Chapter Three

MORTALITY, MORBIDITY AND POPULATION VULNERABILITY

> *"Consequent upon the phenomenal heat the death rate in the city and suburbs last week assumed alarming proportions. A glance at the records of the Necropolis and of the Waverley Cemetery shows that immediately after the excessively high temperature the mortality rate more than doubled, decreasing again towards the close of the week. No less than 250 deaths were recorded during the week within a short radius of the city - a number exceeding that of any period since the influenza epidemic of four or five years ago. ... The great bulk of the deaths recorded were those of infants and very aged people, but there was also a large number of deaths in the prime of life, resulting from sunstroke and heat apoplexy. As there was no other cause which would tend to double the mortality rate during the last week, it may reasonably be assumed that at least 120 of the deaths in the city and suburbs were directly attributable to the effects of the weather."*
>
> Sydney Morning Herald, January 21, 1896 (5e).

This chapter summarises the literature regarding the impact of heatwaves on humans, both in terms of mortality and morbidity, and examines heatwave and heat-related deaths in Australia. Excess death rates during heatwaves at Broken Hill and Sydney provide another perspective on mortality associated with this natural hazard. The concept of heatwave risk is explored, with emphasis on the delineation of high risk locations, times and vulnerable population groups. This chapter begins with some background information as to the health effects of heat on humans, and the methodological problems involved with analysing heatwave-associated mortality.

3.1 Health Effects of Excess Heat

The illnesses directly attributable to the effects of heat are heatstroke, heat exhaustion, heat syncope, and heat cramps. A description of the symptoms and causes of these syndromes is included in *Appendix* 2. Heatstroke is the only one of these ailments with a substantial death-to-case ratio (from 0 to about 40% (Kilbourne, 1989)), and it is therefore reasonable to suppose that most deaths directly attributed to the heat are due to heatstroke. Existing data, although scarce, tends to support this (Henschel, *et al.*, 1969; Jones *et al.*, 1982). All of these illnesses contribute to heightened morbidity.

Heatwaves also increase mortality and morbidity due to the aggravation of pre-existing illnesses. A list of causes of death considered to be weather sensitive is given in *Table 3.1* Although Kalkstein & Davis (1989) concluded that mortality from a wide variety of causes

Table 3.1. Causes of Death Considered to be Weather-Related (source: Kalkstein & Davis, 1989:47).

Active rheumatic fever
Adverse effect of medicinal agents
Cerebrovascular disease
Complications of pregnancy, childbirth, and the puerperium
Contusion and crushing with intact skin surface
Disease of the arteries, arterioles, and capillaries
Diseases of the blood and blood-forming organs
Diseases of the digestive system
Diseases of the musculoskeletal system and connective tissue
Diseases of the nervous system and sense organs
Diseases of the skin and subcutaneous tissue
Diseases of the veins and lymphatics
Effects of foreign body, entering though orifice
Endocrine, nutritional, and metabolic diseases
Fractures of the skull, spine, trunk, and limbs
Hypertensive disease
Influenza
Injury to nerves and spinal cord
Intracranial injury
Ischaemic heart disease
Neoplasms: benign
Neoplasms: malignant
Superficial injury
Toxic effect of substances of chiefly non-medical sources

increases during extreme summer weather, and that attributing excess deaths to a few specific weather-related causes was specious, the bulk of heatwave-associated deaths (up to 90%) are believed to be caused by heart disease and stroke (Schuman *et al.*, 1964; Henschel *et al.*, 1969; Bridger & Helfand, 1968; Schuman, 1972; Kilbourne, 1989). Several studies have concluded that ischaemic heart disease is the primary contributor to excess mortality affecting mostly the elderly (Riebsame et al, 1986; Ellis et al, 1975; Ellis & Nelson, 1978: Tout, 1980).

In this thesis, *heat* or *heatwave-deaths* refer to deaths directly attributed to extreme heat. *Heat* or *heatwave-related* deaths are those which result from the exacerbation of pre-existing illnesses. *Heat* or *heatwave-associated* mortality refers to all deaths attributable to the heatwave; i.e., heat deaths and heat-related deaths combined.

3.2 Methodological Problems

3.2.1 Coding of Heat Deaths

According to the ICD (International Classification of Diseases 1975 revision, 1977) cause of death can be classified as *"excessive heat"* (Code E900), which is in turn broken into *"excessive heat as the external cause of ictus solaris, siriasis, sunstroke"* (Code E900.0); *"of manmade origin"* (Code E900.1) or *"of unspecified origin"* (Code E900.9). Excessive heat may also include dehydration if it is not specifically described as *"thirst"*.

This coding has changed with time. When the first code appropriate to heat-related deaths was introduced in 1907 the descriptor was *'insolation'*. From 1910 the term *'effects of heat'* was implemented, in 1950 this changed to *'excessive heat and insolation'*, and from 1967 to 1978 became *'heat effects'* (Code N992), which excluded burns and sunburn (ICD, 1967). These earlier codes do not exclude deaths caused by heat from other sources besides weather. Changes to the coding system through time result in potential, though unquantifiable, inaccuracies in the data.

Diagnosing heat deaths is difficult, and many researchers have been lead to conclude that certification of death as due to heat is rare, and heat deaths recorded on death certificates underestimate the number of deaths that result from excess heat (Ellis & Nelson, 1978; Schuman, 1972; Oeschli & Buechley, 1970).

Because deaths caused by the exacerbation of a pre-existing condition are generally recorded officially under that pre-existing condition, the number of deaths diagnosed as caused by heat regularly underestimates total heatwave-associated mortality. In the United States, this has resulted in the underestimation of heat associated mortality by 10 to 100% (Ellis, 1972; Ellis *et al.*, 1980; Bridger & Helfand, 1968; Jones *et al.*, 1982)

3.2.2 Excess Mortality

Excess mortality refers to the difference between the number of deaths actually observed and the number of deaths expected, based on the crude death rate in the same geographic area. In this manner it quantifies the total effect of heatwaves on mortality in a method which avoids the complications and inadequacies of the death coding system. Excess deaths provide an estimate of the total heatwave-associated mortality.

Excess mortality appears to represent a real increase in the number of people dying, as opposed to simply the hastening of predestined deaths. Mortality increases are not countered by a corresponding decrease in the weeks following a heatwave (Ellis *et al.*, 1975; Henschel *et al.*, 1969), and Schuman *et al.* (1964) noted that mortality increased in a 1963 heatwave, despite the recent culling of vulnerable people by an influenza epidemic.

3.2.3 Measuring Heat Stress

While temperature is the most important factor in causing heat stress, humidity, air motion and radiant energy are also relevant. Several indices of heat stress have been developed and these include Effective Temperature and Apparent Temperature (Kilbourne, 1989). A review of heat indices is provided by Lee (1980).

3.2.4 Meteorological Data

There is wide variation in the definition of a heatwave used in heatwave-related mortality studies, with some studies making little differentiation between death due to excess heat and death due to heatwave. Definitions adhered to in most of the following studies use *Definition 1* where a heatwave is defined by the media (*Chapter* 2.4). Temperatures recorded for the heatwaves ranged from 20°C (Ellis *et al.*, 1980) to over 40°C (Kilbourne, 1989).

The extrapolation of temperature data to large areas or locations other than the meteorological recording site is essential under most circumstances, but erroneous. Macpherson *et al.* (1967), for example, reported a 4.4°C difference between maximum temperatures in a suburb in Sydney and the temperature recorded at the Sydney Observatory.

3.3 Heatwave-Associated Mortality and Morbidity

3.3.1 Mortality

The global impact of heatwaves on mortality is summarised in *Table 3.2*. Recent estimates conclude that between 175 and 212 Americans die annually as a result of 'excessive heat' (Posey, 1980; Riebsame et al, 1986), with much higher rates in 'heatwave years'. Mortality increases associated with heatwaves have been likened to those experienced in epidemics; in the July 1901 heatwave in the Middle West over 9,500 deaths were attributed to the heat and around 15,000 people in relation to a series of heatwaves in the 1930s (Posey, 1980). A heatwave in St Louis in July 1966 was the primary or secondary cause of death for one fifth of all those who died that month (Oecshli & Buechley, 1970).

According to registered deaths 45 people died annually in the period from 1939-1968 (Gentilli, 1979), and a total of 1,596 deaths were ascribed to excessive heat for the period from 1939-1977 (Gentilli, 1980). *Table 3.3* shows significant years for this period in terms of heat deaths recorded on death certificates, as reported by Gentilli (1980). The maximum number of deaths occurred in 1939, when 420 deaths were recorded on death certificates as caused by excessive heat (Gentilli, 1980).

Table 3.3: Significant years in terms of heat deaths for Australia, 1939 to 1977 (after Gentilli, 1980:85).

Year	No. of deaths
1939	420
1940	80
1943	58
1946	52
1959	145
1960	92
1973	92

Little work has been undertaken in Australia on individual heatwave events in relation to mortality. A coronial inquiry was undertaken following the 1959 Melbourne heatwave

Table 3.2 Mortality Associated with Heatwaves

LOCATION	DATE	COMMENT	REFERENCE
US	per annum	~175 deaths due to heat	Posey (1980)
	per annum	212 deaths annually	US House of Representatives (1984)
	1932	678 people died	Posey (1980)
	1930-36	15 000 Americans killed	Posey (1980)
	1936	4,768 people died. A total of about 15,000 people died during the dust bowl years of the 1930s	Posey (1980)
	1936-1975	20,000 people killed as a result of heatwaves	Posey (1980)
	1952, 1953, 1954, 1955, 1966	More than 500 deaths per annum	Ellis (1972)
	1980	Estimated 1,600 deaths and an economic loss of $15 billion	Riebsame et al (1986)
California	Sept 1955	445% increase in mortality in the 'over 50' age group	Oeschli & Buechley (1970)
Los Angeles	1939	546 excess deaths, in a 9 day period	Oechsli & Buechley (1970)
	1955	946 excess deaths	Oechsli & Buechley (1980)
	1963	580 excess deaths	Oechsli & Buechley (1970)
Detroit	May 1962	104 excess deaths	Schuman *et al.*, 1964
	June 1963	114 excess deaths	Schuman *et al.*, 1964
Georgia	July 1983	35 heat related deaths	MMWR (1984)
Missouri	1979-1988	491 deaths due to excessive heat	MMWR (1989)
St Louis	July 1 to Aug 31, 1936	113 deaths attributed to heat	Bridger *et al.*, 1976.
	July 7 to Aug 8 1953	27 deaths attributed to heat	Bridger *et al.*, 1976.

Table 3.2 Mortality Associated with Heatwaves cont.

LOCATION	DATE	COMMENT	REFERENCE
St Louis cont..	July 1- August 31, 1954	121 deaths attributed to heat	Bridger *et al.*, 1976.
	July 3- Aug 31, 1955	56 deaths attributed to heat	Bridger *et al.*, 1976.
	July 1966	246 deaths were caused by the heat, and heat contributed to a further 40 deaths 570 excess deaths from all causes	Henschel *et al.* (1969) Schuman (1967)
	July 21 to July 18, 1980	230 excess deaths, 108 deaths attributed to heatstroke	MMWR (1980)
	July 11- August 15, 1983	35 heat related deaths	(MMWR, 1984)
Middle West	July 1901	9,508 people died	Posey (1980)
New York	1925	Death rate increased by 60%	Ellis & Nelson (1978)
	1937	Death rate increased by 45%	Ellis & Nelson (1978)
	1948	Over 100% increase in death rate	Ellis & Nelson (1978)
	1955	Increase in mortality of 946 deaths or about 105 per day	Oeschli & Buechley (1970)
	1955	Increase of 445% over the expected number of deaths of persons over 65% after one day of 110F (43.4°C)	Oechli & Buechley (1970)
	1963	Increase in mortality rate of 580 deaths or about 50 a day	Oeschli & Buechley (1970)
	July 1966	Death rates were more than doubled	Posey (1980)
Philadelphia area	July 1- 13, 1993	84 deaths	MMWR (1993)
Texas	July 1978	25 deaths attributed to excess heat	Posey (1980)
Dallas	July 1980	16 deaths attributed to heatstroke	MMWR (1980)
Australia	per annum	7 people dying annually	Curson in Linacre
	1939	420 deaths, 229 in NSW and 77 in SA. Most deaths in Jan. 230 males and 138 females.	Gentilli (1979)

Table 3.2 Mortality Associated with Heatwaves cont.

LOCATION	DATE	COMMENT	REFERENCE
Australia cont..	1939-1968	745 males and 581 females officially attributed to heat	Gentilli (1979)
Melbourne	Jan- Feb 1959	145 people died	Rankin (1959)
	1962	47 cases and 8 deaths occured in babies in a heatwave in Melbourne	Isbister (1980)
Adelaide	Feb 1970	Approximately 3 fold increase in death rate of people aged 65+	Keig & McAlpine (1977)
England & Wales	1976	3000 excess deaths	Ellis *et al.*, 1980
Greater London	late June 1976	33% increase in death rate for a two week period	Tout (1980)
London	1970	3,650 deaths	Linacre
Greece	July 20-27 1987	1,280 deaths in total, 1,115 in Athens and the remaining in the rest of Greece. Athens was also very smoggy	Prezerakos (1989)
	July 4-9, 1988	At least 7 people died, and newspaper reports quoted more thatn 3,000 people going to hospital with heat problems	Giles & Balafoutis (1990)

where 145 people died as a result of heat-related conditions (Rankin, 1959). Most of these people were elderly, and most deaths occurred in the first period of heat, January 9th to 25th, even though the second heat period, January 31st to February 2nd, was equally severe. Danks *et al* (1962) documented a series of 47 cases of heat exhaustion and 8 deaths among babies in a 1962 heatwave in Melbourne. Keig & McApline (1977) showed that mortality from all causes for people over 65 years increased by approximately three-fold during a heatwave in February 1970.

