HUMAN HEALTH AND CLIMATE CHANGE IN OCEANIA: A RISK ASSESSMENT

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Prepared by:

Anthony McMichael and Rosalie Woodruff
National Centre for Epidemiology and Population Health
Australian National University, Canberra

Peter Whetton and Kevin Hennessy
CSIRO Atmospheric Research, Melbourne

Neville Nicholls
Australian Bureau of Meteorology Research Centre, Melbourne

Simon Hales and Alistair Woodward
Department of Public Health, Wellington School of Medicine
University of Otago, New Zealand

Tord Kjellstrom
National Centre for Epidemiology and Population Health
Australian National University, Canberra

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2. EXECUTIVE SUMMARY

It is now widely considered in the scientific community that the world has begun to warm as a result of human influence. Climate change, in turn, causes various environmental and ecological changes. Some of these changes (such as sea-level rise) will continue to respond to this century's warming for many centuries. Climate change differs from many other environmental health problems because of its gradual onset, widespread rather than localised effects, and the fact that the most important effects will probably be indirect.

This document provides a risk assessment of various potential health impacts of climate change over the coming decades in Australia and, in specified instances, neighbouring populations of New Zealand and the Pacific Islands. There are large uncertainties in climate change health risk assessments. To address this, a range of climate change scenarios is used to represent a combination of the various intrinsic uncertainties around projections of future climate. Additional statistical uncertainties exist around the dose-response relationship between climate and each health impact, and the potential modifying effects of future adaptation.

The key findings are summarised below.

- Extreme temperatures currently contribute to the deaths of some 1100 people aged over 65 each year in 10 Australian and 2 New Zealand cities. The projected rise in temperature for the next 50 years is predicted to result in a substantial increase in heat-related deaths in all the cities studied, in the absence of adaptive measures. Temperate cities show higher rates of deaths due to heat than tropical cities. Global warming is projected to reduce the number of cold winter days, and a few cities may experience fewer annual deaths in the short-term. In the medium to long-term, however, these health gains would be greatly outnumbered by additional heat-related deaths.

- Extreme rainfall events are expected to increase in almost all Australian states and territories by 2020. Annual flood-related deaths and injuries may also increase by up to 240%, depending on the region. The situation by 2050 is mixed. As the climate changes, parts of Australia are projected to have substantially less rainfall, and in these places the risk of flooding is predicted to reduce. Most parts of the country, however, are still predicted to be at far greater risk of flood-related deaths and injuries than at present.

- The "malaria receptive zone" may expand southwards, to include regional towns like Rockhampton, Gladstone and Bundaberg. However, in the foreseeable future malaria itself is not a direct threat to Australia under climate change, as long as a high priority is placed on prevention via the maintenance and extension of public health and local government infrastructure.

- Suitable conditions for the transmission of dengue may expand southwest down to Carnarvon, and southeast down to Maryborough and Gympie by 2050. If no other contributing factors were to change, a larger number of people living in northern parts of Australia would be at risk of dengue infection (a total of 0.3-0.5 million in 2020, and 0.8-1.6 million in 2050). This increased risk need not mean an increase in dengue cases, provided there is (i) continuing expansion of vector control and public health surveillance, and (ii) quarantine efforts to ensure that a secondary dengue vector, *Ae. albopictus,* does not become established in the country.

- Warmer temperatures and increased rainfall variability are predicted to increase the intensity and frequency of food-borne and water-borne disease. Successful adaptation to the projected climate changes will require the upgrading of sewerage systems, and safer food production and storage processes. Due to their poor living conditions and access to services, Aboriginal people living in remote arid communities are likely to be at increased risk. An increase of 10% in the annual number of diarrhoeal admissions among Aboriginal children living in the central Australian region is predicted by 2050.

- The number of people exposed to flooding due to sea-level rise in Australia and New Zealand is predicted to approximately double in the next 50 years, although absolute numbers would still be low. For the rest of the Pacific region, however, the number of people who experience flooding by the 2050s could increase by a factor of more than 50, to between 60,000 and 90,000 in an average year. As well as the impact of flooding on settlements, the impact of sea-level rise on freshwater quality and quantity is likely to be a critical threat to Pacific Island health and welfare.

