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Exploring 167 years of vulnerability: An examination of extreme heat events in Australia 1844–2010

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ABSTRACT

Despite their relative importance in terms of human mortality, extreme heat events have not attracted the same level of study compared with other natural hazards in regards to vulnerability and implications for emergency management and policy change. Definitional confusion and inconsistencies in defining heat related deaths over time have made it difficult to determine an absolute death toll. Notwithstanding these issues, this study employs PerilAUS – Risk Frontiers' database of natural hazard event impacts – in combination with official sources in an attempt to provide a lower-bound estimate of heat-associated deaths in Australia since European settlement. From 1844 to 2010, extreme heat events have been responsible for at least 5332 fatalities in Australia and, since 1900, 4555: more than the combined total of deaths from all other natural hazards. Over 30% of those deaths occurred in just nine events.

Both deaths and death rates (per unit of population) fluctuate widely but show an overall decrease with time. The male to female death-rate ratio has fluctuated and approaches but does not reach equality in more recent times. In line with other studies, seniors have been the most vulnerable age group overall, with infants also over-represented. Policy implications in view of a warming climate and an ageing population are discussed.

1. Introduction

Earlier studies by Risk Frontiers (Andrews, 1994; Coates, 1996) suggested that, with the exception of disease epidemics, extreme heat events had been the most significant natural hazard in Australia in terms of loss of life, killing at least 4287 persons since European settlement. [The term "extreme heat event" is preferentially used in this study rather than "heat wave", except when referring to named events and in Section 2.3]. These and more recent studies (e.g., Bi et al., 2011) parallel results from USA, where extreme heat events were responsible for 8015 deaths between 1979 and 2003: more than hurricanes, lightning, tornadoes, floods and earthquakes combined (CDC, 2013).

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The European heat wave of 2003 was one of the first to capture world attention, with an initial estimation of 35,000 *excess deaths* across Europe (e.g., Conti et al., 2005; IPCC, 2011, p. 397; Schär and Jendritzky, 2004; Vandentorren et al., 2006), including over 14,800 excess deaths in France alone (e.g., Fouillet et al., 2006). [*Excess deaths* is the difference between the number of deaths observed and the average number expected for that particular location and time of year – an estimate of the death toll from an extreme heat event often used in place of more accurate data.] More recent work has put the total excess death count in Europe at over 70,000 (Robine et al., 2008).

During 2010 Eastern Europe and Russia experienced an extreme heat event with an estimated excess death count of 55,000 in Russia alone (Barriopedro et al., 2011). These fatalities were related to temperatures and carbon monoxide pollution from extensive wildfires (Shaposhnikov et al., 2014). In the last decade, Australia has witnessed two notable high fatality events: Brisbane, Queensland, February 2004, with an estimated 23% increase in overall deaths (Tong et al., 2010) and January–February 2009, southern Australia, with 374 excess deaths in Victoria – an increase of 62% in overall deaths – and 58 attributed heat deaths in South Australia (BoM, 2009; Department of Human Services, 2009; Johns, 2009).[1]

A study by Lee (2014) examined the occurrence of, and the human casualty from, hot and cold extreme temperature events (ETE) worldwide, held within the International Disaster Database (EM-DAT) 1900–2011. The study identified 422 ETE across 71 countries and, based on event occurrences, numbers killed and numbers affected, identified Australia as a key country 'at risk' from extreme heat. However, despite recent high death tolls and anticipated aggravation of risk in a warming climate, little research has been carried out in Australia on longitudinal mortality counts that explore how vulnerability to this peril is changing over time.

This paper seeks to document a detailed exploration of Australian human mortality using a long time series of extreme heat events and compares this toll with other natural hazards in Australia. Spatio-temporal trends of the vulnerability of different population groups are also investigated. The time period of interest is from 1844 to the present due to quality and quantity limitations in pre-1844 data. Uniquely, this paper examines victims' circumstances and activity at time of death.

1.1. *Australian context – changing climate, demographics and built environment*

Significant changes in temperature and precipitation extremes have occurred across Australia in the 20th century (e.g., Collins et al., 2000; Nicholls et al., 2000; Plummer et al., 1999). The Commonwealth Scientific and Industrial Research Organization (CSIRO) and The Bureau of Meteorology (BoM) report that each decade has been warmer than the previous one since the 1950s (CSIRO and BoM, 2010, 2012). Without adaptive measures, the conjunction of expectations for extreme heat events to be of greater frequency, duration and intensity and an ageing and increasing population suggests an increase in future heat-related fatalities (Alexander and Arblaster, 2009; Keenan and Cleugh, 2011).

Since 1844, Australia's population has increased from approximately 260,000 to 3.7 million in 1900 and 22.3 million in 2010 (ABS, 2008a). This growth has come with greater urbanization and high-density housing, exacerbating the issue through a heat island effect. Furthermore, people are increasingly living in homes not designed to reduce heat stress and more reliant upon air-conditioning (Maller and Strengers, 2011), the operation of which cannot be guaranteed during an extreme heat event.

Based on medium-level growth assumptions, the Australian Bureau of Statistics (ABS) projects the population to grow over the next two decades by 29% to 28.8 million, the number of people aged 65 and over to rise by 91% and those aged 85 and over to more than double (ABS, 2008b).