Heat related deaths have also occurred in the United Kingdom where a maximum daily temperature of just over 20°C is sufficient to cause a concurrent rise in mortality (Bull & Morton, 1978; Ellis *et al.*, 1980). Weekly death rates rose by up to 41% for those aged above 65 in July 1976 (Tout, 1980), and hot spells in 1968, 1975 and 1976 also coincided with increases in the death rate in Greater London (McFarlane & Walker, 1976). In Europe, a heatwave in Greece, July 1987, caused 1,280 deaths when temperatures exceeded 40°C (Giles & Balafoutis, 1990).

While the majority of these studies focus on the effects of individual heatwaves, additional work has addressed the relationship between heat and mortality from a different perspective. Kalkstein & Davis (1989) evaluated the impact of weather on mortality at a national scale in the United States, and derived the Threshold Temperature[1] for 49 cities in the United States. Threshold Temperature represents the temperature above which mortality noticeably increases.

Oeschli & Buechley (1970) empirically formulated an equation for predicting mortality for specific age groups at certain temperatures (ATMR)[2], which was later reworked to the TMR (Temperature Specific Mortality Rate)[3]. This allowed the estimation of excess mortality (% of yearly total) for different temperatures for the age 65-69. The predicted excess mortality for temperatures above 90°F are shown in *Table 3.4.* Marmor (1978)

[1] see *Section 3.4.1.ii.*

[2] Age Temperature specific Mortality Rate (ATMR) is a predictive equation between mortality, age and temperature: ATMR = B1+ exp (B2 + B3Age + B4Temperature), where the constants are estimated by succesive approximations (Oeschli & Buechley, 1970).

[3] $TMR = Cycle + 10e^{2(F'-90)}$, where Cycle is the expected mortality for the date, and F' is yesterday's maximum temperature. (Buechley *et al.*, 1972).

developed a similar predictive equation for New York, with a 5% increase in mortality expected at 30°C, and a 56% increase at 37°C.

Table 3.4. Predictions of excess mortality in the United States for different temperatures based on the TMR (Buechley *et al.*, 1972:87).

Temperature (°C)	Excess Mortality due to heat (% of yearly total)
<32.2	negligible
35	27%
38	75%
40.5	200%
43	546%

Oeschli & Buechley (1970) believed that the maximum temperature with a one day lag period is the single meteorological variable with the greatest predictive value for excess mortality, despite the fact that other meteorological variables undoubtedly influence the intensity of heat stress (see Kalkstein & Davis, 1989; Lee, 1980). Death rates in New York during the heatwave of July 1966 peaked at 2.39 times the expected, one day after the maximum temperature was reached. Other studies have emulated these results (Bull & Morton, 1978; Ellis, 1972; Ellis *et al.*, 1975; Henschel *et al.*, 1969; Kalkstein & Davis, 1989), although different lag rates have been delineated for specific diseases[4]. Henschel *et al.* (1969) believed that this lag reflected the time required for heat to build up in the buildings in which people live and work, and the time required for physiological reserve capacities of individuals to be overwhelmed. Alternatively, heat exposure has been shown to produce changes in blood composition which promote arterial thrombosis[5], and therefore affect health, relatively soon, following a heatwave (Kilbourne, 1989).

Gover (1938, in Kilbourne, 1989) reported that excess mortality during a second heatwave in any year was slight in comparison to excess mortality during the first, even if the

[4] Bull & Morton (1978) noted a 1-2 day lag period for myocardial infarction and a 3-4 day lag for stroke.

[5] Coagulation of blood in the arteries

second is unusually extreme. Kalkstein & Davis (1989) found that hot weather appeared to produce no extra deaths in Jackonsville, Florida. These represent the affect of acclimatisation, which refers to the increased ability of humans to withstand stressful conditions following repeated exposure to those conditions. Acclimatisation may be either seasonal or geographical. Possible explanations include the culling of susceptible or weak members of the community in early heatwaves, or the physiological or behavioural adaption of survivors of heatwaves. A brief analysis undertaken by Kalkstein & Davis (1989) suggested that the position of a hot day within a hot spell has little impact on mortality. This suggests that adaption, as opposed to culling of the weak, is responsible for the diminishing effect of hot spells throughout a summer season.

3.3.2 Morbidity

Mortality statistics represent only the tip of the iceberg, with morbidity in heatwaves widespread, albeit less well quantified. Available statistics suggest that between 1 and 10% of heatstroke casualties actually expire, leaving a vast number of sufferers (Bridger *et al.*, 1976). In addition, the diseases listed in *Appendix 2* also contribute to morbidity, as does the exacerbation of pre-existing conditions. The number of hospital admissions and emergency room visits have been observed to increase during hot weather (Ellis *et al.*, 1980; Hamer, 1990; Jones *et al.*, 1982), and Ellis (1972) showed that the number of accidents increase with temperature in hot and humid climates. In Australia, extreme temperatures caused 2,809 compensated workplace injuries in 1986-87 alone (Budd, 1990).

Heat stress in Israel has been associated with increased neuroticism and extroversion, and lower intelligence and comprehension (Rim, 1975). In America, high temperatures are usually accompanied with an increase in homicides (Bell, 1981; Robbins *et al.*, 1972; Miller, 1968). Conclusions on suicide trends and high temperature are dichotomous (see Schuman, 1972; Robbins *et al.*, 1972), as are those for aggression (see Ellis *et al.*, 1980; Barron, 1972). Similarly, Bell (1981) found a decrease in helping behaviour at high temperatures, in contrast to Schneider (1980) who concluded that Canadians were more helpful at temperatures around 33°C.

Temperatures over 27.2°C have been found to impair vigilance, mental performance and manipulation skills (Budd, 1979). Night-time temperatures above 27°C result in a disturbed and unsatisfying sleep, also inhibiting an individual's ability to function (MacPherson & Muncey, 1962; Lambert, 1963). Conception rates fall at temperatures above 23°C, and exceptionally hot weather in the third month of pregnancy increases the chance of schizophrenia or mental deficiency in the newborn child (Tromp, 1967).

Because of the limited quantity of research into these specific subject areas with often contradictory results, there is need for replication of results before specific conclusions regarding the relationship of heatwaves to morbidity can be sustained.

3.4 The Impact of Heatwaves on Australians

There are three components to this analysis of the effects of heatwaves on Australians:-

1. A Database of Deaths caused by Heatwaves/Excessive Heat since 1803 which provides the most comprehensive compilation of heat victims available in Australia.
2. The analysis of daily death rates in conjunction with daily maximum temperature at Sydney and Broken Hill to ascertain Excess Death rates and Threshold Temperatures for these two sites.
3. An examination of crime statistics to determine if temperature effects this aspect of human behaviour.

3.4.1 Data Sources and Methodology

i. *Database of Heat Deaths*

This database was developed by the author from information available at the Australian Bureau of Statistics (ABS) and *The Sydney Morning Herald.*

ABS data is subject to the changes in the coding discussed in *Section 3.2.1.* Records for the years 1907 to 1962 were available from Annual Record Books at the ABS library, where yearly totals of heat deaths are divided by age (5 year brackets), sex and state. From 1911 the month of registration of deaths (as opposed to the month of death) was recorded. For 1963 to 1992, records of individual deaths were obtained in computer format from the Registries of Births, Deaths and Marriages for the various States and Territories. The deceased's age, sex, date of death, and (if male) occupation were provided. Because of changes to Shire Boundaries, and additional changes in the techniques of coding location (from place of registration to usual residence), the location of individuals was supplied at a State level. This records the location of usual residence. Vital statistics for full-blooded Aborigines were not included in ABS statistics until 1968, and occupation was omitted from female records until 1989. Occupation refers to the occupation at time of death.

These data were supplemented with accounts of heat deaths obtained from *The Sydney Morning Herald* (formerly *The Sydney Gazette*) since 1803 (with the exception of 1868-69 and 1971-76) collected by the Natural Hazards Research Centre. These newspaper registrations provide a record of deaths before the onset of the official recording of heat deaths in 1907. *The Sydney Morning Herald* was originally a chronicler of incidences and life in the colony, and therefore provides a reasonably thorough historical record of heat deaths before 1907. Records are, however, biased towards Sydney and New South Wales, well-populated areas, long-established areas, and locations which had the means and inclination to communicate with *The Sydney Morning Herald* in that period. It is also likely that deaths of women, aborigines and convicts were viewed as less news-worthy in the early years of colonisation because of their lower status within the community.

Reports of heat deaths in *The Sydney Morning Herald* are portentous in the contribution of personal statistics regarding the heat victim, information which is unavailable from official sources until 1963. Details regarding the age, sex and occupation of the deceased, their activity before death and the location at death were acquired, when available. The temperature and length of the heat period, and the time of death within the heat period were also included. Deaths recorded in *The Sydney Morning Herald* were cross tabulated by year, age, sex and state with statistics from the ABS to determine if the reported death was officially a heat-death. If there was no official record of a death that satisfied the victims vital statistics, then *The Sydney Morning Herald* record was ignored. If the quota for each year, age, sex, state group from ABS records was already filled with *The Sydney Morning Herald* records then the death was also ignored.

Where otherwise noted, analysis of deaths is centred on the official ABS data from 1907.

ii. ***Excess Deaths at Sydney and Broken Hill***

The total number of deaths on a daily basis for Sydney and Broken Hill, 1977 to 1992 were provided by the ABS. These two sites were chosen because of the availability of maximum daily temperature data (*Chapter Two*).

Excess Death rates were derived for heatwaves in accordance with *Definitions* 2 and 3 (*Chapter* 2.4), using the equation described in Marmor (1978):

> Excess death $(E) = n1 - (nc/dc)d1$, where $n1$ is the number of deaths which occur in a period of interest lasting $d1$ days, and nc is the number of deaths which occur in a control period dc.

In their analysis of specific heatwaves, Oeschli & Buechley (1970) specified the control period as a 42 day period, minus 9 days of hot spell, while Marmor (1978) defined the control as all days in the relevant summer which satisfied certain temperature requirements. For this study, the control period is the 10 day period immediately prior to the defined heatwave. If a heatwave occurred in this control period another earlier control was used.

A computer model was created[6] to derive threshold temperatures for Sydney and Broken Hill, based on Kalkstein & Davis (1989)[7].

iii. *Crime Rates*

Daily totals of the incidence of various crimes; motor vehicle accidents, arson, general stealing, sexual assault, aggravated sexual assault, offensive behaviour, murder, manslaughter, liquor offences, aggravated assault and other assault; were obtained for Sydney from The Bureau of Crime Statistics for 1992-93. These rates were correlated with daily maximum temperature.

3.4.2 Results

A total of 4,287 deaths have occurred as a result of excessive heat since 1803, 3,835 of these registered by the ABS since 1907, and the remaining 752 reported in *The Sydney Morning Herald* for the years 1801 to 1906. Information on individual victims of excessive heat is available for 1,607 casualties, based on *The Sydney Morning Herald* records until

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[6] by Laraine Hunter (Natural Hazards Research Centre, Macquarie University)

[7] Threshold temperature is calculated objectively by measuring the dissimilarity of mortality rates above and below a given temperature. For a given temperature the mean mortality is calculated for all days above and all days below that temperature. Then the sum of the squared mean deviations is computed for each group, yielding two variance measures. Finally, the sum of these variances or the total sum of squares (TSS) is calculated for this temperature. The procedure is then repeated at one degree increments, producing an array of TSS values. The temperature with the smallest TSS is chosen as the threshold temperature, since this represents the point where between group variances are minimised, (Kalkstein & Davis, 1989:49).

1962, and ABS data post-1962.

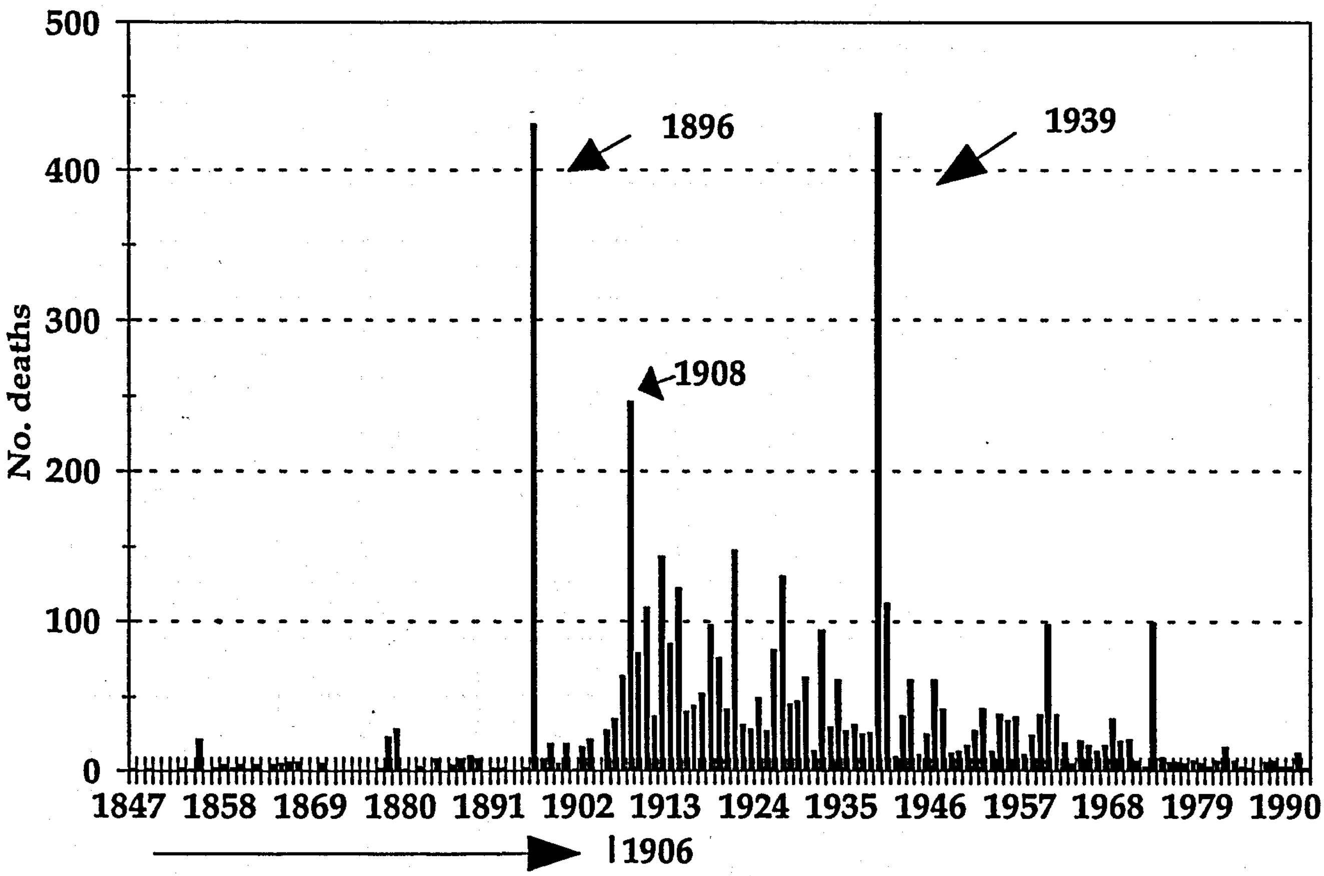
Figure 3.1 shows the distribution of heat deaths by financial year since 1846 when the first death was recorded. Substantial peaks occurred in the summer of 1895/1896 and 1938/1939 when in excess of 400 deaths were recorded[8]. Substantial numbers of deaths also occurred in 1907/08. Summers of numerous heat deaths are listed in *Table 3.5.*

Table 3.5. Summers of Numerous Heat Deaths.