- The first *detectable* changes in human health may well be alterations in the geographic range and seasonality of certain vector-borne infectious diseases. Summer-time food-borne infections (e.g. salmonellosis) may show longer-lasting annual peaks. The public health consequences of the disturbance of natural and managed food-producing systems, of rising sea-levels, and of population displacement for reasons of physical hazard, land loss, economic disruption and civil strife may not become evident for several decades.

- Reducing the total level of greenhouse gas emissions remains a primary preventive health strategy. Given that current levels of greenhouse gases will continue to influence climate over the next several hundred years, a greater research effort must now also be directed towards how humans can adapt to these changes.

- The health impacts of climate change will be strongly influenced by the extent and rate of warming, as well as local environmental conditions and social behaviours, and the range of social, technological, institutional, and behavioural adaptations taken to reduce the threats.

- Some individuals and communities are likely to lack the resources required for adequate response. Remote Aboriginal communities, people on low incomes, elderly people and many Pacific Island countries will be most vulnerable.

3. INTRODUCTION

It is now widely acknowledged in the scientific community that Earth's climate system has demonstrably changed since the pre-industrial era, and that at least some of these changes are due to human activities *(IPCC 2001a)*. Already, changes have been observed to many physical and biological systems, and there are preliminary indications that social and economic systems have also been affected. Even if global concentrations of greenhouse gases (GHG) were stabilised, Earth would continue to respond to warming for many centuries *(IPCC 2001a)*. There is no doubt that there has been an unusually rapid increase in average global surface temperature over the past quarter-century. Climatologists assess that most of the increase since around 1950 is attributable to human activities (IPCC 2001).

Projected climate change is expected to have beneficial and adverse effects on environmental and socio-economic systems, with both direct and indirect effects on human health. The impact of climate change will depend on the rate and extent of warming, as well as the adaptive capacity of society. It is thus necessary for national, state, and local governments, as well as individuals, to prepare for a changing environment by understanding the risks to public health, and to develop plans to reduce and adapt to these risks.

In 1991, the National Health and Medical Research Council (NHMRC) published a two-volume report entitled *Health Implications of Long Term Climate Change*. That report was based primarily on an extensive review of expert opinion. Selected experts wrote detailed chapters on specific aspects of the topic. There were, at that time, virtually no empirical data directly relating to the human health impact of a long-term change in climatic conditions. Further, there were very few peer-reviewed results of mathematical modelling of this relationship. This dearth of information was clearly reflected in the First Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) in 1990, in which the topic of potential health impacts was dealt with summarily within several brief paragraphs. The NHMRC's 1991 report – viewed within that context – was a ground-breaking exercise that helped to raise the profile of the research questions pertaining to climate change and health.

Subsequently, during the 1990s, there was a steady increase in the amount of formal research in this topic area. This was reflected in the growing emphasis given to the work of the IPCC, especially in its Second and Third Assessment Reports (1995 and 2001). In recent years, a number of national governments have commissioned scientific assessments of the actual and potential impacts of climate change on the health of the national population. These include: the USA, the UK, Canada, New Zealand, Portugal, the Netherlands, and Japan. In 2002, the World Health Organization completed an estimate of the contribution of 26 risk factors to the global and regional burden of disease *(Ezzati et al. 2002)*, which included an estimate of the impact of global climate change. Ten years on from the publication of the original NHMRC report, there is now an opportunity to examine this question on the basis of more sophisticated modelling of both climate change and its impacts, greater insights into the nature of the uncertainties in this domain of science and a better understanding of the priority needs for further research.

4. SCOPE OF ASSESSMENT

4.1 Assessment objectives

This document provides a risk assessment of the potential health impacts of climate change in the medium-term in Australia and, in specified instances, the neighbouring populations of New Zealand and the Pacific Islands.

There are only limited empirical observations of climate-health relationships yet available from research in Australasia. However, there is now a well-reviewed body of evidence from other countries. This empirical information base, along with recently evolved mathematical models, now enables a quantitative approach to be applied to much of this scenario-based health risk assessment task. Quantitative approaches are possible for assessing the future risks of some health outcomes (e.g. mortality impact of heatwaves; altered transmission probability for some vector-borne diseases), but not for others (e.g. social and public health consequences of increased flow of refugees from low-lying Pacific islands; impacts on human well-being due to changes to the physical and socio-economic environments). The public health consequences of the latter type of issue are addressed qualitatively in this report.

