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Climate Change, Wildfires, Heatwaves and Health Impacts in Australia

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Abstract Heat-related extreme events, such as wildfires and heatwaves, have historically imposed a burden on Australian society, and according to rigorous and robust scientific literature, it is expected that there will be increases in frequency, intensity and duration of these types of natural hazards. Within Australia, wildfires and heatwaves are currently responsible for more than 60% of all direct fatalities related to natural hazards, and it is highly likely that this is an underestimation as some health impacts are not routinely quantified (e.g. premature death related to air pollution from wildfire smoke exposure). Deaths attributable to heatwaves and fire smoke pollution are more commonly due to exacerbations of pre-existing health conditions, than to specific direct impacts such as heat stroke. Some groups, such as the elderly, infants and those with pre-existing conditions, tend to be more vulnerable to these impacts. Furthermore, evidence suggests that there are synergistic additional impacts when exposed to high temperature and air pollution, and that probably health impacts are considerably underestimated in the case of some specific groups such as those with occupational chronic exposure to fire smoke. To avoid increases in public health effects, society at all levels needs to increase its adaptive capacity. Measures need to be taken from a planning and management perspective through to community response at a local level, adequately focusing resources to include vulnerable sectors and population groups.

Keywords Climate change, bushfires, wildfires, heatwaves, health, Australia

Wildfires and heatwaves and climate change: global context

Wildfires and heatwaves are important natural hazards that will be exacerbated by climate change. Fire is a process that is complex by nature and is highly variable in how it behaves in space and time; it needs to be ignited, have available fuel to burn, and be set in particular weather and topographic conditions that will allow it to successfully spread (Hughes & Alexander, 2017). Wildfires, in contrast to prescribed burning, are less predictable processes, with high uncertainty in their behaviour and impacts due to variations in how they start, the fuel being burnt and the existing meteorological conditions that may or may not be beneficial to their spreading.

For heatwaves (or heat events) there is no quantitative universal definition, and different metrics to identify these have been used. According to the World Meteorological Organization and World Health Organization, heatwaves are defined as: “periods of unusually hot and dry or hot and humid weather that have a subtle onset and cessation, a duration of at least two to three days and a discernible impact on human activities. During such periods of hot weather, not only do daytime temperatures reach high values but nocturnal temperatures and humidity levels may also rise well beyond their long-term mean.” (McGregor, Bessemoulin, Ebi, & MenneB., 2015, p. 1). A key feature is a marked departure from typical background weather conditions for the affected geographic region (Nairn & Fawcett, 2013). This means, for example, that a heatwave in Tasmania may be considered as moderate weather conditions in another place such as Adelaide, and therefore the definition of a heatwave is relative to the place being analysed.

A wide body of scientific literature supports the fact that global warming will produce more frequent and intense extreme weather events worldwide, and there is very high confidence that these shifting patterns, including those caused by changing temperature and occurrence of heat waves and fires, have an impact on human health (Bowman et al., 2017; Mora, Dousset, et al., 2017; Smith et al., 2014). In the IPCC's Fifth Assessment Report (AR5), Smith et al. (2014, p. 713) state that there is a "greater risk of injury, disease, and death due to more intensive heat waves and fires" with some level of climate change.