Year	No. of deaths
1895/96	431
1907/08	246
1909/10	109
1911/12	143
1913/14	122
1920/21	147
1926/27	130
1938/39	438
1939/40	112
1959/60 .	98
1972/73	99

The annual number of deaths has declined substantially since 1974, in comparison with earlier years. The assumption that this is the result of changes in the coding of deaths would be specious, since the latest change occurred in 1977 (see *Section 3.2.1*); however, it is a potential factor. Decadal death rates are given in *Table 3.6* and reveal a steadily declining death rate, and indeed a declining gross total of deaths. The maximum death rate occurred in the period 1907-1909, when over 3 deaths per 100,000 population were attributed to heat. This rate has subsequently declined to a low 0.04 per 100,000 since 1980. The cause of this drop may be changes in clothing, with a trend since the 1900s to

[8] These two years will be discussed in more detail in *Section 3.4.2.iv.*



Deaths recorded in the SMH before official records
NB: deaths for years 1907-1910 are by calender not financial year

Figure 3.1 Distribution of Heat-deaths in Australia by financial year, 1846-1992.

lighter and more sensible fashions. Infants in particular were overdressed around the turn of the century.

Table 3.6. Total number of deaths and death rates per 100,000 from excessive heat. *Not official records: Data is obtained from *The Sydney Morning Herald.*

Decade	No. deaths	Death Rate per 100,000	Ratio of Males to Females
1840-1849*	2	0.07	1.0
1850-1859*	34	0.46	3.3
1860-1869*	29	0.21	4.4
1870-1879*	58	0.16	4.8
1880-1889*	41	1.36	7.5
1890-1899*	469	0.56	3.4
1900-1906*	120	0.02	6.5
1907-1909	389	3.21	1.90
1910-1919	827	1.69	2.14
1920-1929	616	1.03	1.50
1930-1939	803	1.19	1.65
1940-1949	384	0.51	1.24
1950-1959	285	0.31	1.19
1960-1969	276	0.24	1.06
1970-1979	164	0.13	0.5
1980-1989	56	0.04	1.55
1990-1992	15	0.04	1.14

i. ***Vulnerable Populations***

Males, the elderly, and infants aged less than 1 are the most likely to die from the effects of excessive heat in Australia. *Figure* 3.2 shows the age and sex distribution of heat victims in Australia, 1907 to 1992. Total deaths are greatest among children less than 2, especially babies in their first year of life, males at age 55-59 and 70-74 and females aged 80-84. Because these are total figures it would be fallacious to assume that they illustrate

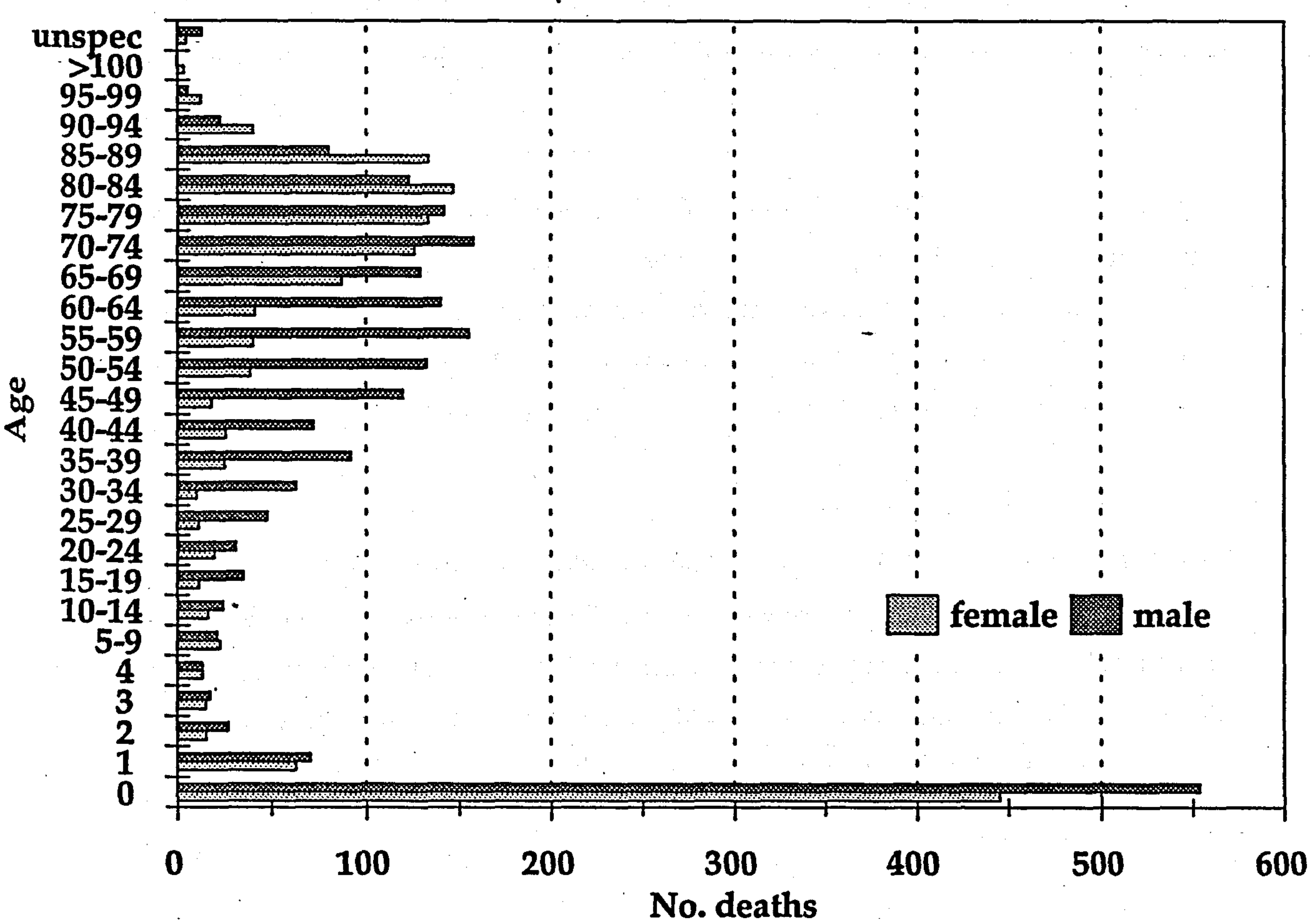


Figure 3.2 Age-Sex Distribution of Heat Fatalities in Australia, 1907-1992.

relative vulnerability between age:sex groups. Breaking the data into thirty year time periods provides a more sensible time span in which to analyse age:sex standardised mortality rates, and these are displayed in *Figure 3.3*. Since these graphs take into account the relative population size in each group, they show that older people are significantly more vulnerable to the effects of heat, and this vulnerability increases with age. The exception to this rule is the relatively high number of children aged 0-4 effected by heat. Interestingly, while men are generally more vulnerable than women, the number of women dying increases relative to the number of men as age increases. Since these data are age:sex standardised it appears that in older age groups, women are more vulnerable to the effects of heat. Although mortality rates have decreased since 1907, *Figure 3.3* also shows that the general distribution of vulnerability has not changed much between the three time periods.

Occupations associated with outdoor and physical activities dominate the professions of male heat fatalities. *Table 3.7* lists the employment types of fatalities for which information is available (170 fatalities) with the number of deaths in each category. Jobs associated with farming and the land, construction and building and trade and labouring were those most frequently occupied by heat victims. Other occupations range from publicans to pilots.

The activity of the victim immediately before death or onset of illness was recorded from *The Sydney Morning Herald*, and the results are summarised in *Figure 3.4*. Information was available for 167 victims, 67% of whom were engaged in some sort of outside activity prior to death with 41% of fatalities being physically active. Labouring, walking and travelling appear to be dangerous past-times in terms of vulnerability to heat stress.

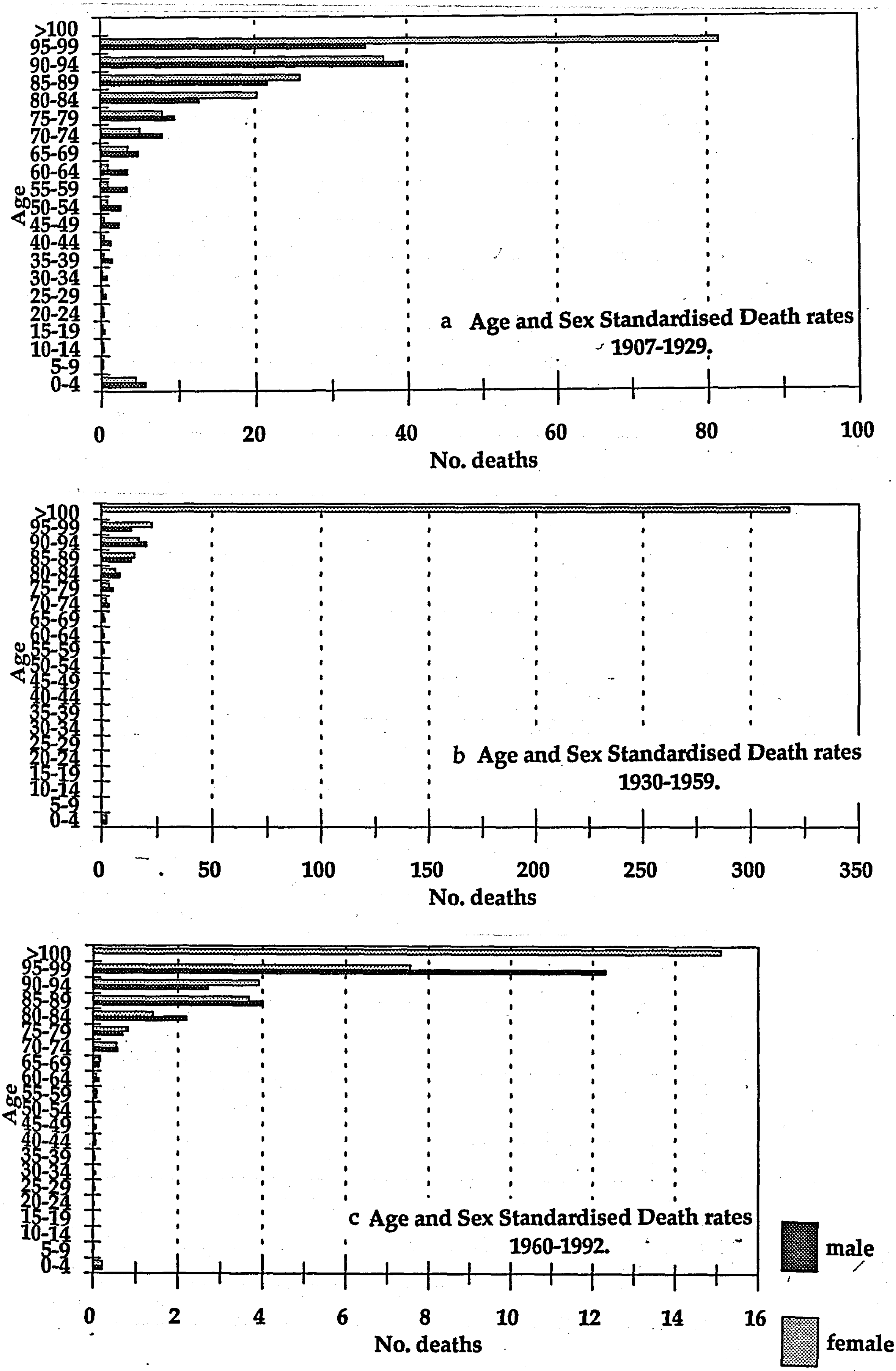


Figure 3.3 Age-Sex Standardised death rates for Heat-death Fatalities in Australia
a: 1907-1929
b: 1930-1959
c: 1960-1992

Table 3.7. Occupations of Victims of Heat Stress (based on records from *The Sydney Morning Herald*, 1803-1983 and ABS, 1964-1992).