1.2. *Mortality and vulnerability to extreme heat – current understanding*

Epidemiological studies world-wide have demonstrated that impacts of extreme heat are felt disproportionately within society (e.g., Fouillet et al., 2006; Klinenberg, 2002; Loughnan et al., 2010a; Luber and McGeehin, 2008; Nicholls et al., 2008; Saez et al., 1995; Vandentorren et al., 2006). The most important socio-economic and physiological risk factors identified are age; pre-existing medical conditions; chronic mental disorders; medications; alcohol/narcotics; social isolation; low-economic status; homelessness and strenuous outdoor physical activities (Bi et al., 2011; Bridger et al., 1976; Buechley et al., 1972; Ebi and Meehl, 2007; Fouillet et al., 2006; Hansen et al., 2008; Kinney et al., 2008; Klinenberg, 2002; Loughnan et al., 2010a–c; Luber and McGeehin, 2008; Vandentorren et al., 2006).

Socio-economic and physiological risk factors often overlap. For example, the elderly have reduced thermoregulatory and physiologic heat-adaptation capability and are more likely to experience poor health and to be living alone with fewer social contacts and limited finances (Luber and McGeehin, 2008). Many of the most vulnerable groups also live in substandard housing poorly adapted to extreme heat. Race and sex have been noted as important due to the marginalization of these groups in some societies. Examples include higher death rates for non-white, male populations in USA (e.g., Buechley et al., 1972; Klinenberg, 2002) and females in Paris during the 2003 European heat event, even after controlling the data for age (Toulemon and Barbieri, 2008).

The significance of extreme heat in Australia in terms of human mortality largely escaped public attention until Coates (1996) compared fatalities from different Australian natural hazards. This situation has changed: for example, Bi et al. (2011) provide an overview of the literature, the majority of which has either focused on individual extreme heat events, relatively short periods of time or specific cities or regions. An

[1] Exact comparisons between fatalities in South Australia (SA) and Victoria for the 2009 event cannot be made. The Government of SA have released the exact number of fatalities believed directly related to the event while in Victoria only an excess fatality count is known. Issues of determining attributed fatalities from heat events and the lack of a standardized recording procedure are discussed in Section 2.4.

Table 1 – Findings of relevant longitudinal studies on heat related mortality.

Author	Method	Findings (heat related only)
Astrom et al. (2013)	Analysis of daily mortality data between 1980 and 2009 and temperature data between 1900 and 2009 in Stockholm, Sweden	Increase in heat related mortality over the last 30 years due to more frequent heat events when compared with the beginning of the 20th century
Christidis et al. (2010)	Cold and heat related mortality in those aged over 50 years in England and Wales examined between 1976 and 2005	Slight increase in heat related deaths
Carson et al. (2006)	Weekly mortality in London, UK, analysed during four periods (1900–1910, 1927–1937, 1954–1964, and 1986–1996) to examine vulnerability trends in relation to season and temperature	Declining number of heat related deaths despite an ageing population Fall in childhood mortality Predominance of chronic disease mortality in later periods
Davis et al. (2003)	Annual excess mortality on days of extreme heat examined for 28 major metropolitan areas in the US between 1964 and 1998	Declining number of heat related deaths
Bi and Walker (2001)	Monthly Australian mortality trends analysed for extreme heat and cold between 1910 and 1997	Declining number of heat related deaths Significant spike in 1939 Narrowing of the gender differential from early 1940s

exception is Bi and Walker (2001), who examined mortality from excessive heat and cold in Australia from 1910 to 1997. The salient findings from this study and four relevant international longitudinal studies are summarized in Table 1. Three studies, including that of Bi and Walker (2001), identified a declining number of heat related deaths, which they explain are due to improved technology, infrastructure, social and health care factors. However, two recent studies show an increase in mortality which the authors attribute to increased exposure and failure to adapt.

2. Methodology

2.1. *PerilAUS*

This study draws from Risk Frontiers' PerilAUS database of impacts and consequences of natural hazards in Australia. PerilAUS is based on material collected from news media, government reports, published literature, state Coroner records, ABS and registries of Births, Deaths and Marriages for Australia's States and Territories. Where available, data are collected on economic, social and environmental impacts of the event and number of people injured, evacuated and/or homeless. Data range from European settlement (1788) to the present, with more complete records from 1900, and cover bushfires, earthquakes, floods, hailstorms, extreme heat events, landslides, lightning strikes, rainstorms, tornadoes, tropical cyclones, tsunamis and windstorms. The database has served as the underpinning resource of a number of other hazard- and risk-related studies (e.g., Blong, 2005; Coates et al., 1993; Coates, 1996, 1999; Crompton et al., 2010; Haynes et al., 2009, 2010b).

Entries in PerilAUS contain data on location – state/territory, nearest town, postcode, latitude, longitude and dates – year, month and day. Where available, physical attributes of each event are recorded: for example, maximum, minimum and average temperatures for the day and preceding day of a heat death and the duration of the event; relative humidity and the presence of hot winds, rain, water shortage (drought) and bushfires. Information is included on deaths and injuries and, where available, age and sex of the deceased; date, time and cause of death and occupation and circumstances at time of death (news media reports in particular were invaluable for the latter).

2.2. *Other data sources*

In addition to PerilAUS data, and in order to capture the most comprehensive dataset possible, *Cause of Death* data were sourced from ABS (ABS, 2013a,b) and the National Coronial Information Service (NCIS) (NCIS, 2013).