During a forest fire, the process of combustion, produces great amounts of smoke, consequently being an important contributor to air pollution in urban and rural settings. Air pollution is one of the largest threats to humans, one of the main causes of death in the world, and there is no evidence of a safe threshold level of exposure below which no negative effects occur (WHO, 2013). It is estimated that outdoor and indoor air pollution (urban and rural sources) is responsible for around 7 million premature annual deaths (1 out of 8 total deaths), mostly from cardiovascular diseases, and from the development of respiratory diseases such as acute respiratory infections (ARIs) and chronic obstructive pulmonary diseases (COPDs) (WHO, 2014a). In fact, a study published in 2012 in the Lancet found that for the year 2010, household air pollution from solid fuels was the third leading risk factor for global disease burden (Lim et al., 2012). Air pollution produced by landscape fires is not very different in the way it impacts health, and one of the main differences would be related to exposure. With urban air pollution people usually suffer from chronic exposure, whilst with landscape fire smoke people might be exposed for short periods of time to very high levels of air pollution. It is estimated that landscape fire smoke is responsible for 340,000 annual deaths globally (F. H. Johnston et al., 2012), and for a high number of morbidity effects such as increased respiratory hospital admissions and chronic diseases, asthma attacks, emergency department visits, and reduced productivity, amongst others (Adetona et al., 2016; Black, Tesfaigzi, Bassein, & Miller, 2017; Duran, 2014; Kochi, Donovan, Champ, & Loomis, 2010; Liu, Pereira, Uhl, Bravo, & Bell, 2015; Reid et al., 2016b; Youssouf et al., 2014). Mortality estimates may have a great variation related to climatic conditions, ranging from 262,000 deaths globally with strong La Nina conditions to 532,000 with strong El Nino conditions (F. H. Johnston et al., 2012), and may potentially be underestimated as long-term effects have not been quantified. In fact, landscape fires could well be one of the most relevant emission sources, because of the uncertainty in its nature and its capacity to negatively influence air pollution reduction efforts, producing average increases of annual PM2.5 concentration (Larsen, Reich, Ruminski, & Rappold, 2018) and producing greater impacts in public health (Ford et al., 2018).

According to the World Health Organization (WHO, 2014b) and supposing no adaptation to climate change, by the year 2030, heat will be responsible for 92,207 (95% confidence intervals: 64,458 – 121,464) additional deaths globally for people aged 65 and over. This value will rise to 255,486 (191,816 – 364,002) for the year 2050. Worldwide, a significant amount of people (30%) are currently exposed to extreme heat conditions for at least 20 days per year, and it is expected that by the year 2100, exposure will increase to about 48% in a conservative climate change scenario (Mora, Dousset, et al., 2017), whilst severe warmings could produce increasingly intolerable conditions (Sherwood & Huber, 2010).

These two types of extreme events and their impacts are not necessarily disconnected, and there are often strong associations between them. A heatwave can occur in isolation, but it will increase the risk and likelihood of a severe wildfire (Cardil, Salis, Spano, Delogu, & Terrén, 2014; F. Johnston, Hanigan, Henderson, Morgan, & Bowman, 2011; Shaposhnikov et al., 2014).

Impacts of extreme weather events related to increased temperatures translate into multiple impacts on human wellbeing. The objective of this chapter is to integrate research and findings both from government and non-government reports and assessments and peer-reviewed scientific articles to present an overview of the growing health and wellbeing implications the Australian community will face with increasing risk of wildfires and heatwaves driven by change in climatic conditions. The following sections will present in more detail the health impacts produced by exposure to wildfires and heat waves, will discuss the conjoined effects of high temperatures and wildfires, and will highlight the need to increase adaptation capacities throughout Australian society.

Wildfires and health impacts in Australia

Wildfires (known as bushfires in Australia) and their consequences have always been a part of the Australian landscape (Hughes & Alexander, 2017), and their projected increase in frequency and intensity, is of great concern when the effects on human wellbeing (and health specifically) are considered.

Impacts of wildfires on human wellbeing are diverse by nature, and include:

- Loss of houses and other buildings (Ashe, McAneney, & Pitman, 2009; Blanchi et al., 2014)
- Property damage and destruction (Ashe et al., 2009; Blanchi et al., 2014)
- Threats to water security (F. H. Johnston, 2009)
- Loss of agricultural crops (Stephenson, Handmer, & Betts, 2013)
- Fatalities (Blanchi et al., 2014; Haynes, Handmer, McAneney, Tibbits, & Coates, 2010)
- Injuries (Cameron et al., 2009)
- Loss of livestock (Whittaker, Handmer, & Mercer, 2012)
- Loss of biodiversity (Stephenson, 2010)
- Pollutant emissions and its consequences in human health (Adetona et al., 2016; Cascio, 2018; Hyde et al., 2017; Liu et al., 2015; Navarro, Schweizer, Balmes, & Cisneros, 2018; Reid et al., 2016a)
- Mental health problems (e.g. Post-Traumatic Stress Disorder) (Gibbs et al., 2013; Hughes & Alexander, 2017; Reid et al., 2016a; Stephenson, 2010)