Occupation	No. of Deaths
Associated with Farming and the Land	48
Construction and Tradespeople not including Labourers	46
Labourers	26
Students	22
Railway Worker	20
Not in Workforce	16
Administration/Clerical	13
Pensioner/Child	11
Miners	11
Coachmen/Travellers/Team Drivers	8
Cooks/Butchers/Bakers/Food Workers	8
Proprietor/Publican	5
Ranger/Gardener	5
Sales Worker	4
Seaman/Water Transport Crew	4
Religious (Priest/Reverend)	3
Tailors	3
Caretaker	3
Postman	3
Painters and Decorators	2
Jockey	2
Glazier	1
Wheelwright	1
Professional Athlete	1
Professional	1
Superintendent	1
Lamplighter	1
Lifter	1
Oddboy	1
Pilots and Navigators	1
Radio/TV Technician	1

HAZARDOUS ACTIVITIES

- OUTSIDE (67%)
  - LABOURING OUTSIDE (22%)
  - WALKING (19%)
- TRAVELLING (15%)
  (Train, Coach, Ferry)
- INSIDE (16%)
  - PHYSICAL WORK INSIDE (2%)
  - NOT PHYSICAL WORK (14%)
- DRINKING (2%)

Figure 3.4: Activity prior to death of heat-victims recorded from *The Sydney Morning Herald.*

ii. *Vulnerability and Location*

The distribution of deaths by year and state, based on ABS records is given in *Figure 3.5,* and provides a chronology of the heat risk to the various states and territories. The majority of deaths in 1939 occurred in New South Wales, while in 1908 over half of all deaths took place in Victoria. Almost 100 deaths occurred in South Australia in 1927. The total number of deaths by state are displayed in *Figure 3.6,* and the majority took place in New South Wales. The number of deaths in the Northern Territory, the Australian Capital Territory and Tasmania are very low in comparison with the other states.

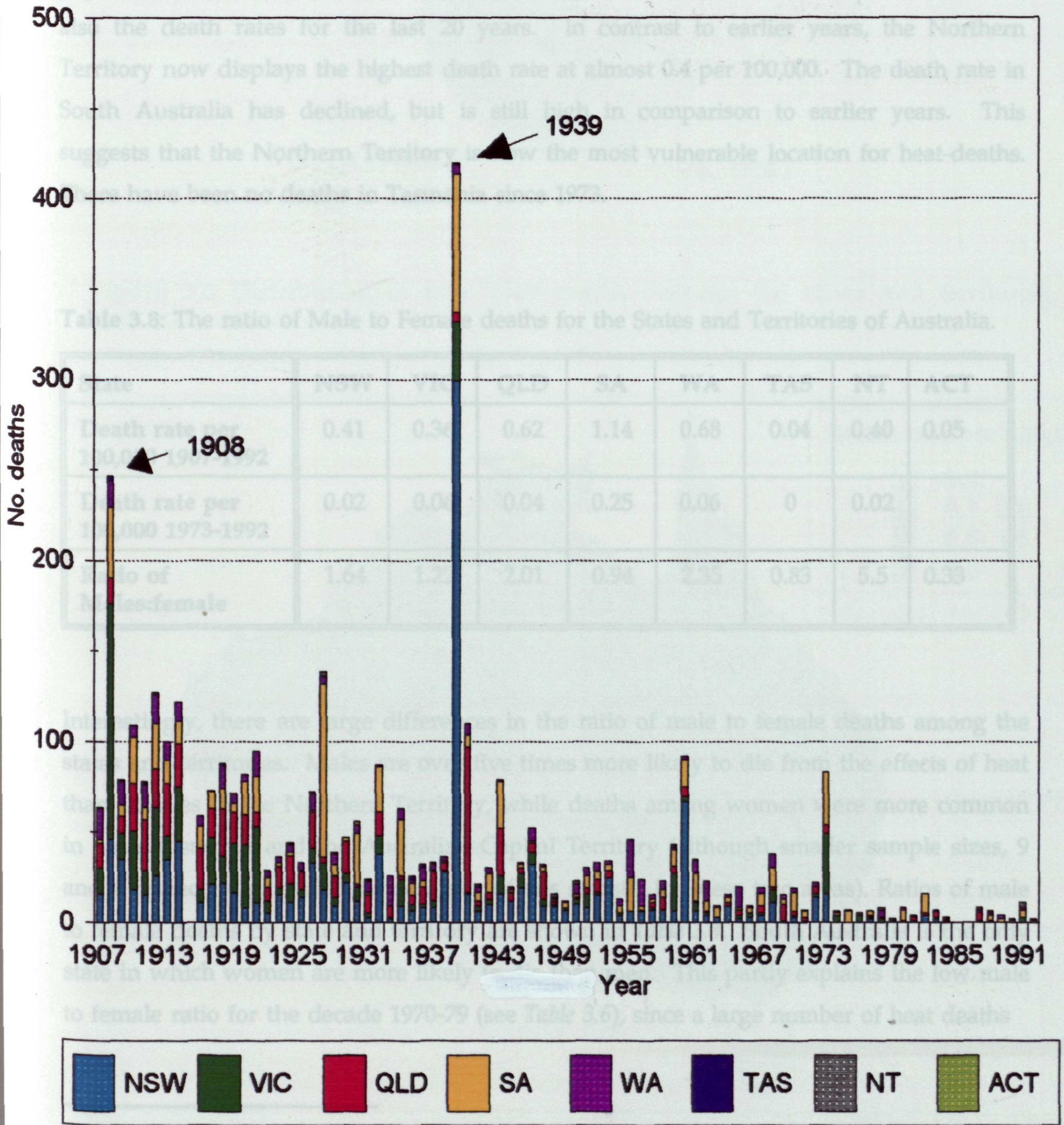


Figure 3.5 Total number of Heat-deaths by year and state, 1907-1994.

Total death rates[9] for the states and territories show that people in South Australia are historically the most vulnerable to the effects of the heat, with more than one death per 100,000 population. The relative vulnerability of the Australian states and territories, 1907-1992 is illustrated in *Figure 3.7*. In addition to South Australia, Western Australia and Queensland also display high death rates. Surrounded by relatively high-risk states, the Northern Territory displays an anomalously low death rate. This may reflect the younger population in the Northern Territory. *Table 3.8* presents the death rates for each state, and also the death rates for the last 20 years. In contrast to earlier years, the Northern Territory now displays the highest death rate at almost 0.4 per 100,000. The death rate in South Australia has declined, but is still high in comparison to earlier years. This suggests that the Northern Territory is now the most vulnerable location for heat-deaths. There have been no deaths in Tasmania since 1973.

Table 3.8: The ratio of Male to Female deaths for the States and Territories of Australia.

State	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Death rate per 100,000 1907-1992	0.41	0.36	0.62	1.14	0.68	0.04	0.40	0.05
Death rate per 100,000 1973-1992	0.02	0.06	0.04	0.25	0.06	0	0.02	
Ratio of Males:female	1.64	1.22	2.01	0.94	2.35	0.83	5.5	0.33

Interestingly, there are large differences in the ratio of male to female deaths among the states and territories. Males are over five times more likely to die from the effects of heat than females in the Northern Territory, while deaths among women were more common in both Tasmania and the Australian Capital Territory (although smaller sample sizes, 9 and 4 respectively, inhibit the accuracy of this statistic for these two areas). Ratios of male to female deaths by state and territory are shown in *Table 3.8*. South Australia is the only state in which women are more likely to die than men. This partly explains the low male to female ratio for the decade 1970-79 (see *Table 3.6*), since a large number of heat deaths

[9] Death rate = Average annual number of heat deaths divided by the average population for the period 1908-1992, and multiplied by 100,000.

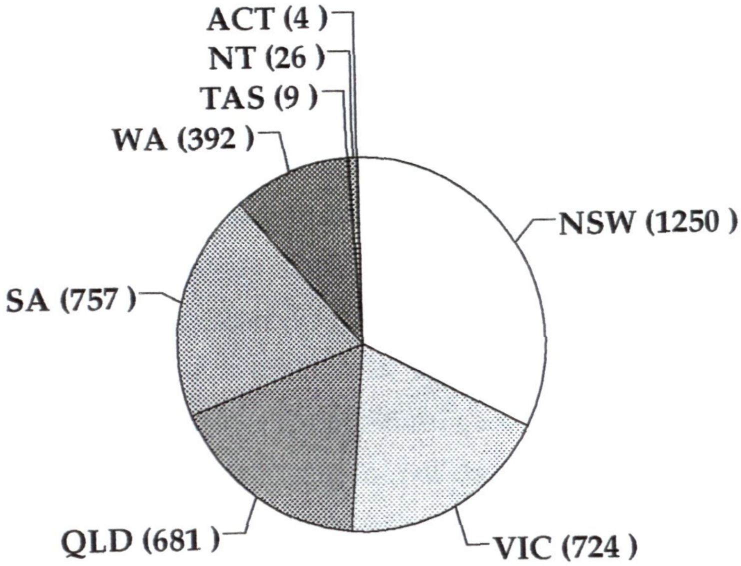


Figure 3.6 Distribution of total Heat-deaths between the states and territories, 1907-1994.

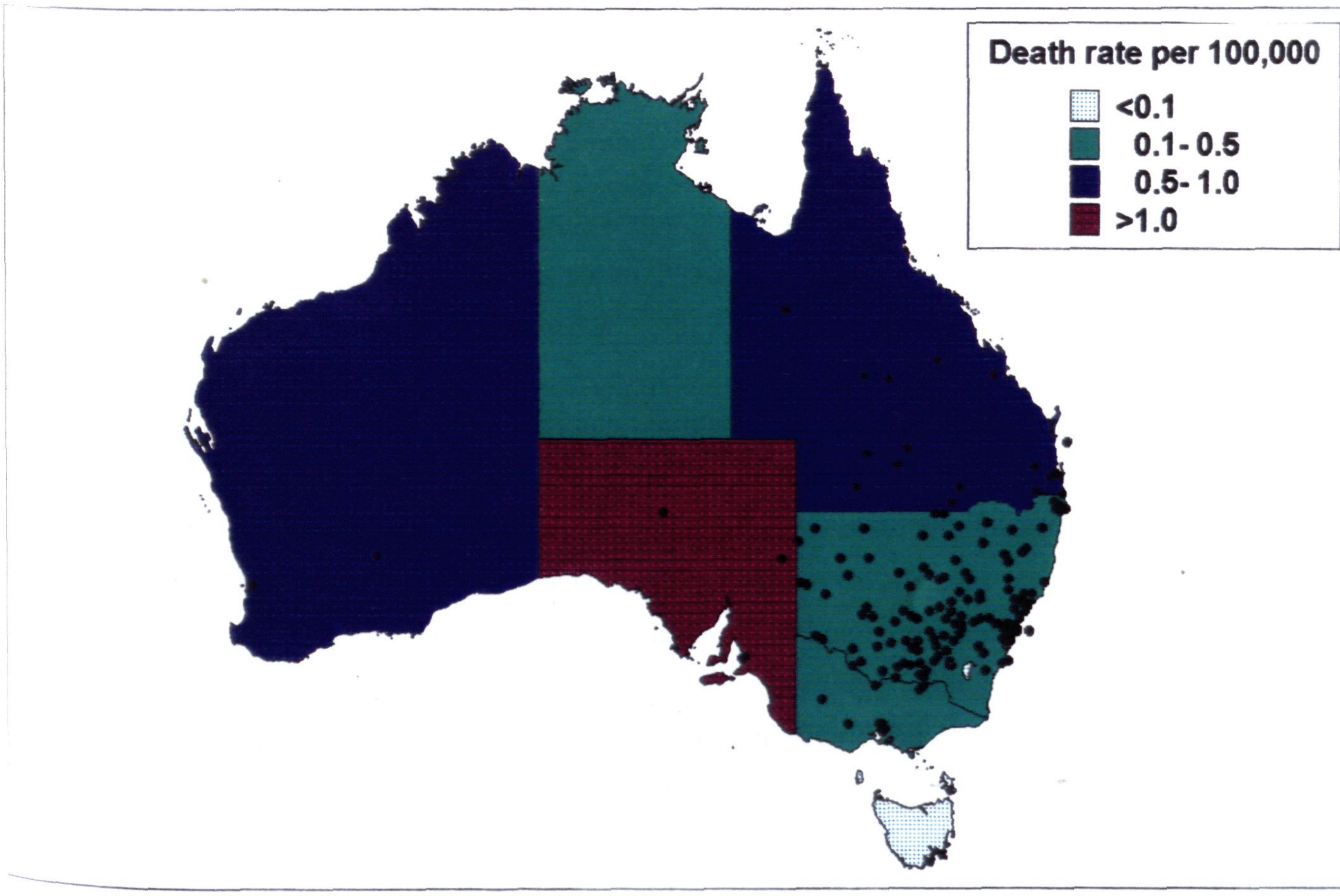


Figure 3.7 Map of Australia showing the number of heat-deaths per 100,000 people by state, 1907-1994.

in this decade occurred in South Australia (see *Figure 3.5*).

Figure 3.7 also displays the point location of deaths reported in *The Sydney Morning Herald*, and as expected (see *Section 3.4.1*) there is a dominance of deaths in New South Wales. Within New South Wales, the dispersion of heat deaths has been mapped by postcode in *Figure 3.8*, which demonstrates a very high incidence of deaths in the western areas. Considering the smaller population base in these regions the impression given is one of very high vulnerability for western areas. In *Figure 3.8*, an overlay of the spatial distribution of the frequency of summer temperatures exceeding 35°C illustrates that these high risk areas coincide with a high frequency of hot days. Sydney experienced the most deaths by postcode, but this result is more fallacious than significant because deaths which occurred in the region of 'Sydney', with no further information given, were placed within this postcode. In addition, both Sydney and Parramatta, where there is also a concentration of deaths, have been settled longer than anywhere else in New South Wales. Within the Sydney region more deaths have occurred in inner- and outer-western postcodes than northern areas, a pattern which may reflect the time of settlement of the suburbs, or socio-economic status.

iii ***Vulnerable Times of the year***

Based on reports in *The Sydney Morning Herald*, 1803-1962 and ABS data, 1963-1992[10], the overwhelming majority of deaths occur in January. February and December are also significant months, as shown in *Figure 3.9*.

