

State Fire Authorities, listed below, have the resources available to help you prepare for a bushfire. Use these resources to inform yourself and your family.

ASSESS YOUR LEVEL OF RISK

The excellent resources of State Fire Authorities are also available to assist you to assess your level of risk from bushfire. Take advantage of them.

MAKE A BUSHFIRE SURVIVAL PLAN

Even if your household is not at high risk from bushfire (such as suburbs over 1 km from bushland), you should still educate yourself about bushfires, and take steps to protect yourself and your property. State Fire Authorities have excellent resources available to help you to prepare a bushfire survival plan. Look on your State Fire Authority's website to start or review your plan.

PREPARE YOUR PROPERTY

Regardless of whether you decide to leave early or to stay and actively defend, you need to prepare your property for bushfire. Check out the excellent resources and guides available on State Fire Authorities websites. An important consideration is retrofitting older houses to bring them in alignment with current building codes for fire risk and assessing the flammability of your garden.

PREPARE YOURSELF AND YOUR FAMILY

Preparation is not only about the physical steps you take to prepare—e.g., preparing your house and making a bushfire survival plan. Preparing yourself and your family also involves considering your physical, mental and emotional preparedness for a bushfire and its effects. Take the time to talk to your family and to thoroughly prepare yourself on all levels.

STATE FIRE AUTHORITIES

NSW RFS
www.rfs.nsw.gov.au
1800 679 737

Queensland Fire and Rescue Service
www.fire.qld.gov.au
13 74 68

SA Country Fire Service
www.cfs.sa.gov.au
1300 362 361

Tasmania Fire Service
www.fire.tas.gov.au
03 6230 8600

Country Fire Authority (Victoria)
www.cfa.vic.gov.au
1800 240 667

WA Department of Fire and Emergency Services
www.dfes.wa.gov.au
1300 657 209

ACT Rural Fire Service
http://esa.act.gov.au
13 22 81

Secure NT (Find the Bush Fires section under 'Preparing for Emergencies')
http://www.securent.nt.gov.au/index.html
For a list of region-specific phone numbers, visit:
http://www.pfes.nt.gov.au/Contact-Us.aspx

NB: Information correct as of 5/12/13