The occurrence of wildfires has a very high impact on Australian society, with a recorded yearly average of 100 fatalities, 3,000 direct injuries, and 83 lost homes per year, with an estimated cost of AUD $12,000 million or 1.3% of GDP for 2005 (Ashe et al., 2009). Blanchi et al. (2014) developed and analysed a dataset regarding wildfire with loss of life for the period between 1901 and 2011. Complementing this analysis with official fatality figures reported by the Australian Disaster Resilience Knowledge Hub (AIDR, 2018), it is estimated that only 7 fire events were responsible for 71% of all civilian fatalities (Table 1) for the period studied.

Table 1 Major fire events in Australia according to the number of direct civilian fatalities– adapted from Blanchi et al. (2014) *and AIDR* (2018)

#	Date of fire	Bushfire	Location	Number of civilian fatalities	Number of homes destroyed
1	Feb/1926 – Mar/1926	1926 bushfires	Gippsland, Victoria	60	550
2	Jan/1939	Black Friday bushfires	Victoria	71	1,000
3	14/Jan – 14/Feb 1944	1944 bushfires	Victoria	15 - 20	> 500
4	7/Feb/1967	Tasmanian "Black Tuesday" bushfires	Hobart, Tasmania	62	1,400
5	Jan/1969	1969 bushfires	Lara, Victoria	23	230
6	Feb/1983	Ash Wednesday bushfires	South Australia	75	2,000
7	Feb/2009	Black Saturday bushfires	Victoria	173	2,029

Although these numbers seem relevant by themselves, impacts of wildfires go further, negatively impacting the quality of the air that we breathe and imposing substantial health burdens on society. But in general, the study of the effects that fire smoke has on human health tends to be challenging (compared to urban air pollution) for a myriad of reasons that include (1) the unpredictability of episodes, (2) disperse and heterogeneous spatial and temporal distribution of smoke impacts compared to those of other sources, (3) exposure affecting both urban and rural areas with differing levels of population density, (4) peak concentrations of $PM_{2.5}$ tend to be higher, (5) lack of availability of monitoring data in rural areas affected by fires, (6) exposure of small populations not representative of broader community, and (7) short duration of episodes (even on large populations) don't allow for detection of significant changes (F. H. Johnston et al., 2011; Salimi, Henderson, Morgan, Jalaludin, & Johnston, 2017). Also, the study of health impacts due to exposure to fire smoke have had less attention than those related to urban air pollution, but there is still a considerable amount of literature available, and it has been found that health outcomes are significantly diverse in the nature and size of populations affected as shown in Figure 1.