To gain an understanding of the way high risk times change with location in Australia, the percentage distribution of deaths by month for each state is shown in *Figure 3.10*. The rings on this figure represent the percentage of deaths, the outer ring being 100%, and the middle ring 50%. People are most likely to die in January in all states with the exception of the Northern Territory and Western Australia. In Western Australia, heat deaths are distributed almost equally between January and February. Deaths in the Northern Territory are more evenly spread between the months, reflecting the area's tropical climate with less annual variation of temperature.

[10] ABS deaths for 1920-1962 are recorded under month of registration as opposed to month of death.

a

b

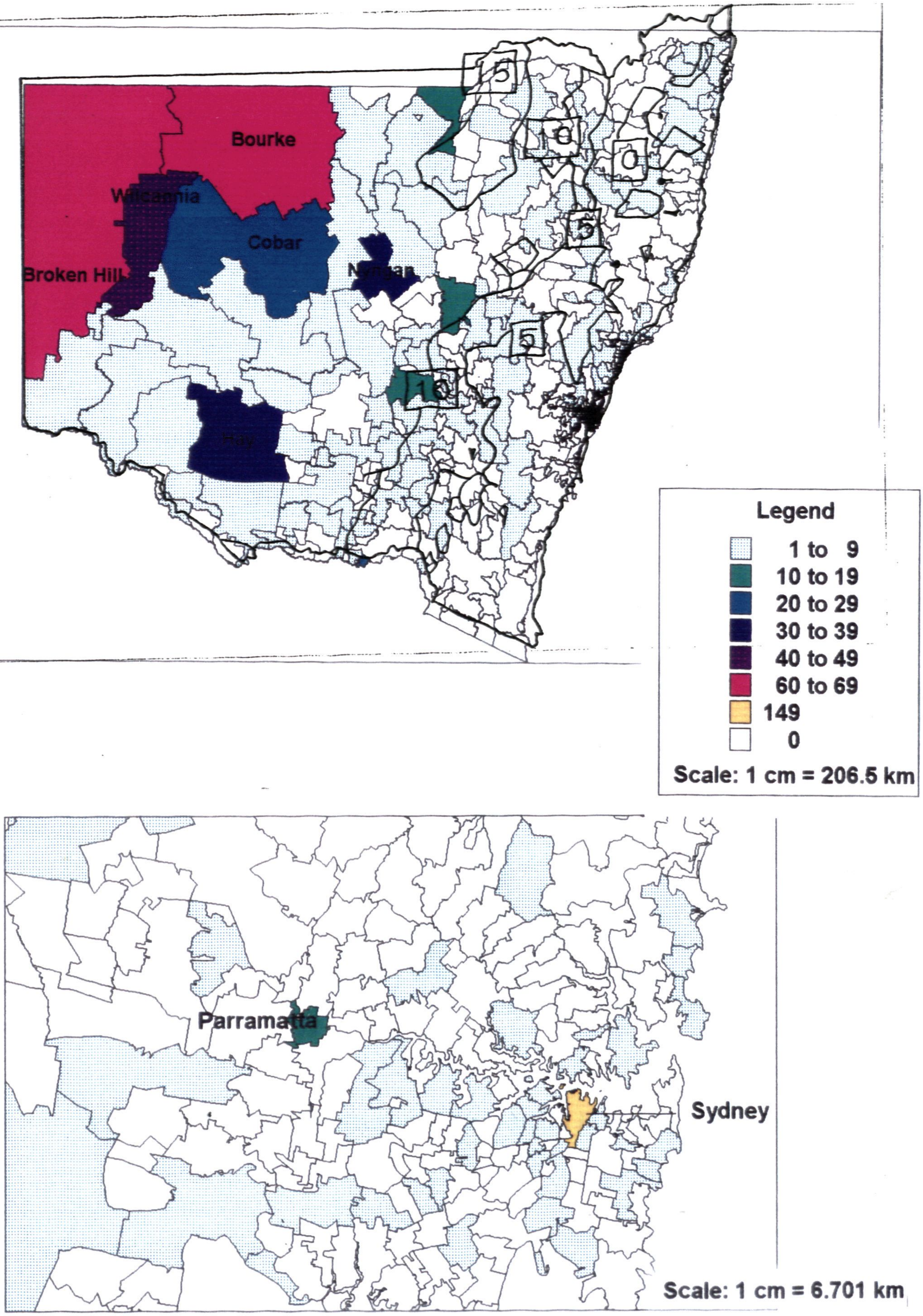


Figure 3.8 The number of Heat-deaths by postcode in **a.** New South Wales and **b.** Sydney and suburbs, based on reports in *The Sydney Morning Herald*, 1846-1983. Overlay is a contour plot of the number of summer (December, January, February) days which exceed 35°C (source McInnes *et al.*, 1994:24).

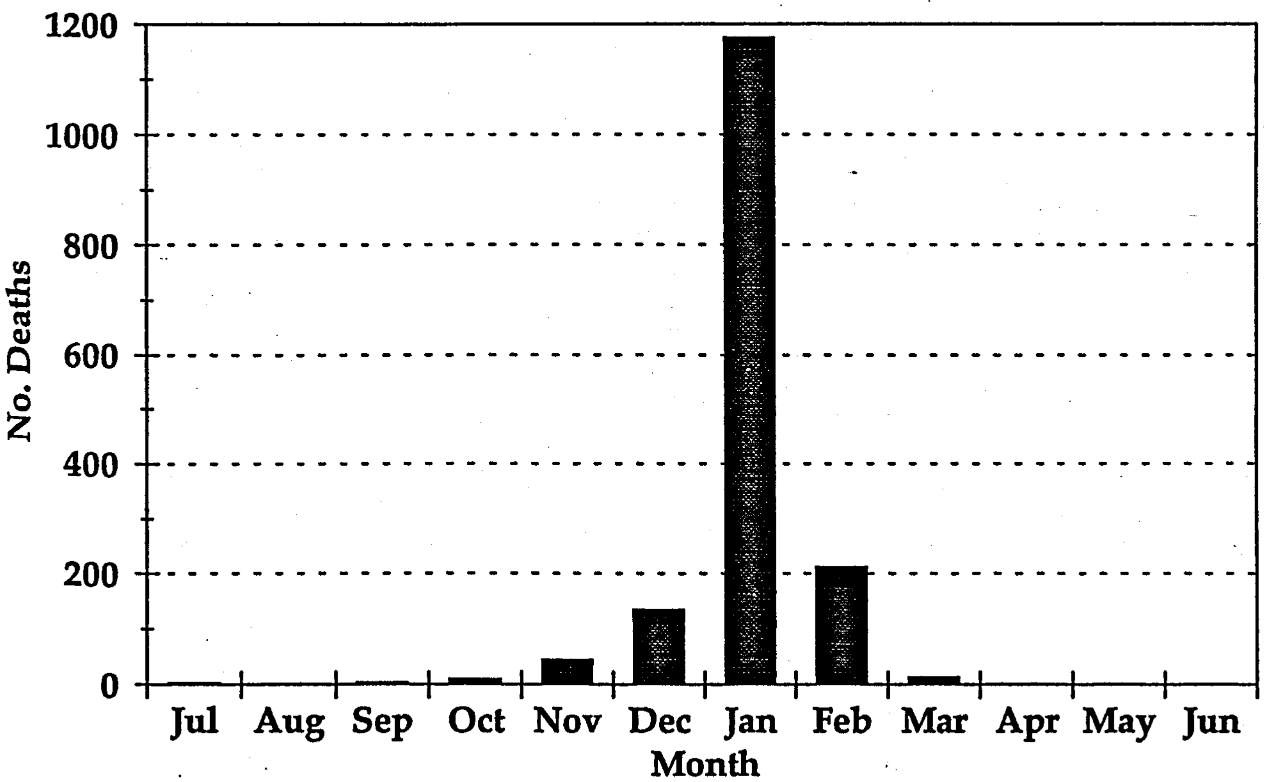


Figure 3.9 Monthly distribution of Heat-deaths in Australia, 1846-1992.

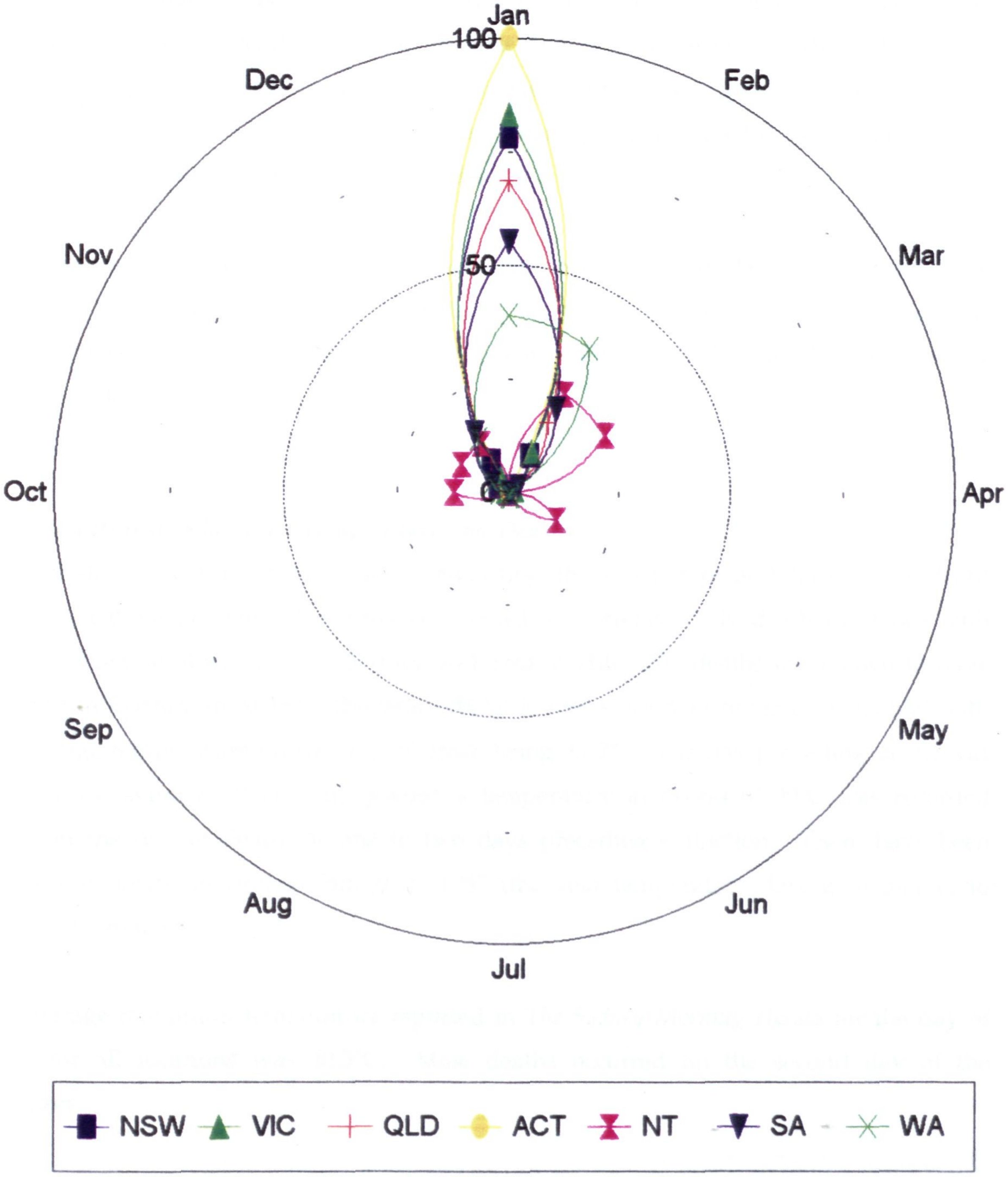


Figure 3.10 Monthly distribution of Heat-deaths among the Australian States and Territories, 1847-1992. The outer ring represents 100% of all deaths, and the middle represents 50% of all deaths.

iv. *The Years of 1896 and 1939*

1896 and 1939 were disastrous in terms of the total number of deaths, with 437 deaths occurring in the summer of 1895/96 and 420 deaths in 1938/39. Age:sex distributions for 1896 and 1939 are shown in *Figure 3.11a,b*. Male deaths were more common in both years. Noticeable peaks occurred in the older population, at 50-65 for males in 1896 (with no discernible female peak), and at 75-79 years for males and females in 1939. However, the high frequency of deaths of infants in their first year of life in 1939 did not occur in 1896. Once again, the 1896 data should be treated with caution because of the potential inaccuracies inherent in the record source. Perhaps infant deaths were simply not reported in *The Sydney Morning Herald* in 1896.

Temperatures were very high during these summers. Record daily maximums were reached in 1939[11], while in 1896 temperatures in Sydney exceeded 35°C on 8 occasions throughout January, reaching 40.7°C on January 6 and 42.5°C on January 13 (see *Appendix 1* for more detail).

v. *The Relationship between Temperature and Deaths*

Unfortunately, insufficient information regarding the exact date and location of death means that there are limited records with which to correlate daily death incidence with maximum temperature data for Sydney and Broken Hill. 205 deaths are known to have occurred in Sydney since 1859 (the year official temperature data becomes available) with the average temperature on the day of death being 33.5°C. The day preceding death was also hot, on average 30.3°C. In general, a temperature in excess of 30°C was recorded either on the day of death, or one to two days preceding extinction. There have been insufficient deaths at Broken Hill since 1957 (the year temperature data is available) to enable any analysis.

The average maximum temperature reported in *The Sydney Morning Herald* for the day of death for all locations was 40.5°C. Most deaths occurred on the second day of the heatwave.