ABS data was available in different formats and detail from 1907 to 2009 (see also Section 2.4). The NCIS is an internet-based data system containing information about every death reported to an Australian coroner since July 2000 (January 2001 for Queensland) (http://www.ncis.org.au/).

2.3. *Definitions*

There exists no universal definition of "heat wave" as the term is relative to the usual weather of the area. Lee (2014) provides a comprehensive discussion and summary of the various qualitative and quantitative extreme heat (heat wave) definitions provided within the international literature.

The difficulty in defining extreme heat means it is challenging to ascertain whether a death occurred during a recognized period of extreme heat or not. This means that heat-associated deaths are generally not well documented, in large part because such deaths outside of recognized extreme heat events tend to be overlooked (e.g., Lee, 2014). Furthermore, even during a recognized event, heat can often contribute to cause of death without being the direct or main cause. Heat-related fatalities most often refer to the exacerbation of pre-existing medical conditions such as heart disease or stroke. Such deaths are generally recorded officially under that medical condition, resulting in an underestimation of heat-associated mortality.

Because of the nature of extreme heat, authorities can be slow to recognize and therefore respond to its impacts. Diagnosing heat deaths is also difficult as those responsible for recording cause of death may not consider heat a potential cause – therefore heat deaths recorded on death certificates may well be an underestimation. Haynes et al. (2010a) identified this to be a problem during the 2009 Southern Australian extreme heat event, where attending police officers did not collect sufficient evidence at the scene (temperature in the home, use of air-conditioning, etc.) in order to correctly attribute the cause of death as due to excess heat or not. It is beyond the scope of this study to resolve this ambiguity. However, we consider the *Excess Heat Factor index* proposed by Nairn et al. (2009), based on maximum and minimum daily temperatures in a specific location relative to recent and historical temperatures, to be a reasonable definition.

The PerilAUS Extreme Heat Events Database and this research paper uses the definition supplied by Nairn et al. (2009) as well as more subjective definitions of "heat wave" and "excessive heat" often ascribed in news media or government and census documentation. For example, deaths associated with extreme heat events of less than three days duration have been included in the PerilAUS database; as have deaths reported by sources such as news media, BoM reports, etc., especially where these reports exist prior to the availability of official sources such as ABS.

This paper adopts the following operational definitions:

A *heat deaths* – deaths directly attributed (by news media, government departments, etc.) to extreme heat: for example, heat stroke,

B *heat-related deaths* – deaths reported (by news media, government departments, etc.) as resulting indirectly from extreme heat: for example, from heat exacerbation of a pre-existing illness, and

C *heat-associated deaths* – all deaths attributed, directly or indirectly, to extreme heat: the sum (C = A + B) of the above.

Using *excess deaths* as an approximation of total heat-associated deaths avoids the longitudinal inconsistencies of the *Cause of Death* coding system (see Section 2.4). However, the extent to which excess deaths could actually be displaced mortality must be considered as, depending on the context, a percentage of excess deaths represent people who, because of preexisting illness, would have died very soon even in the absence of the period of extreme heat. Hajat et al. (2005) conducted a study examining mortality displacement from heat related deaths 1991–1994 in Delhi, Sao Paulo and London. They identified an increase in all-cause mortality in each city: however, the short-term mortality displacement was very high in London (net effect zero after 11 days), very low in Delhi and intermediate in Sao Paulo. The authors concluded that in London the greatest number of deaths were the elderly with underlying chronic diseases, while in Delhi a high proportion of the deaths were children who died of infectious causes and otherwise may have lived, indicating a significant shortening of their lives. In comparison, a study by Le Tertre et al. (2006), who examined mortality displacement across nine French cities during the 2003 event, identified fairly low levels of short-term displacement, with a range between 1% and 30%. In Paris, where demographics are comparable to London, the proportion of excess deaths identified as short-term displacement was only 6%. Overall, and in comparison to the previous study in London, despite the greatest proportion of deaths occurring in the elderly, over 90% of the victims were not expected to die in the immediate future (Le Tertre et al., 2006). This demonstrates that the context, timing and duration of extreme heat events has a significant impact on the short-term displacement effect. This was also noted in a study by Kysely (2004), who examined mortality displacement during 17 events 1982–2000 in the Czech Republic and identified that net mortality change was most significant for severe and long running events.

Overall, the research noted above demonstrates that in many circumstances excess deaths do represent an increase in deaths rather than a short-term forward shift in mortality, particularly during severe and long running episodes of extreme heat.

2.4. Calculations and data limitations

Trends were analysed for different time series: from 1844 to 2010, the most encompassing PerilAUS data set, and also from 1907 to 2010, the period for which official statistics were available. To identify longitudinal trends invulnerability of various population groups, data were broken into different, context-dependent time intervals.

To better identify vulnerability trends, death rates of heat-associated deaths per 100,000 population were calculated, for differing time intervals (see Section 3).

Exact ages of victims have rarely been recorded in media and other accounts although qualitative descriptors were often given. For this reason, this study adopted the following conventions to combine qualitative and quantitative data:

- "infant": aged 0–4,
- "child" (or similar): aged 5–9,
- "teenager": aged 10–19,
- "young adult" (mainly interpreted from other data about victim): aged 20–39,
- "middle-aged" (or similar): aged 40–64 and
- "senior" (or similar): >64 years of age.

ABS and NCIS data represented the best estimates of heat-associated deaths available, and, as official data sources, their reported totals were preferentially used. Prior to 1907, PerilAUS figures were utilized, where deaths were recorded as heat, heat-related or heat-associated deaths according to the description given in news media/government reports.