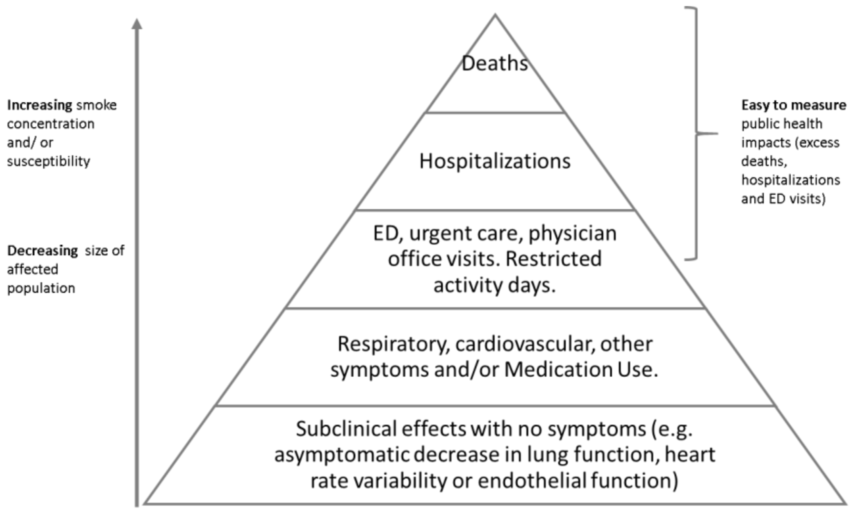

Figure 1 Total public health impacts of Wildfire Smoke or $PM_{2.5}$ – adapted from Cascio (2018)

There is robust evidence for an increase in respiratory morbidity and all-cause mortality, and mixed findings in the case of both cardiovascular morbidity and cause-specific mortality. due to short-term exposure to fire smoke (Black et al., 2017; Cascio, 2018; Reisen, Duran, Flannigan, Elliott, & Rideout, 2015; Youssouf et al., 2014). Exacerbation of respiratory health conditions is likely to be the most common immediate impact (Black et al., 2017). Long term health effects due to exposure to fire smoke should also be taken into account, as some studies have shown that a considerable amount of population may be exposed to an average annual increase of more than 0.75 $\mu g/m^3$ of $PM_{2.5}$ (Cascio, 2018; Rappold, Reyes, Pouliot, Cascio, & Diaz-Sanchez, 2017), in which case public health impacts in terms of morbidity and mortality will likely be considerable.

Epidemiological studies following Australian bushfire smoke events have found positive associations for multiple effects, especially respiratory (Table 2), while results for cardiovascular morbidity and mortality in general have been more variable. In 2010, Morgan et al. (2010) studied fires occurring in Sydney between 1994 and 2002 and found no consistency in associations between wildfire particulate matter (PM_{10}) with cardiovascular admissions and mortality. Later in 2011, Johnston et al. (2011) analysed fires between 1997 and 2004 and found that smoke events could produce a 5% increase in non-accidental and cardiovascular mortality. Evidence regarding cardiovascular impacts has been strengthened, as Dennekamp et al. (2015) and Haikerwal et al. (2015) have found positive associations between exposure to smoke from the 2006-2007 wildfires in Victoria and out-of-hospital-cardiac-arrest (OHCA) and ischaemic heart disease (IHD). Results seen in Australian studies are consistent with those done elsewhere, where evidence is robust and consistent around positive associations between fire smoke and respiratory morbidity, evidence is increasing regarding positive associations between smoke and respiratory infections and all-cause mortality, but there are still important gaps in research with respect to effects on cardiovascular morbidity, specific causes of mortality and other endpoints such as birth outcomes and mental health (Reid et al., 2016a).

Table 2 Examples of positive associations between fire-smoke PM and health effects – Australian studies

Health outcome	Place	Year/Period/Episode	Reference
Increased respiratory and cardiovascular emergency ambulance dispatches (EAD)	Sydney Greater Metropolitan Region	2004-2015	(Salimi et al., 2017)
Increased emergency department (ED) attendances for asthma	Victoria	1st Dec 2006 – 31st Jan 2007	(Haikerwal et al., 2016)
Increased out-of-hospital cardiac arrest (OHCA)	Melbourne	July 2006 - June2007	(Dennekamp et al., 2015)
Increased out-of-hospital cardiac arrest (OHCA) and ischaemic heart disease (IHD)	Victoria	1st Dec 2006 – 31st Jan 2007	(Haikerwal et al., 2015)
Increased non-accidental and cardiovascular mortality	Sydney	January 1994 to June 2007	(F. Johnston et al., 2011)
Increased ED attendances for all non-trauma conditions, respiratory conditions, asthma, and chronic obstructive pulmonary disease (COPD)	Sydney	1996-2007	(F. H. Johnston et al., 2014)
Increased admissions for respiratory infections for Indigenous people	Darwin	Fire seasons between 1996-2005 (1st April – 30th November)	(Hanigan, Johnston, & Morgan, 2008)