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[11] see *Chapter 1.1*

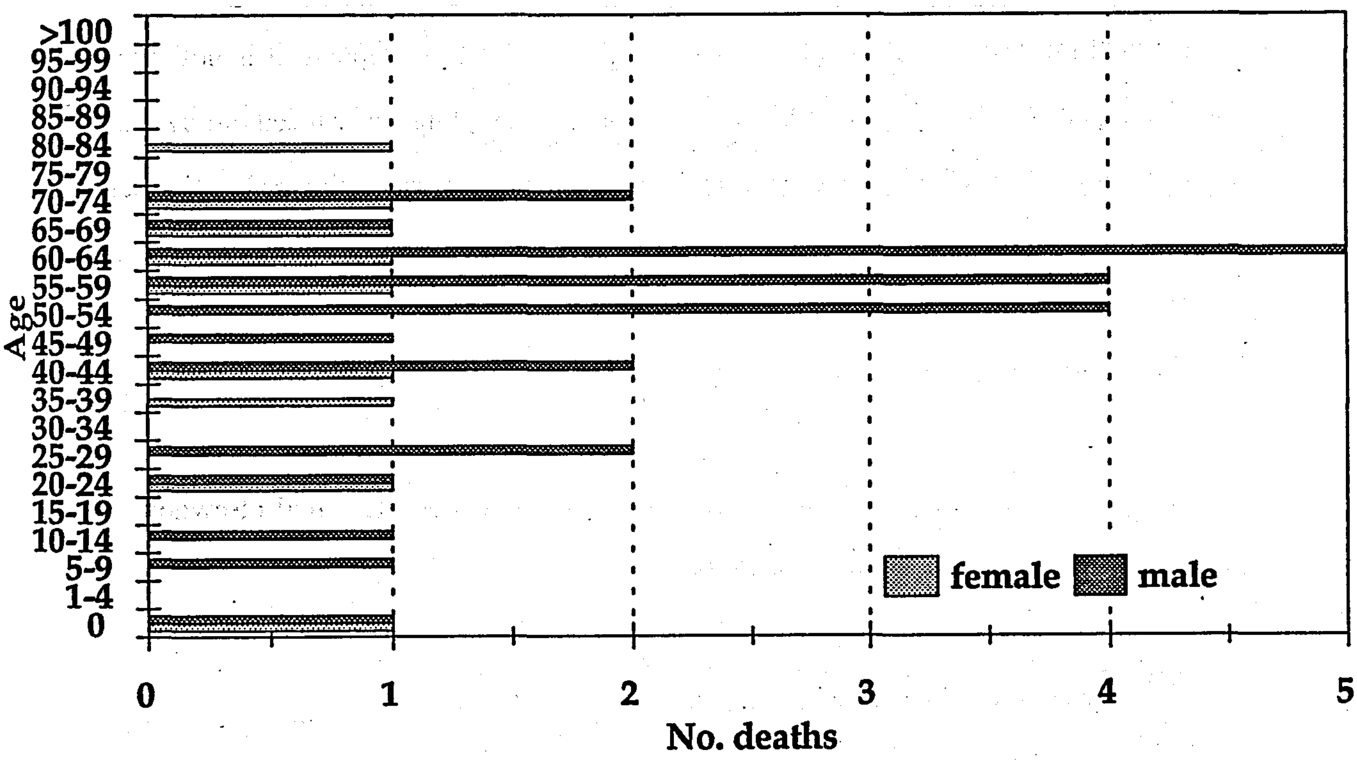

Figure 3.11a Age-Sex Distribution of Heat-deaths in Australia in 1896.

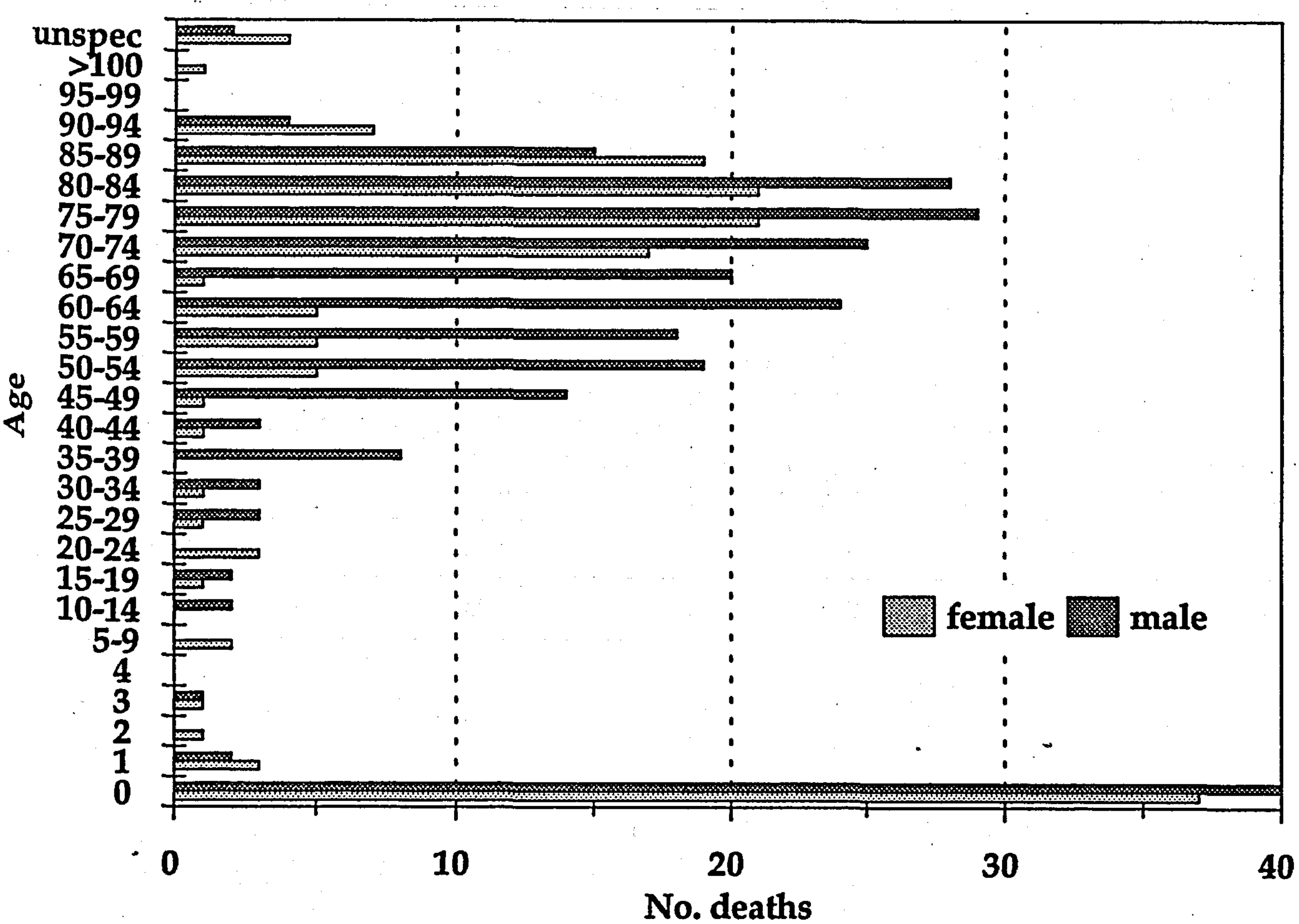

Figure 3.11b Age-Sex Distribution of Heat-deaths in Australia in 1939.

A scatter diagram[12] of daily summer mortality for all deaths and maximum temperature for Sydney and Broken Hill, 1979-1992 is shown in *Figure 3.12a,b.* There appears to be no discernible relationship between mortality and maximum temperature at Broken Hill. In Sydney, mortality increases slightly with increasing temperature. An unusually high number of deaths occurred on three occasions; 1/10/1979, 1/9/1983 and 1/10/1983; all of which were on days when the maximum daily temperatures exceeded 35°C (39.6°C, 40°C and 35.6°C respectively). The fact that these high death rates have not occurred consistently on hot days suggests that other factors, in addition to maximum temperature, are significant in influencing mortality.

Interestingly, the 60 plus age group was the only age group to show any relationship between daily mortality and maximum temperature in Sydney (*Figure 3.13a*). While a similar relationship might be expected for infants less than 1 based on findings discussed earlier, this was unsubstantiated, as illustrated in *Figure 3.13b.*

When mortality is correlated with the maximum temperature of the preceding day, a less significant relationship is obtained to the correlation with the temperature on the day of death, as illustrated by the correlation coefficients displayed in *Table 3.9*. This result is disparate to American studies which conclude a one day lag to be a common feature of heatwave associated mortality (see *Section 3.3*). *Table 3.9* also emphasises that the relationship between temperature and mortality is very weak at Broken Hill.

Table 3.9: Correlation coefficients (r) of the relationship between summer mortality and temperature on day of death and temperature on day preceding death.

	Correlation Coefficient (r): Temperature on Day of death	**Correlation Coefficient (r): Temperature on Day Preceding death**
Sydney	0.1247	0.049
Broken Hill	0.0260	-0.0002

[12] containing 2,418 points.

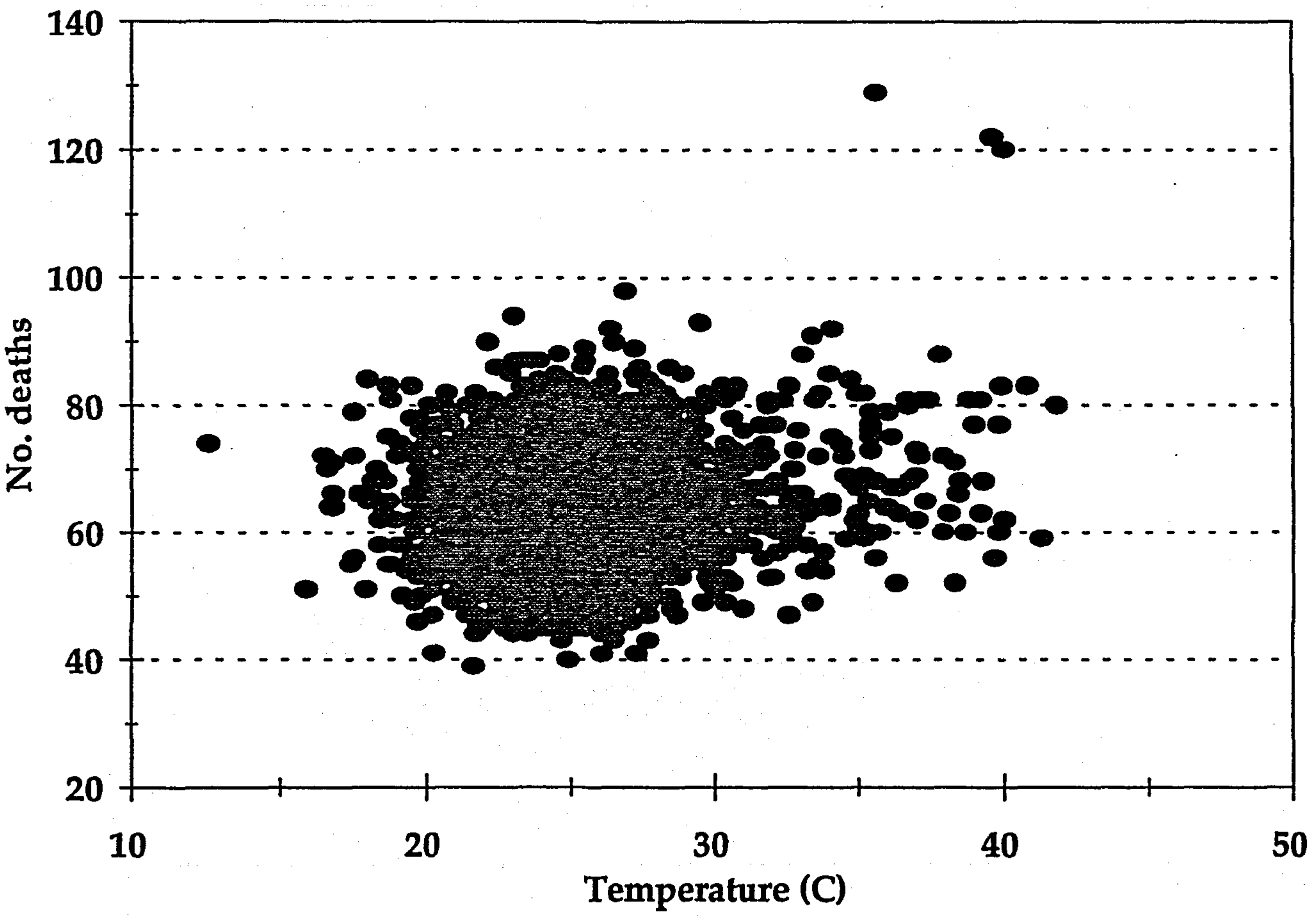

Figure 3.12a Scatter diagram showing the relationship between total deaths (all causes) and maximum daily temperature in Sydney, 1977-1992.