However, death totals for the 2009 Southern Australia heat event were taken from PerilAUS as, in this instance, data were available from the South Australian Coroner, who recorded 58 heat-related deaths in South Australia (Johns, 2009), and from the Victorian Registry of Births, Deaths and Marriages and the Victorian Coroner's Office, who estimated 374 excess deaths in Victoria (Victorian Department of Human Services, 2009). ABS provisionally records just 56 nationally for the entire year, a figure which cannot be considered correct in light of the figures from the other sources; this is also the case for the total of 46 listed by NCIS. The other exception is the use of a report by BoM (Rankin, 1959), which gives a figure of 145 attributed deaths for a Melbourne, Victoria heat event in 1959: nationally, the ABS lists but 43 for the entire year.

Even after official data sources became available (post 1907), data quality and/or completeness is uneven. For example, in recent years ABS has adopted the practice of "randomly assigning" data cells with small values to protect the confidentiality of individuals. Changes have also occurred in the coding of *Cause of Death* with time. For example, from:

- 1907 the term "insolation" was used.
- 1910 the term "effects of heat" was used.
- 1950 the term "excessive heat and insolation" was used.
- 1967–1978 the term "heat effects" (code N992) was used.
- 1989–1997 (ICD-9) the term "Excessive heat due to weather conditions" (code E900.0) was used.
- 1997 onwards (ICD-10) the term "Exposure to excessive natural heat" (code X30) is used.

The first four codes do not exclude deaths caused by non-weather sources. Other changes that may result in inconsistencies in the data include time periods where the date and state of registration of death were used instead of the actual date and state where death occurred; Indigenous Australian being included only from 1968, occupations of females being included only from 1989, etc. In each case, the figures provided by ABS were accepted as heat-associated deaths.

ABS data for 2009 were still subject to revision and figures for 2010 onwards were unavailable at the time of request.

Any fatalities that could not unquestionably be assigned to extreme heat events were not included in the database. This, and the fact that a number of remotely located (and therefore unrecorded) extreme heat fatalities have no doubt occurred, especially in the earlier years of the colonies, means that the figures presented here are likely to be underestimates.

3. Results and discussion

This section deals with the identification of vulnerable groups and changes within those groups over time in terms of deaths and death rates, cause of death and trends in location, seasonality, age, sex, activity and occupation. The ranking of extreme heat events as a cause of death relative to other natural hazards is considered.

3.1. *Identification of and trends within vulnerable groups*

3.1.1. *Total deaths and death rates*

A total of 363 extreme heat events have been recorded in PerilAUS from 1789 to 2011; 350 from 1844 to 2010. Combining these records with ABS and NCIS data, it is estimated that at least 5332 heat-associated deaths have occurred in Australia between 1844 and 2010. For reasons given earlier, this figure is likely a lower bound for the true toll of heat-associated deaths in Australia.

The raw heat-associated death totals and the death rate are both displayed in Fig. 1a (1844–2010) and Fig. 1b (1900–2010). Generally, low numbers of heat-associated deaths are punctuated by episodic excursions for particularly severe events. The most severe, in terms of raw numbers, was that of 1896 (450 heat-associated deaths for that year), followed by 2009 (432) and 1939 (420). Highest ranked in terms of death rate are 1896 (12.66 deaths per 100,000 population), 1908 (5.81), 1939 (6.00) and 2009 (1.99).

From 1907, when official records were available, both death totals and death rate show a general and gradual downward trend over time (Fig. 1), except for years of significant extreme heat events. The overall decadal death rate (Table 2) has fluctuated over time but has steadily declined from a high of 1.69 deaths in the 1910s.

3.1.2. *Spatial trends*

Fig. 2 shows total deaths by state for the period 1907–2010. The greatest numbers of heat-associated deaths have occurred in Victoria with New South Wales (NSW) and South Australia (SA) also notable. The shading in Fig. 2 represents the death rate, which is highest for SA across the period. As noted elsewhere in the paper, the figures are likely a lower bound estimate.

Only one heat-associated death was revealed for the Australian Capital Territory (ACT) and none have been recorded for Tasmania; however, it is highly likely that heat-associated deaths have occurred and further investigation is required.

3.1.3. *Seasonal trends*

Month of death was not available from ABS for 1907–1909, so PerilAUS was examined from 1844–1909 and ABS and NCIS from 1910 onwards. Fig. 3 shows deaths by month.

The majority of deaths have occurred in January, followed by February and December – coincident with the southern hemisphere's summer. By state, the picture is very similar except for Western Australia, where the distribution is equal between January and February, with slightly fewer deaths in December, and the Northern Territory, where heat-associated deaths have a more even spread between November and January, reflecting a smaller variation in monthly temperatures in the tropics.

Curiously, most deaths have occurred on 27 January – the day after Australia's national day, a public holiday.

3.1.4. *Sex/age trends*

Most deaths have been amongst males – 61.5 per cent of known deaths over the entire record. The male to female death ratio has fluctuated over time from 5.67 in the 1880s to 0.50 in the 1970s, but shows a trend towards equality (Table 2) over the last five decades and between 2000 and 2010, male and female deaths have been almost equal. Accounting for temporal variations in male and female populations, males have been overrepresented in extreme heat-associated deaths for the majority of the record but the trend is still towards equality, from a high of 4.81 in 1880–1889 to the current death rate ratio of 1.10.