Similar to the effects of air pollution in general, certain population groups tend to be more vulnerable to these outcomes, such as pregnant women, the elderly, infants, smokers, firefighters, and people with pre-existing respiratory or cardiovascular conditions (Hughes & Alexander, 2017; Rappold et al., 2017; Youssouf et al., 2014). Australian indigenous people might also be affected more strongly than the rest of the population (Hanigan et al., 2008). Johnston et al. (2007) found effects to be higher in Indigenous people compared to the rest of the population: associations for COPD and asthma were more than double, and they appeared to have a higher risk of being admitted for cardio-respiratory effects. This likely being a reflection of how Indigenous people are at higher risk from environmental hazards like air pollution (F. H. Johnston et al., 2007). Some areas of Australia tend to be at higher risk of suffering bushfires and the largest effects will be experienced in high-density urban areas, where concentrated populations are potentially exposed to fire smoke.

Heatwaves and health impacts in the Australian context

Australians have been heavily impacted from extreme heat events throughout history. It is a country that is highly vulnerable to changing climatic conditions, and it is expected that the number of hot days, warm nights and heatwaves will increase by the end of the 21st century (Cowan et al., 2014), and Australian society will experience various types of impacts, such as:

- increased human morbidity and mortality (Cheng et al., 2018; Lindstrom, Nagalingam, & Newnham, 2013; McGregor et al., 2015; Mora, Dousset, et al., 2017; Tong, Wang, Yu, Chen, & Wang, 2014; Turner, Connell, & Tong, 2013; Wilson et al., 2013)
- increased risk for outdoor activities (Nairn & Fawcett, 2013)
- stress for people, animals and plants (Sherwood & Huber, 2010)
- increased bushfire risk (Cardil et al., 2014)
- damage to crop and vegetation (Wreford & Neil Adger, 2010)
- increased demand for resources (e.g. water, energy, etc.) (Zuo et al., 2015)
- stress on infrastructure such as roads and buildings (McEvoy, Ahmed, & Mullett, 2012)
- negative impacts in tourism (Nairn & Fawcett, 2013)

Heatwaves will be responsible, in the case of Australasia (Australia and New Zealand), for an estimated additional 217 (132 – 345) yearly deaths by the year 2030 and for 605 (434 – 980) by 2050 (WHO, 2014b). Although, these numbers may increase considerably when in the presence of an extreme heat event. For example, a major heat wave struck Europe during the summer of 2003, and was responsible for over 70,000 deaths (Robine et al., 2008). In Australia, the highest number of recorded deaths from natural hazards are attributable to heat waves, and even with their relative importance in terms of fatalities, these have not been studied with similar intensity as other natural hazards such as floods and storms (Coates, Haynes, O'Brien, McAneney, & De Oliveira, 2014; Lee, 2014). Only 11 events (out of 350) are responsible for more than 30% of all recorded heat wave-related deaths for the period 1844-2011 (Table 3). Victoria, New South Wales and South Australia have the highest number of fatalities, with most of these occurring during summer months.

Table 3 Significant heat events in Australia, 1844-2011 (Coates et al., 2014)

#	Date of event	Area affected	Total heat-associated deaths
1	January-February 1879	NSW, Vic	22
2	October 1895-January 1896	WA, SA, Vic, Qld, NSW	435
3	January 1906	NSW, SA	28
4	January 1908	Vic, SA, NSW	213
5	January 1939	Vic, SA, NSW	420
6	January 1940	Qld, NSW	65
7	February 1955	Perth (WA)	30
8	January-February 1959	Melbourne (Vic)	145
9	January 1960	Greater Sydney (NSW)	25
10	January 2000	Southeast Qld	22
11	January-February 2009	Vic, SA	432
		TOTAL deaths	**1,837**

It is probable that many earlier studies underestimated the real impact of heat waves on Australians, as only uncommon but specific heat-related diseases such as heat stroke, were attributed to the heat event (Coates et al., 2014). However epidemiological studies increasingly use statistical methods to attribute excess hospital admissions, regardless of the specific medical diagnosis, to specific events such as heatwaves, and the pathophysiological processes that lead from elevated body temperature to death through direct toxicity and exacerbations of cardiovascular, renal and metabolic conditions are well characterised (Mora, Counsell, Bielecki, & Louis, 2017).