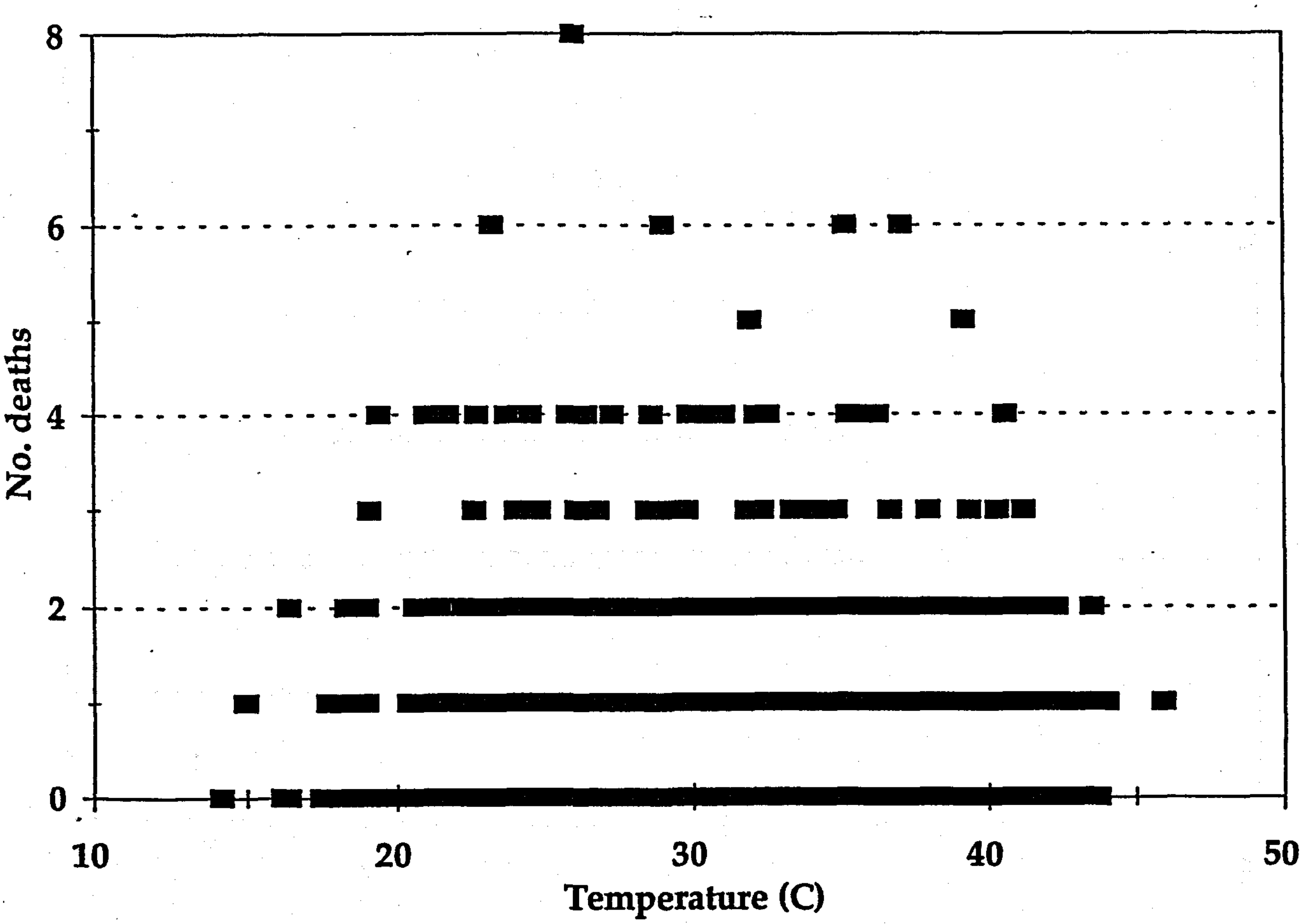

Figure 3.12b Scatter diagram showing the relationship between total deaths (all causes) and maximum daily temperature in Broken Hill, 1977-1992.

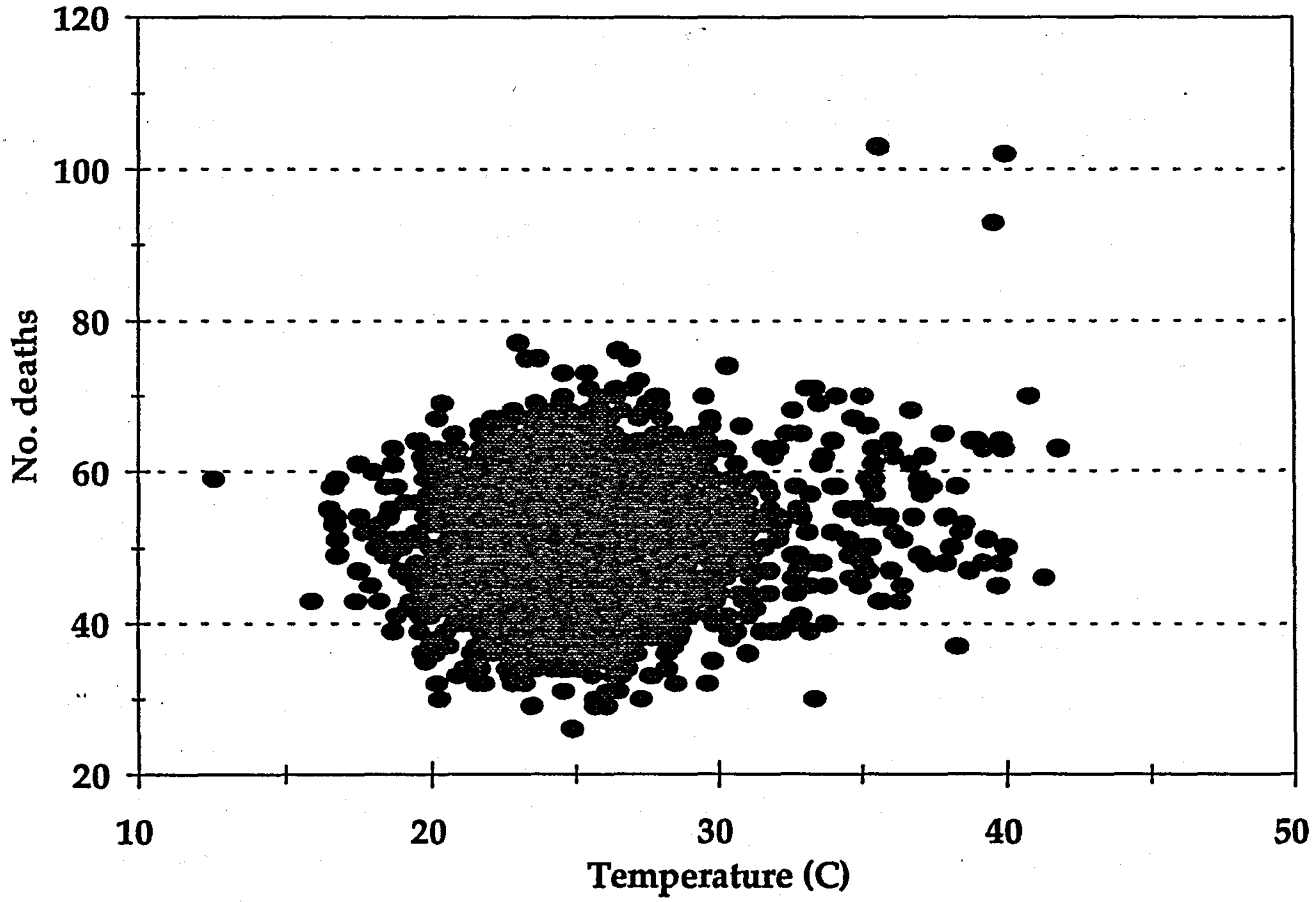

Figure 3.13a Scatter diagram showing the relationship between total deaths (all causes) for persons aged over 60, and maximum daily temperature in Sydney, 1977-1992.

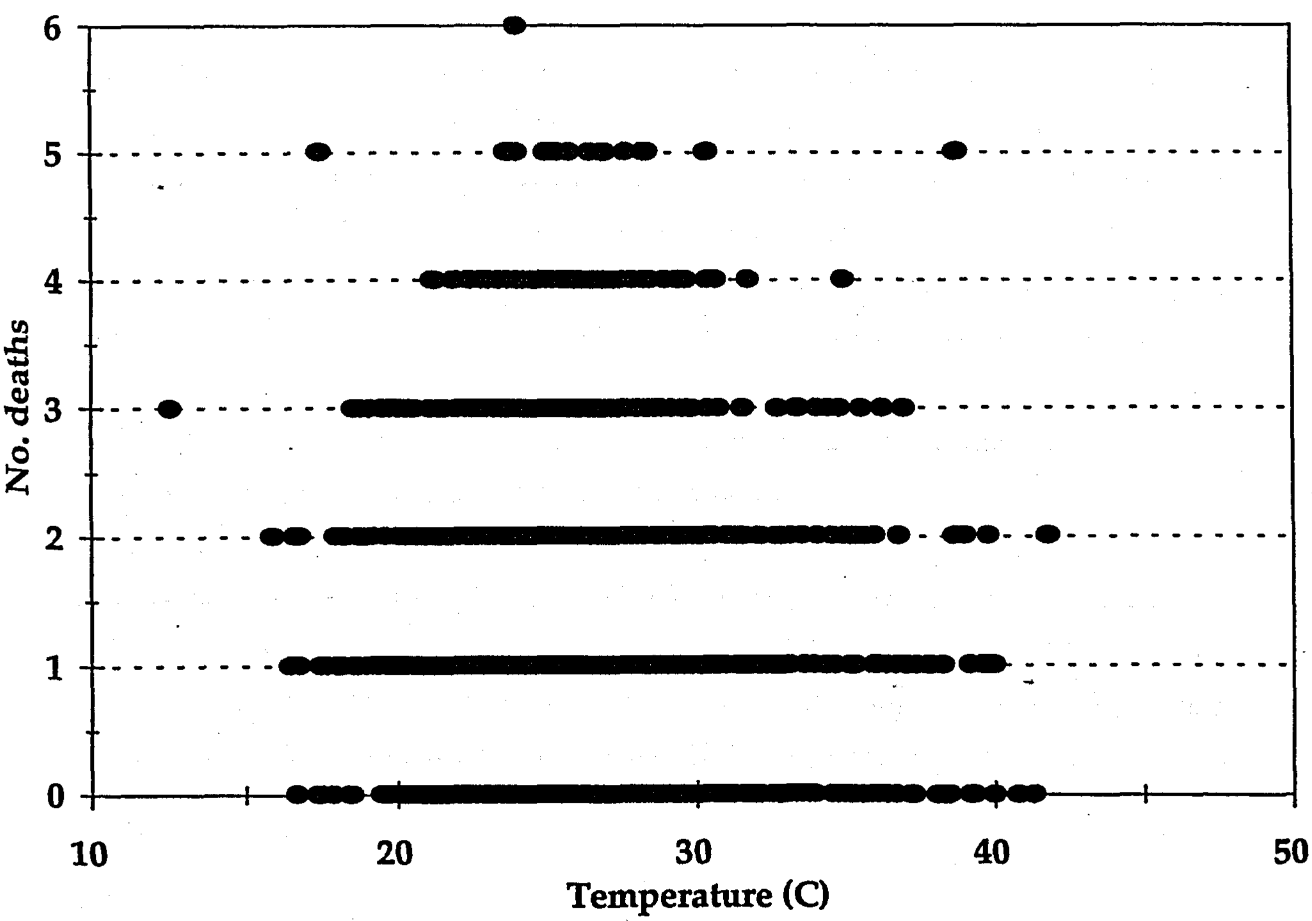

Figure 3.13b Scatter diagram showing the relationship between total deaths (all causes) for infants aged less than 1, and maximum daily temperature in Sydney, 1977-1992.

The calculation of threshold temperatures (following the method of Kalkstein and Davis (1989)) for Sydney and Broken Hill yielded inconclusive results. At Broken Hill, no threshold temperature above which mortality increases substantially could be established. Thresholds were identified in Sydney at 36°C and 40°C. However, according to the method used, significant thresholds also occurred at all temperatures below 30°C. The calculations of the Total Sum of Squares for Sydney and Broken Hill by age group are included in *Appendix 3.*

vi. *Heatwave Associated Mortality*

In Sydney, a total of 731 excess deaths occurred in the period 1978 to 1992 for heatwaves with temperatures above 35°C (*Definition* 2), and 1,285 excess deaths taking a heatwave as an event with temperature above 29.3°C (*Definition* 3). The majority of these deaths were among the elderly (aged over 60). On average, there was a 10% increase in mortality above expected total mortality during heatwaves when temperatures exceeded 35°C, and a 4% increase when temperatures exceeded 29.3°C, although mortality did not always increase. These represent, on average, an increase of 9 deaths a day, and 2 deaths a day respectively.

Figure 3.14 shows the difference of the mean and standard deviation between the expected and the actual mortality for the two heatwave definitions. The spread of the standard deviation for actual mortality exemplifies the fact that mortality did not always increase during heatwaves. When temperatures exceed 35°C the average actual mortality is outside the range of one standard deviation from the average expected mortality. Using a two sample t-test, the difference between the means were significant at less than 0.001 for *Definition* 2 and less than 0.002 for *Definition* 3. These highly significant increases suggest that, on average, mortality increases are to be expected following hot days in Sydney.

At Broken Hill there was a 7% increase in mortality during heatwaves when the temperature exceeded 35°C, and a 16% increase when the temperature was over 36.9°C. While these increases appear large they are not significant (using a 2 sample t-test). This result, in conjunction with that yielded from the investigation for threshold temperature, suggests that high temperatures do not have any real affect on mortality at Broken Hill. This result is contrary to the findings for heat-deaths (as compared to heat-associated deaths) presented in Figure 3.8 where Broken Hill is situated in a high risk location region.