The ABS dataset of heat-associated deaths from 1907 to 1992 was examined by sex against 5-year age groups (not

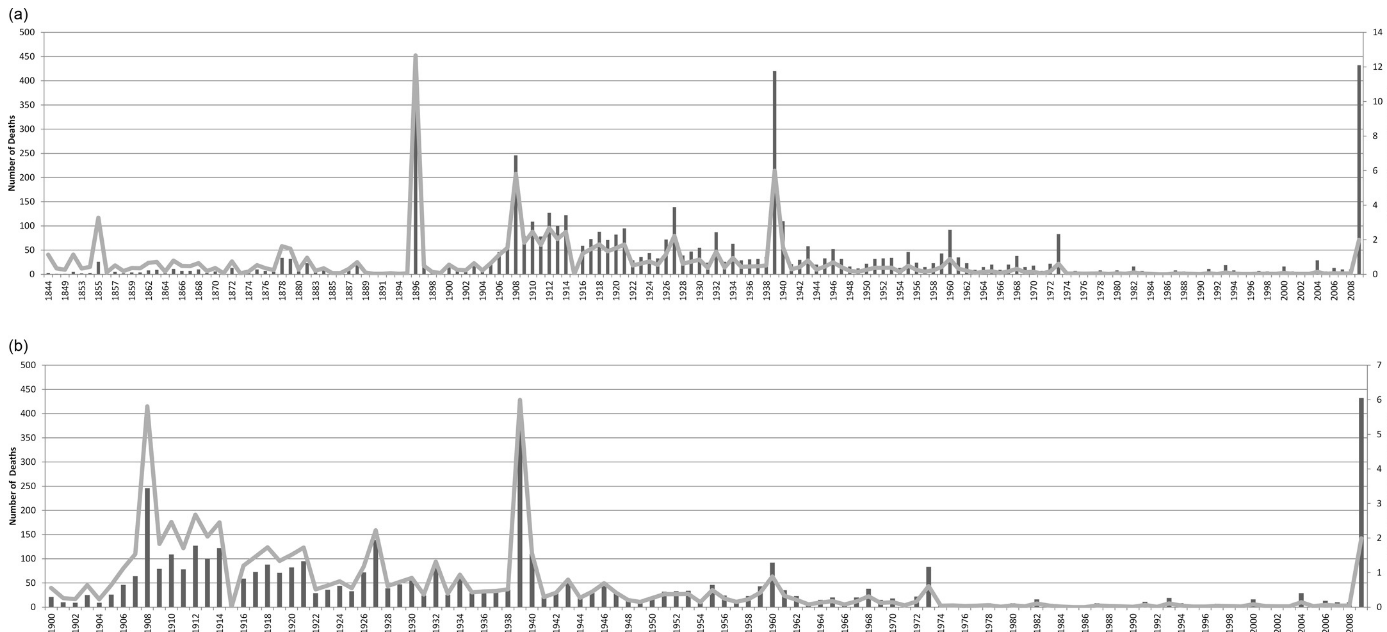

Fig. 1 – (a) Heat-associated deaths in Australia by year, 1844–2010 (from PerilAUS, ABS and NCIS). The solid continuous line represents the heat-related death rate per 100,000 based on the contemporaneous national population and (b) the same data from 1900.

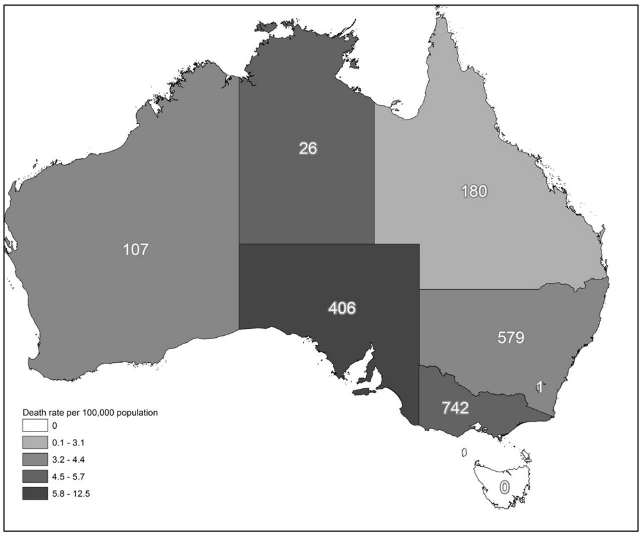

Fig. 2 – Heat-associated mortality by state 1907–2010 (from PerilAUS [2009 only], ABS and NCIS). The total death counts have been overlaid on each state/territory. The death rate per 100,000 population is calculated each year using the contemporaneous State population from ABS and then averaged over the length of the record.