The enHealth Council has published guidelines for the conduct of environmental health risk assessments *(enHealth Council 2002)*. In the context of this climate change risk assessment, the exercise entails estimating the population at risk of, or the attributable burden of disease from, specified health consequences of climate change for the years 2020 and 2050, for alternative greenhouse gas emissions scenarios *(IPCC 2000)*, and using future projections of the Australian population (by statistical local area).

4.2 Regions considered in this report

This assessment is principally focused on determining possible impacts to health resulting from climate change to populations in Australia. In addition, impacts for New Zealand and the Pacific Islands were considered where data availability and resources permitted. Quantitative estimates are provided for Australia for six health impacts (dengue, malaria, diarrhoeal diseases, deaths due to extreme rainfall, flooding due to sea-level rise, and heat-related deaths). The quantitative estimates provided for New Zealand are for dengue, sea-level rise, and heat-related deaths. Quantitative estimates provided for the Pacific are for dengue and sea-level rise. In addition, a qualitative discussion of some health issues relating to the Pacific Islands is presented.

4.3 Vulnerable populations

Not all populations will be equally affected by changing climate conditions. The social stability of a community, existing health of population groups, access to and availability of resources, and the capacity to respond to changing conditions, all effect a community's ability to adapt to the additional challenges climate change will bring to human health states. Each section of the report identifies sub-populations that are expected to be at greatest risk of a particular health impact. General issues relating to vulnerable populations are provided in Section 10.

5. IMPACT OF CLIMATE CHANGE ON HEALTH

5.1 Evidence for climate change

A review of the scientific evidence collected so far indicates that: (i) Earth's temperature has already increased by 0.6 ± 0.2°C on average since 1900, and (ii) this increase can be attributed to the influence of human activities (principally the burning of fossil fuels) *(IPCC 2001c)*. Australia's continental-average temperature has risen by about 0.7°C from 1910–1999, with most of this increase occurring since after 1950 *(CSIRO 2001)*. Minima have generally increased more than maxima. While Australian rainfall has varied substantially over time and space, there has been no significant continental-average trend since 1910.