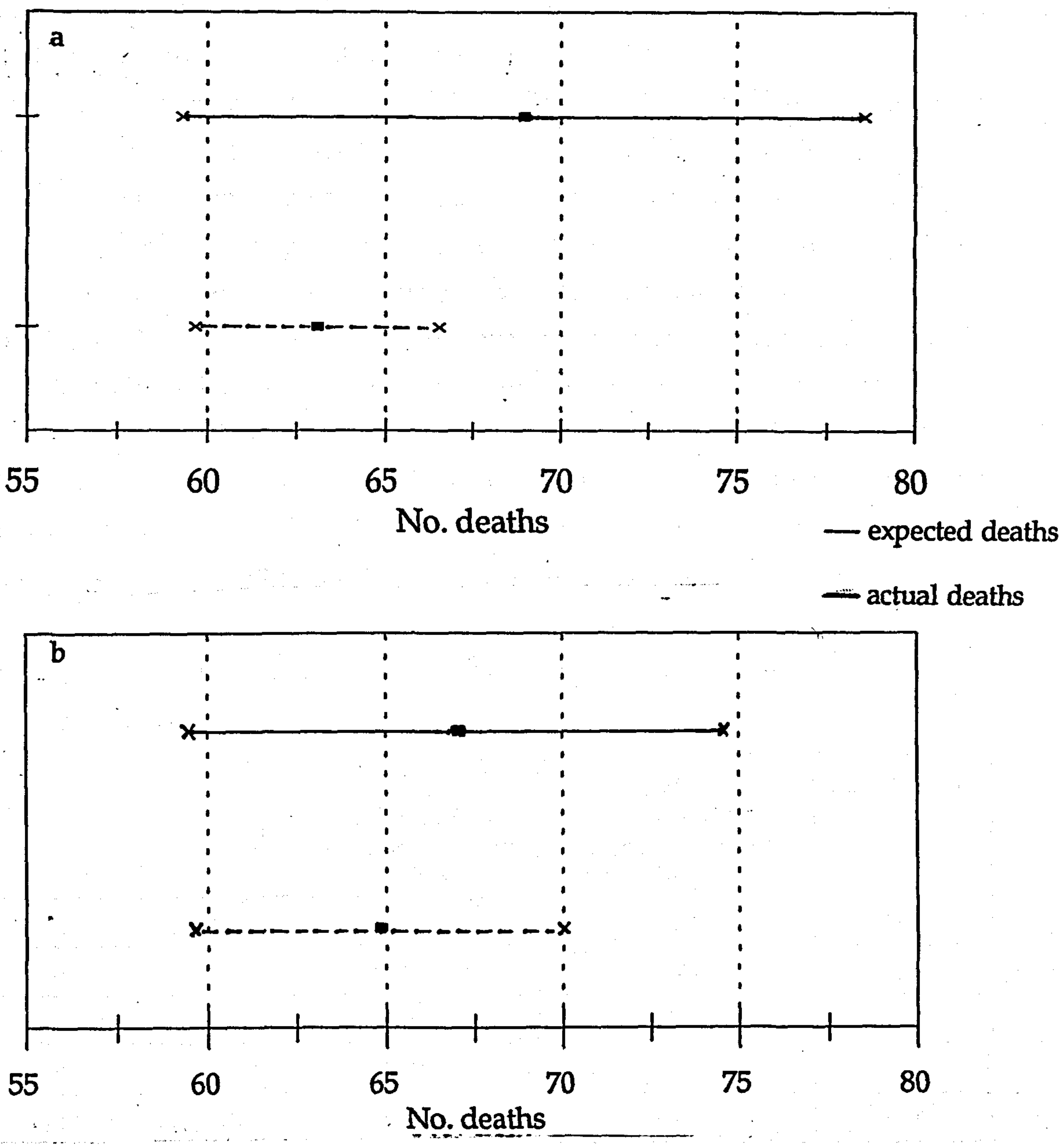

Figure 3.14 Comparison of the mean and standard deviation of the number of excess deaths that occur in Sydney during heatwaves defined by **a:** *Definition 2* (maximum temperature ≥ 35°C) and **b:** *Definition 3* (maximum temperature ≥ 29.3°C), with the mean and standard deviation of the number of deaths that would be expected if no heatwave occurred.

vii. *Crime Rates*

The correlation coefficients for the relationships between the maximum daily temperature and the incidences of motor vehicle accidents, arson, general stealing, sexual assault, aggravated sexual assault, offensive behaviour, murder, manslaughter, liquor offences, aggravated assault and other assaults, are shown in *Table 3.10*. The relationship between temperature and offensive behaviour and stealing is significant, even though the correlation coefficients are reasonably low. The negative relationship between general stealing and temperature implies that there is a decrease in general stealing as temperature increases. Perhaps it becomes too hot to steal? The number of offences involving offensive behaviour is positively related to maximum daily temperature, as shown in *Figure 3.15*. Perhaps this result reflects the preference for beer during hot weather, and the behaviour it can engender. Interestingly the number of offences reaches a peak at about 31°C, declines relatively at 36°C and increases again at temperatures above 37°C. The low sample size for higher temperatures suggests caution in interpreting this pattern. In many ways the relationship between maximum temperature and these two crimes is a curious result that warrants further investigation.

Table 3.10. Correlation coefficients of the relationship between various Crime Rates and Daily Maximum Temperature.

	Correlation Coefficient (r): Temperature on day of Crime	Correlation Coefficient (r): Temperature on day preceding Crime	Sample Size
Motor Vehicle Accidents	0.02	0.03	731
Arson	0.002	-0.02	720
General Stealing	-0.46	-0.10	731
Sexual Assault	0.07	0.05	555
Aggravated Sexual Assault	0.03	0.01	410
Offensive Behaviour	0.24	0.17	731
Murder - Attempt	-0.14	-0.13	75
Murder - Actual	-0.16	-0.13	112
Manslaughter	0.19	0.24	27
Liquor Offences	0.06	0.04	458
Aggravated Assault	-0.03	0.008	37
Other Assaults	0.16	0.07	731

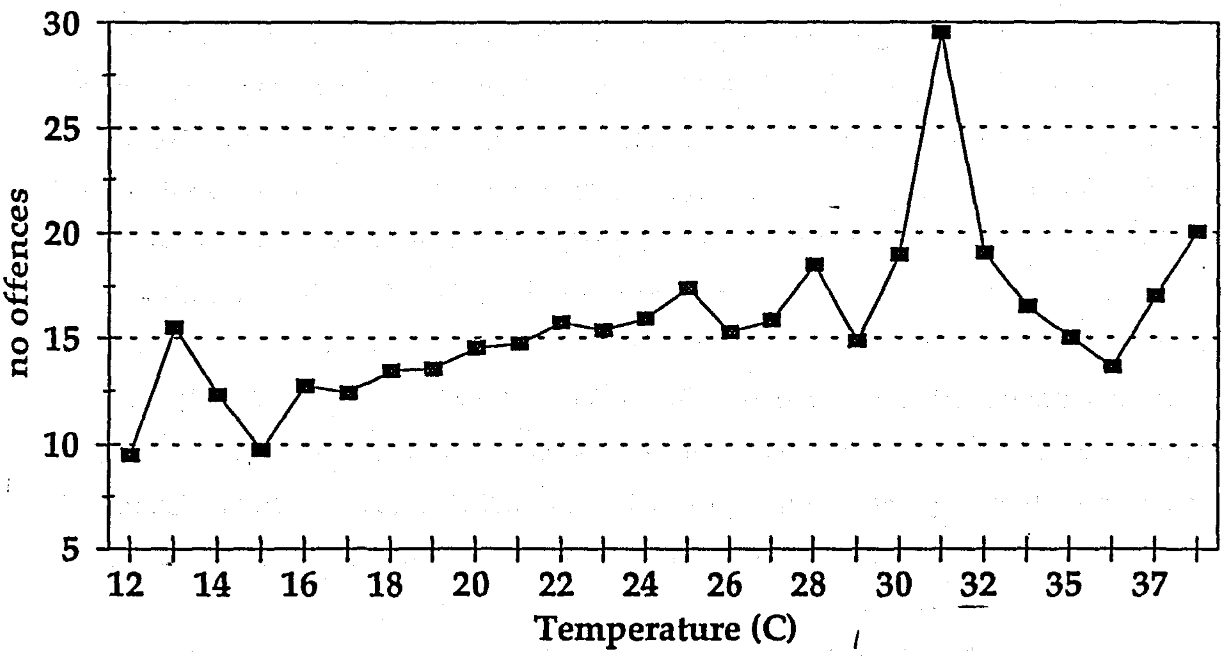

Figure 3.15 The increase in the number of Offensive Behaviour misdemeanours in Sydney with daily maximum temperature.

3.5 Further Discussion of Risk Factors

While overseas studies have also found that young children, especially babies[13], are particularly vulnerable to heat illness (Bridger *et al.*, 1976; Ellis, 1972), the most common conclusion has been, as in this analysis, that the elderly are the most vulnerable to the effects of heat, both in regards to deaths attributed directly to heat, and excess deaths (Henschel *et al.*, 1969; Ellis & Nelson, 1978; MacFarlane & Walker, 1976; Crowe & Moore, 1973; MMWR, 1989; Oeschli & Buechley, 1970).

The reason for this predominance of the elderly among heatwave victims appears to be partly explained by an inability to sufficiently increase cardiac output during hot weather (Kilbourne, 1989). In addition, the body temperature at which sweating, and thus cooling, begins increases with increasing age (Crowe & Moore, 1973). The elderly are also more likely to suffer from chronic disease; the sick elderly being at a much greater risk than the healthy elderly (Ellis, 1972; Macpherson *et al.*, 1967). Furthermore, many of the medications[14] commonly taken by the elderly have been reported to increase the risk of heatstroke (Jones *et al.*, 1982; MMWR, 1980; Schuman *et al.*, 1964). Infants are more susceptible to heat because of a high metabolic rate and a less efficient heat-regulating mechanism (Isbister, 1980). Danks *et al.* (1962) reported 8 deaths among infants in Melbourne in 1959; it is interesting that there were no breastfed babies among those who died. Kutschenreuter (1960, in Kilbourne, 1989) found, however, that children & young adults between the age of 1 to 24 were more resistant to seasonal change.

While males in Australia are more likely to be casualties of heat than females, conflicting conclusions have been drawn regarding differences in the vulnerability between the sexes in American studies. Some researchers have found that more females than males died as a result of heat (Henschel *et al.*, 1969; Schuman, 1972), others have concluded males to be more susceptible to heat than females (Bridger *et al.*, 1976; Ellis, 1972; Marmor, 1978),

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[13] less than one year old.

[14] Hypotensive agents, ie. diuretics (eg. chlorothiazide; phenothiazines); the major tranquillisers (eg. chlorpromazine); and anti-chlorinerigins such as atropine or belladonna (Schuman *et al.*, 1964; MMWR, 1980).

while States (1977) reported no difference at all. Kilbourne (1989) concluded that although death rates in the United States are generally higher in males than females, this trend was most evident in young adults, being less apparent in other age groups. Shattuck & Hilferty (1932) revealed similar results in 1933. This confers with trends in heat-deaths for the Australian population.

Risk factors such as age and sex, are essential in assessing the likely impact of a period of high temperatures on a population. Martinez *et al.* (1989) found that the pattern of heat deaths in the United States, from 1979 to 1985, did not simply correspond to the pattern of occurrence of the highest daily maximum temperature, even when the effect of humidity and other weather variables were taken into account. The distribution of heat deaths was instead more likely to correspond to the density of populations at risk. Regional differences in population density, architecture, proportion of air conditioned dwellings and human acclimatisation were also relevant.

Studies on the influence of air-conditioning on heat mortality exhibit contrary results (Henschel *et al.* 1969; Oeschsli & Buechley, 1970; Schuman, 1977; Marmor, 1978; Ellis & Nelson, 1978; Kilbourne *et al.*, 1982; Kalkstein & Davis, 1989; Martinez *et al.*, 1989). The real effect of air conditioning probably depends on how much time is spent *outside* air conditioned environments since air conditioning may actually prevent the acclimatisation of an individual to high temperatures, thereby increasing their vulnerability when they are away from the air conditioned environment.

Schuman (1977) and Kilbourne *et al.* (1982) found that heatstroke tended to occur in homes which are surrounded by minimal vegetation. Urban dwellers are also more vulnerable than people who live in the country and Buechley *et al.* (1972) found the heat island effect to be a significant determinant behind 178 deaths in New York in a heatwave in 1966. Differences in temperatures of up to 11°C have been recorded between high density residential areas and suburban and rural zones, with the deaths increasing by up to 64% in comparison to 10% in nearby rural areas (Cech *et al.*, 1976). However, mapping of heat deaths in the United States (1979- 1985) demonstrated that predominantly rural counties were also among high incidence areas (Martinez *et al.*, 1989) illustrating the complexity of heat death patterns.

The concentration of heat-related deaths within the inner city seems intimately related to socio-economic status (Buechley *et al.*, 1972; Henschel *et al.*, 1969; Kilbourne *et al.*, 1982; MMWR, 1980; MMWR, 1981; Posey, 1980), although there are contrary conclusions (Schuman *et al.*, 1964). A ten fold difference between the number of deaths in low socio-economic areas and high socio-economic areas was reported in Kansas City during the 1980 heat wave (Buechley *et al.*, 1972). Elderly men and women in the poorer regions of town appear to be particularly susceptible (Ellis & Nelson, 1978). A solitary existence is an additional risk factor (Bridger *et al.*, 1976). In the Unites States, non-white populations are also generally more vulnerable (Bridger *et al.*, 1976; Buechley *et al.*, 1972; Henschel *et al.*, 1969), although overcrowding, poorer housing conditions, lower economic status and poorer general health among non-whites are probably the driving force behind this differences in heat tolerance among races (Henschel *et al.*, 1969)

3.6. Conclusions

This analysis has quantified the mortality associated with heatwaves in Australia, isolated vulnerable populations, locations and time periods and reviewed additional risk factors. The number of deaths that have resulted from heatwaves in Australia is higher than for any other natural hazard[15] as shown in Table 3.11, which lists the number of deaths from natural hazards in Australia. In addition these results are likely to underestimate the number of heat-deaths (see *Section 3.1*), and definitely underestimate the number of heat-associated deaths, as demonstrated by the analysis of excess deaths.

This places heatwaves as the most significant natural hazard in Australia in terms of loss of life, a result which complies with findings in America.

Table 3.11: Number of deaths attributed to various natural hazards in Australia since records began (source, Coates, *et al*, 1993; Natural Hazard Research Centre, Macquarie University..

Hazard	No. deaths
Heatwaves	4287
Floods	>1000
Lightning	650
Cyclones	600
Bushfires	400
Earthquakes	15

[15] excluding epidemics