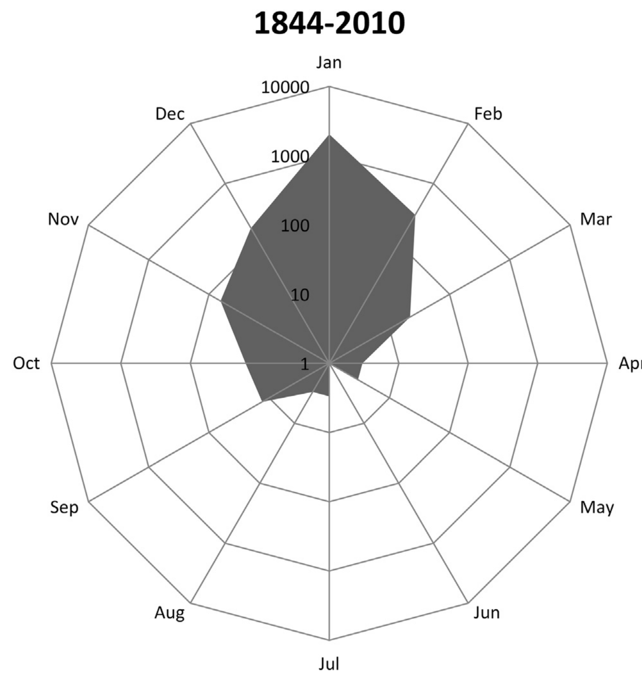

Fig. 3 – Monthly distribution of heat-associated mortality in Australia, 1844–2010 (from PerilAUS [1844–1909 and 2009], ABS [1910–1992] and NCIS [July 2000–2010]). The total number of heat-associated deaths per month appears on the vertical axis as a logarithmic scale below "Jan".

shown). Infants are overrepresented and there is a bell distribution for the remainder of the graph, with a "bulge" of deaths at around 50–89 years of age. Males are overrepresented until about 80 years of age.

When these data are shown as death rates (Fig. 4) there is a slight overrepresentation of infants and an increasing vulnerability of seniors with age. When examined in greater detail within three 55 year periods, the most recent time period displays a much lower death rate for the very young (data not shown). Death rates amongst seniors also show a decrease with time: however, seniors are increasingly overrepresented from about 75 years of age even in the most recent time interval.

One reason for relatively higher numbers of heat-associated deaths amongst the young is because even when

Table 2 – Deaths death rates and male-to-female death and death rate ratios per 100,000 population from extreme heat in Australia by decade, 1844–2010 (from PerilAUS 1844–1906 and 2009, ABS and NCIS). The final column adjusts the death rates for the gender imbalance in the early part of the 19th century.

Decade	No. of deaths	Death rate[a] per 100,000	Male to female *death* ratio	Male to female *death rate* ratio
1844–1849	5	0.30	1.00	0.63
1850–1859	48	0.65	4.00	2.75
1860–1869	61	0.45	5.40	4.25
1870–1879	112	0.59	4.67	3.93
1880–1889	80	0.30	5.67	4.81
1890–1899	483	1.40	3.44	3.03
1900–1909	535	1.33	2.17	1.99
1910–1919	827	1.69	2.14	2.06
1920–1929	616	1.04	1.50	1.45
1930–1939	803	1.19	1.65	1.60
1940–1949	384	0.52	1.25	1.23
1950–1959	285	0.31	1.19	1.17
1960–1969	276	0.24	1.06	1.04
1970–1979	164	0.12	0.50	0.50
1980–1989	56	0.04	1.55	1.55
1990–1999	65	0.04	0.75	0.76
2000–2010	532	0.26	1.08	1.10
Total: 5332				

[a] In this case, death rate was calculated using total deaths divided by national population from ABS averaged over the decade.

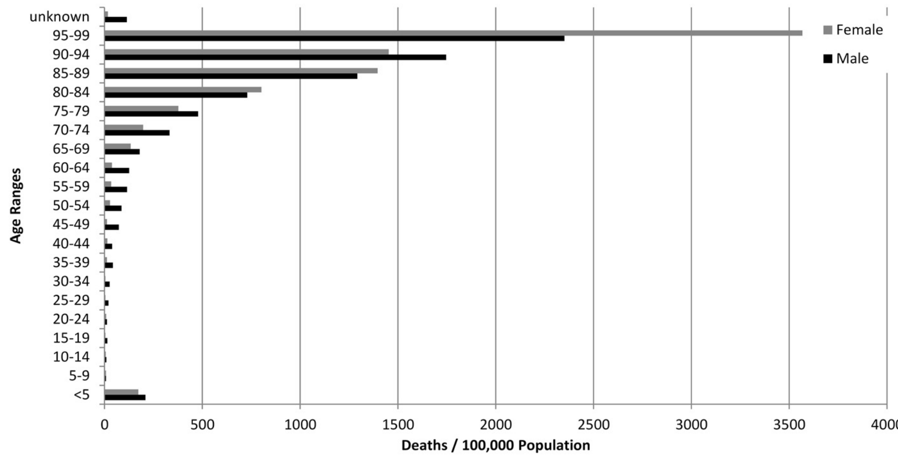

Fig. 4 – Heat-associated death rates in Australia by sex and 5-year age range, 1907–1992 (from ABS). The death rate per 100,000 population is calculated for each 5-year age range using the contemporaneous national population from ABS.

circumstances of death were not stated, especially in media reports, the approximate age often was, and so a death record with little more than "infant" was sufficient for it to be counted in this category. This also applies, to a certain extent, to seniors, whereas an "adult" could refer to anyone over 20.

In summary, excepting infants, especially those aged under one year, the elderly are significantly more vulnerable to the risk of heat-associated death than the general population, and this vulnerability increases with age. This holds true across the study period, except that infants and males of age 50–79 have become less vulnerable (or less exposed) than they were in earlier days.