Australian regions are prone to high temperatures, hot summer and extreme heat, and the association of these conditions with adverse health impacts have been well studied (Bi et al., 2011), with a more intense focus on mortality rather than morbidity effects (Dalip, Phillips, Jelinek, & Weiland, 2015; Loughnan, Nicholls, & Tapper, 2010), and with less available studies for the southern hemisphere including Australia (Loughnan et al., 2010). Health impacts include dehydration, heat strokes, cardiovascular morbidity effects, renal diseases and death. Recent studies (Table 4) have addressed the associations between heat events and multiple health effects in various cities around Australia and have found increased adverse health effects that range from increased use of health services to increased total mortality.

Table 4 Examples of positive associations between heat waves and health effects – Australian studies

Health outcome	Place	Year/Period/Episode	Reference
Increased health service utilisation	New South Wales	2005-2015	(Jegasothy, McGuire, Nairn, Fawcett, & Scalley, 2017)
Increased mortality in the elderly	Brisbane, Melbourne, Sydney	1988-2009	(Tong et al., 2015)
Increased emergency department visits	Brisbane	Summer seasons (December to February) from 2000-2012	(Toloo, Yu, Aitken, FitzGerald, & Tong, 2014)
Increased emergency hospital admissions for renal diseases in children (0-14 yrs.)	Brisbane	1st Jan 1996 to 31st Dec 2005	(Wang et al., 2014)
Increased all-cause, cardiovascular and respiratory mortality and hospital admissions for heat related injuries, dehydration, and other fluid disorders	Sydney	Mortality (1997-2007) Hospital admissions (1997-2010)	(Wilson et al., 2013)
Significantly increased total hospital admissions, emergency department presentations, general medical admissions, and rise in number of deaths	Melbourne	2009 heatwave (Jan/Feb 2009)	(Lindstrom et al., 2013)
Increased daily mortality, total emergency department presentations, renal-related emergency department presentations	Perth	1994-2008	(Williams et al., 2012)
Increased ambulance call-outs, renal morbidity for elders, heat-related admissions, ischaemic heart disease in the 15-64 age group, total mortality particularly in the 15-64 age group	Adelaide	Summers of 2008 and 2009	(Nitschke et al., 2011)

The very young, the elderly (especially those 75+), and people with pre-existing medical conditions are especially vulnerable, and more socially advantaged groups (In terms of socioeconomic status) tend to have lower impacts (Cheng et al., 2018; Coates et al., 2014; Dalip et al., 2015; Xiao et al., 2017). Other population characteristics such as living in urban or rural areas (Jegasothy et al., 2017), gender (Xiao et al., 2017) and geographical location (Tong et al., 2014), may define the level of vulnerability and adaptability that exists towards heat-related health impacts. Cowan et al. (2014) estimate that changes in frequency and duration of heat events will affect mainly northern tropical regions of Australia, whilst higher maximum temperatures will be felt in southern Australia.

Wildfire and heatwaves: relative and combined effects

Severe fire and heat events have been recorded and will likely increase in the future, producing important environmental, social and economic consequences (Bowman et al., 2017). For Australia, 2017 was its third hottest year on record, including highest historical maximum temperatures during winter and very low rainfall, shaping a perfect scenario for heat-related extreme weather events such as wildfire and heatwaves to develop (Steffen, Rice, & Alexander, 2018).