3.1.5. *Activity of victims*

Table 3 summarizes circumstances surrounding heat-associated deaths. Data were queried for several different fields pertaining to radiant heat exposure, activity and other vulnerabilities such as location, age and whether the victim

Table 3 – Circumstances of victims of extreme heat in Australia, 1844–2010 (from PerilAUS [1788–2000 and 2009] and NCIS). Numbers in brackets are percentages of the category total of known deaths.

Interval	1844–1899	1900–1955	1956–2010
Total heat-associated deaths for that interval	789	3345	1198
In/out: number of known deaths	298	102	90
Indoors	17 (5.7)	26 (25.5)	33 (36.7)
Outdoors	281 (94.3)	76 (74.5)	57 (63.3)
Activity prior: number of known deaths	117	63	65
Working	58 (49.6)	28 (44.4)	13 (20.0)
Domestic duties	1 (0.9)	–	6 (9.2)
Travelling	19 (16.2)	11 (17.5)	13 (20.0)
Recreation	6 (5.1)	9 (14.3)	20 (30.8)
Walking	7 (6.0)	9 (14.3)	12 (18.5)
Other (talking; in camp; too young)	26 (22.2)	6 (5.1)	1 (1.5)
Other vulnerabilities: number of known deaths	208	182	380
Alcohol	3[b] (1.4)	–	10[a] (2.6)
Mental health issues	–	–	10[a] (2.6)
Sedentary activities	6[b] (2.9)	3 (0.2)	16 (4.2)
Disabled/being cared for by others	8 (3.8)	1 (0.1)	6 (1.6)
In the city	11[b] (5.2)	4[b] (0.2)	
In rural location	31[b] (14.9)	19[b](10.4)	1 (0.3)
Newly arrived	15 (7.2)	4[b] (0.2)	1 (0.3)
Senior	60[b] (28.8)	118[b] (64.8)	332[a,b] (87.3)
Very young (0–9 years)	88 (42.3)	39 (21.4)	24 (6.3)
Healthy/strong/young	2 (1.0)	–	–
Strenuous activity	1 (0.5)	1[b] (0.1)	–
Lived alone	–	–	3[b] (0.8)
Medical condition	–	–	35[a,b] (9.2)

[a] Large number influenced by Victorian Coroners' estimate of 2009 event.
[b] The "Other vulnerabilities" fields include some double counts, where more than one vulnerability factor was noted for a victim.

Table 4 – Significant heat events in Australia, 1844–2011 (from PerilAUS).

Date of event	Area affected	Total heat-associated deaths
January–February 1879	NSW, Vic	22
October 1895–January 1896	WA, SA, Vic, Qld, NSW	435
January 1906	NSW, SA	28
January 1908	Vic, SA, NSW	213
January 1939	NSW, Vic, SA	420[a]
January 1940	Qld, NSW	65
February 1955	Perth (WA)	30
January–February 1959[b]	Melbourne (Vic)	145[c]
January 1960	Greater Sydney (NSW)	25
January 2000	Southeast Qld	22
January–February 2009[b]	Vic, SA	432
Total deaths		1837

[a] The literature reports different totals: Gentilli (1980) quotes ABS total for the entire year, the figure used here is from PerilAUS.
[b] Two separate events.
[c] The figure used here is from a Bureau of Meteorology report (Rankin, 1959).

was newly arrived to the region. Temporal trends were examined across three time intervals. Some caveats are listed below.

Data (mainly from news media reports, which often have a wealth of descriptive detail) were available for only some of the events listed in PerilAUS and the NCIS dataset; none were available from the ABS. The percentage of deaths for which any data on circumstances are known for 1844–1899 is 52.1% (411 known out of 789 total deaths). Equivalent percentages for 1900–1955 and 1956–2010 are 7.3% (245 out of 3345 total) and 69.0% (827 out of 1198) respectively. These figures give an indication of trends but should be viewed with some caution due to the relatively low numbers involved.

As might be expected, most heat-associated deaths for which data are available have occurred outdoors (Table 3): however, this proportion is decreasing over time. This could be due to people working and spending less time outdoors than in earlier years and/or to a better understanding of potential dangers of heat and how to minimize them. However, those listed as dying indoors include some in hospital, or for whom the implication was they had recently moved indoors from outdoors: in many cases there was insufficient information to determine exactly what sort of temperature exposure had been experienced.

Table 3 shows changes according to other vulnerabilities, including a reduction in deaths occurring in rural locations; a number of these are also confounded by changing demographics. The overriding risk factor, however, is the vulnerability that comes with being very old.

3.1.6. *Occupation*

Data on occupation was available for only 7%, or 362, of the 5332 heat-associated deaths and therefore limited results were considered representative enough for discussion. Nonetheless, the proportion of those recorded as working at time of death has decreased over the period of study: from at least 26.6% (of those known) in 1844–1899 and at least 24.5% in 1900–1955 to at least 5.7% and exactly 9.4% in 1956–1999 and 2000–2010 respectively.

While labouring and/or working outdoors pose the most consistently at-risk professions across all time intervals, indoors occupations that have presented a risk on days of extreme heat are mining and, in the earlier years, food preparation. Both occupations are subject to lack of ventilation and hot working conditions.