Heatwaves and wildfires were responsible for more than 65% of the 8,256 direct fatalities attributed to natural hazards in Australia for the period between 1900 and 2011 (Figure 2). Heatwaves alone accounted for more fatalities than all other natural hazards (> 50% of deaths), while wildfires were responsible for more than 10% of these deaths (Coates et al., 2014), with most wildfire fatalities (> 65%) concentrated in the State of Victoria (Blanchi et al., 2014). As we discuss above in the case of wildfires though, it is highly likely that the size of these impacts would increase considerably if indirect deaths caused by exposure to fire smoke were included. Increases in air pollution can have a large public health impact if large populations are affected. For example, Horsley et al. (2018) estimated that 183 days of exposure to landscape fire smoke were responsible for 197 premature deaths, 436 cardiovascular hospitalisations and 787 respiratory hospitalisations in a period of 13 years (2001-2013) in Sydney alone. This represents almost 23% of all direct fatalities recorded for Australia in a 111-year period.

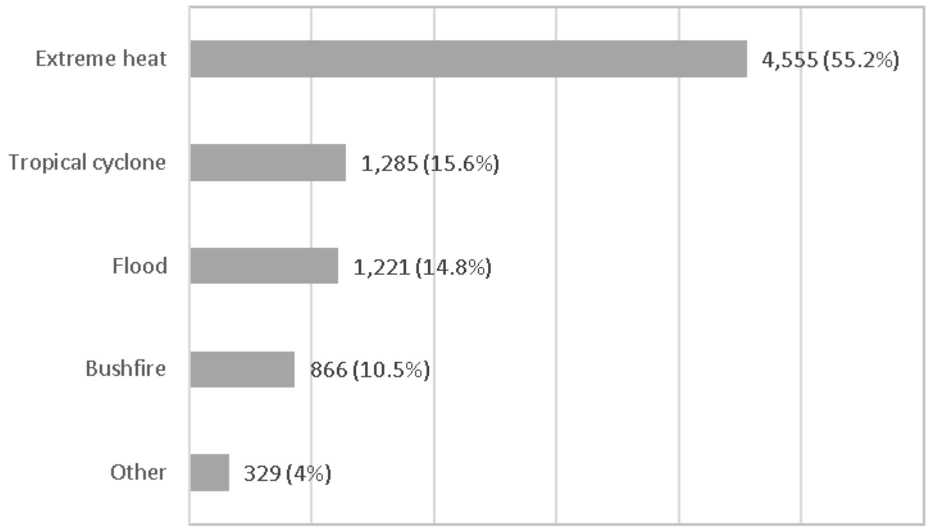

Figure 2 Total fatalities from bushfires and extreme heat compared with other Australian natural hazards between 1900 and 2011 – adapted from Coates et al. (2014)

As mentioned earlier, days of high temperature (heat events) have a strong influence on increasing the likelihood of large wildfires, especially when combined with high wind. Conditions for fires become highly favourable, and as moisture content decreases the probability for ignition increases, and fires can burn more intensely and rapidly (Cardil et al., 2014). Additionally, there may even be interactions in mortality effects produced by exposure to heatwaves and fire smoke (Katsouyanni et al., 1993; Shaposhnikov et al., 2014). In 1987, a major heat wave impacted Greece, and high levels of smoke and ozone were present during the same period. Katsouyanni et al. (1993) found statistically significant interactions between high temperatures (> 30 ºC) and sulphur dioxide (SO_2), and statistically suggestive interactions for ozone and smoke with high temperatures. In 2010, Moscow experienced a disastrous heat wave with high levels of air pollution simultaneously, with 44 days of continuous heat during major heat event and PM10 exceeding 300 $\mu g/m^3$ on multiple days. During this period, there was an estimated near 11,000 excess deaths, almost doubling the expected 300 deaths per day during this period (Shaposhnikov et al., 2014). According to the authors, the interactions between pollution from fire smoke and high temperatures were responsible for more than 2,000 of these deaths.

Different studies have been undertaken in Australian cities, and there is suggestion for a synergistic effect between high temperature and air pollution (PM_{10}, SO_2, and ozone) and that this impact (excess mortality) is additional to that of the sum of effects from each exposure variable (Green, 2018).

Furthermore, there are few studies that relate the effects of occupational exposure (e.g. firefighters) to fire smoke (Adetona et al., 2016). These type of professionals, are part of the population segments that are particularly more vulnerable to health effects associated with fire smoke exposure (Youssouf et al., 2014). The exposure to smoke that firefighters experience is very different to that of the rest of the population, they work very close to the actual sources of emission, and are exposed to high concentration levels of particulate matter and other pollutants (Adetona et al., 2016). Some of the effects experienced by firefighters include the increase of pulmonary and systemic inflammation and a decrease in lung function (Youssouf et al., 2014). A study carried on in Australia, assessed exposure of firefighters to smoke during prescribed burns and wildfires, and found that a considerable proportion of the firefighters had high to very high levels of exposure, and this would result in an increased likelihood of having acute and chronic health effects (Reisen, Hansen, & Meyer, 2011).

It is very likely that the total public health impacts of fire smoke exposure have consistently been underestimated. There appears to an opportunity and need to adequately assess the effects produced by a conjoined exposure to fire smoke and heatwaves, particularly for emergency personnel, as the synergistic impacts might be higher than the sum of its parts. Also, it seems relevant to consider impacts due to occupational exposure and find ways in which this could be reduced.

Adaptation to heat-related extreme weather events

As climate change shapes the future of Australia with increasing heat-related extreme weather events, there will be a higher demand for resources, capacities and planning that should be available to approach these issues. There is an urgent need to act regarding future potential natural hazards produced by climate change (Steffen et al., 2018). Wildfires and heatwaves will become a norm for Australian society, and it is necessary that authorities and decision makers focus adequate amount and type of resources on reducing risks (Clayton, Mylek, Schirmer, Cary, & Dovers, 2014; Cleland, Proud, Spinks, & Wasiak, 2011; Nairn & Fawcett, 2013). Actions such as increasing effectiveness of communication channels and levels with the community (Fish et al., 2017), education programs aimed at changing behaviour (Richardson, Champ, & Loomis, 2012; Walker & Salt, 2006), improving emergency response, and incorporating wildfire and heat wave events into the planning and management of our built environment and social processes are necessary to improving the adaptive capacity that systems will have in an ever-changing environment (Tong et al., 2014). Resources must be focused on increasing adaptation to climate change, improving and increasing preparedness for bushfire disasters (F. H. Johnston, 2009) and extreme heat events, including improvement of public health services, identification of vulnerable sectors and population groups, and development of early warning systems (Lowe et al., 2016; Smith et al., 2014).

Conclusions

As global warming imposes important changes in climate and weather, with increasing temperatures and levels of drought, Australians will experience a higher risk of suffering from extreme wildfires and intense heatwaves. The many impacts will probably be distributed unequally throughout society. Infants, the elderly, labourers, people with pre-existing conditions, lower socioeconomic status, or belonging to indigenous groups may be at higher risk of suffering from smoke and heat-related illnesses while those living at the urban-rural interface are at higher risk of being direct affected wildfires. Geographically, population exposure and density differ around Australia, and studies suggest that the Southeast of Australia has higher risk of mortality and disease from wildfire and smoke-related impacts while South Australia presents the highest heat-related mortality rates, although most fatalities have concentrated in Victoria, NSW and South Australia. There are some important aspects that have had relatively limited consideration, such as the possible synergistic adverse health impacts of simultaneous exposure to fire smoke and heatwaves, and the more extreme personal exposures of professionals who work outside during heat waves and bushfire air pollution events. Necessary steps should be taken at federal, state, and local levels to ensure safety of communities and minimise the loss of resources, lives and wellbeing, especially focussing on the sectors of society that are more vulnerable due to their physical locations, social and economic disadvantage, or higher risk occupational groups.

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