3.2. *Significant heat events*

Table 4 lists the most catastrophic heat events in terms of fatalities that have occurred since European settlement of Australia. Events have been included if they caused 20 or more fatalities. As with other natural hazards (e.g., Blong, 2005; Coates, 1996; Haynes et al., 2010b), a large percentage of deaths has occurred in a small number of events. In the case of extreme heat, available PerilAUS data (and using ABS data for all post-1906 years bar 1959 and 2009) suggests that 1837 deaths have occurred in just 11events since 1844: approximately 34.5% of the 5332 known deaths. Using the more reliable data from 1900 this percentage becomes 30.3% in just nine events: 1380 out of an estimated 4555 deaths.

3.3. *Comparison with other Australian natural hazards*

Table 5 shows that extreme heat has been responsible for approximately 55% of all listed natural hazard fatalities recorded in PerilAUS from 1900: more than any other natural

Table 5 – Comparison of fatality totals with other Australian natural hazards (from PerilAUS).

Natural hazard	Deaths 1900–2011	% total natural hazard deaths 1900–2011
Extreme heat	4,555	55.2
Flood	1,221	14.8
Tropical cyclone	1,285	15.6
Bush/grassfire	866	10.5
Lightning	85	1
Landslide	88	1.1
Wind storm	68	0.8
Tornado	42	0.5
Hail storm	16	0.2
Earthquake	16	0.2
Rain storm	14	0.2

hazard, as determined earlier by Coates (1996), and also more than *all* other listed hazards together. [The natural hazards listed in PerilAUS include all geological and meteorological phenomena that have caused loss of life and/or damage to property.] Few of the other hazards listed have been supplemented by ABS *Cause of Death* data: however, it is unlikely that its provision would materially change the figures, as mortality from these hazards is much more readily identified from other sources. Moreover, with the under-reporting of heat-associated deaths, it is likely that extreme heat has killed many more people than has been reported here.

4. Conclusions and implications

Heat-associated deaths are, in general, not well documented. The present study has used a combination of lengthy historical record and other official sources to put a lower bound estimate of 5332 heat-associated deaths in Australia since 1844. There may be a good case for an upwards revision of these figures. Even so, Risk Frontiers' PerilAUS Extreme Heat Database suggests that extreme heat has been the most significant natural hazard of those listed in Table 5 in Australia in terms of fatalities, with the exception of disease epidemics and, since 1900, responsible for approximately 55% of fatalities caused by Australian natural hazards.

Most fatalities have occurred within the southeastern region of Australia, mainly in Victoria, NSW and South Australia and mostly during the summer months, particularly January. 27 January, the day after a public holiday to celebrate 'Australia Day', stands out historically as the date with the most heat associated deaths. Many people, in celebrating this holiday with barbeques and picnics outdoors, are subject to a significant amount of heat exposure and dehydration, the latter exacerbated by consumption of alcohol. This requires further investigation and investment in public safety communications.

The historical death rate has been highest in South Australia. The decadal death rate has fallen from 1.69 deaths per 100,000 population in the 1910s to 0.26 in the 2000s. The decrease can be attributed to a variety of factors, but mainly to reduced numbers of people working outside, a better-informed public, greater freedom of dress and improvement in utilities and services, such as home cooling, access and breadth of health services including aged care services, warning systems and rescue services.

Males have been most at risk and for most age ranges. The male:female death rate ratio has fluctuated over time and approaches but does not reach equality. This seems reasonable given that males have been most exposed to the elements, especially in relation to work such as farming, mining, labouring and travelling. Not surprisingly, those involved in physical work, especially if exposed to sun or other heat sources or in poorly ventilated areas (for example, labourers, farmers, cooks, miners) have an increased risk of dying in conditions of extreme heat. Although these results are based on limited data, the trends agree with the few other Australian studies (Andrews, 1994; Bi and Walker, 2001) and those from USA (e.g., Ebi and Meehl, 2007), but differ from the experience in the 2003 European heat event in Paris, where females represented 60% of excess deaths (Toulemon and Barbieri, 2008).

While Workplace Health and Safety messages and laws exist today, a ''business as usual'' attitude outside of work is evident in many cases, with likelihood of death aggravated by deliberate decisions. For the 1956–2010 period, for example, recreation has been the riskiest activity, indicating a lack of understanding of, or respect for, inherent dangers of extreme heat. Again, this data is based on limited figures and further investigation is required.

Overriding the above risk factors for dying in an extreme heat event is the vulnerability that comes with being old (see Section 1.2) and, to a lesser extent, very young. Increasingly, the elderly are relatively much more at risk from extreme heat than those engaged in any particular profession or in recreational activities, a conclusion supported by other studies (Bi et al., 2011; Fouillet et al., 2006; Henschell et al., 1969; Oeschli and Buechley, 1970). This is likely to be an increasingly important factor with an ageing population and if global mean temperatures increase as projected (IPCC, 2012). Reducing future impacts of extreme heat will be especially challenging as many of the most vulnerable groups represent those sectors of society most marginalized, lacking resources and difficult to reach.

During the 2009 extreme heat event, Haynes et al. (2010a) observed that South Australian emergency, social and health services were unprepared and had to develop a response as the event unfolded. Victorian plans were still under development when the event struck: their response was also ad hoc. Most planning currently relies on reducing risks through information and education to influence and change public behaviour, and emergency response when an event unfolds. However, while public education and emergency management is important, long term risk reduction must also consider urban planning, building design, community development and social equity (Bi et al., 2011; Haynes et al., 2010a; PricewaterhouseCoopers, 2011). The dangers from extreme heat within Australia remain neglected, and fundamental changes will not take place until extreme heat is given the priority it deserves as Australia's number one natural hazard killer.

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