5.2 Future trends in greenhouse gases

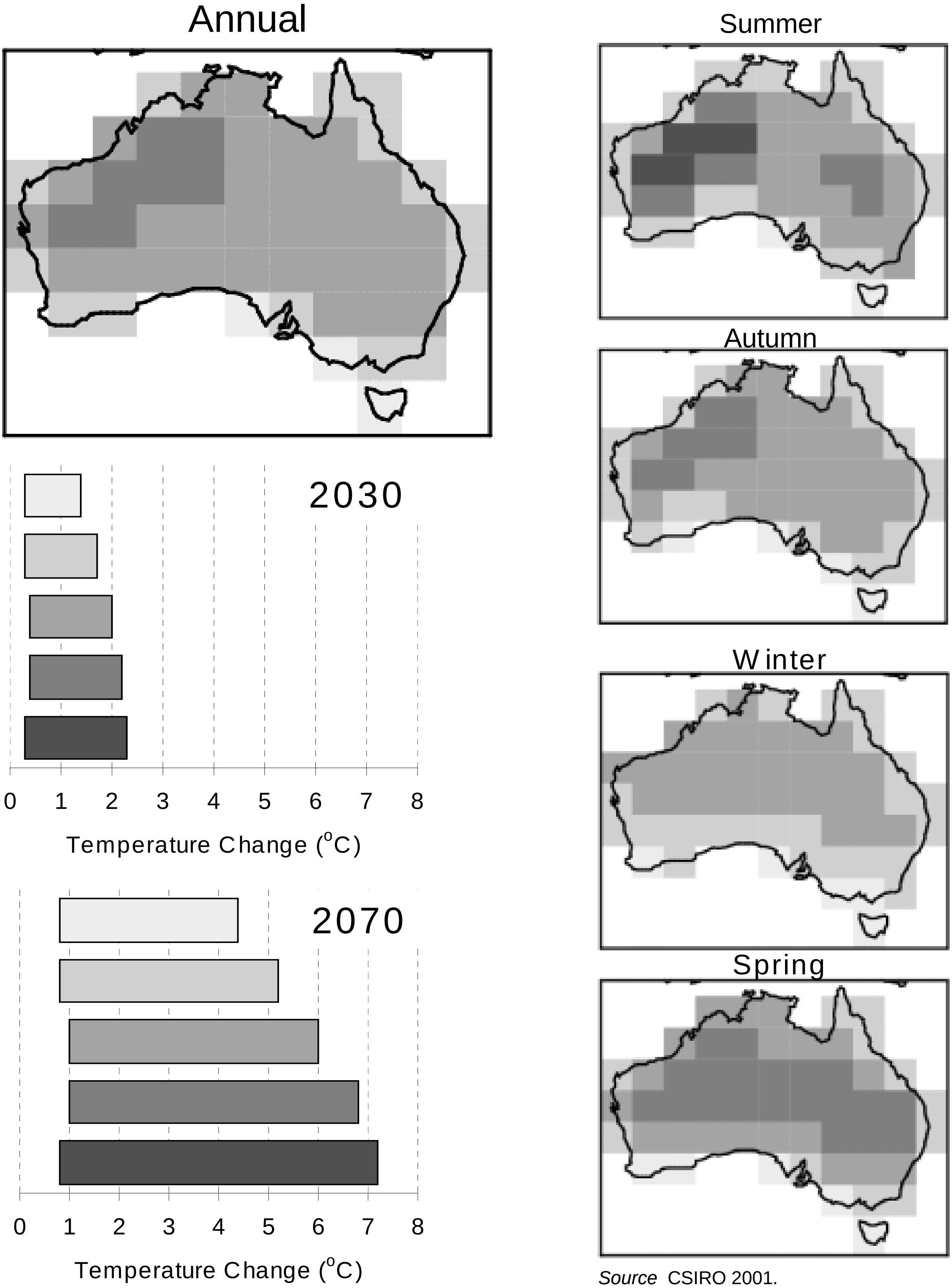
The Intergovernmental Panel on Climate Change *(IPCC 2001a)* produced forty future world scenarios based on a range of possible greenhouse gas and sulphate aerosol emissions *(IPCC 2000)*. The Special Report on Emissions Scenarios (SRES) is based on a range of assumptions about population, energy sources and regional or global approaches to development and socio-economic arrangements. The scenarios do not include any specific greenhouse gas mitigation activities. From the SRES, the IPCC projects a globally averaged warming of 1.4 to 5.8°C by 2100 relative to 1990 baseline climate. This range includes the uncertainty about how the climate system will response to increased greenhouse gases, as well as the uncertainty about the total amount of emissions. The projected rate of warming is 0.1 to 0.5°C per decade. Since the 1970s, the observed rate of warming has been 0.15°C per decade.

Sea-level is projected to rise by 9 to 88 cm by 2100, or 0.8 to 8.0 cm per decade, associated with this warming. The observed rise over the 20th century has been 1 to 2 cm per decade.

5.3 Australian climate change

The estimates of future Australian climate change have been prepared by the CSIRO *(CSIRO 2001)*.

Figure 1 Average seasonal and annual warming ranges (°C) for around 2030 and 2070, relative to 1990 (shaded bars show ranges of change for areas with corresponding shades in the maps)



Source CSIRO 2001.

5.3.1 Temperature

Simulated ranges of warming for Australia are shown in Figure 1. By 2030, annual average temperatures are 0.4 to 2.0°C higher over most of Australia, with slightly less warming in some coastal areas and Tasmania, and the potential for greater warming in the north-west. By 2070, annual average temperatures are increased by 1.0 to 6.0°C over most of Australia, with spatial variation similar to those for 2030. The range of warming is greatest in spring and least in winter. In the north-west, the greatest potential warming occurs in summer.

Model results indicate that future increases in daily maximum and minimum temperature will be similar to the changes in average temperature. This contrasts with the greater increase in minima than maxima observed over Australia in the 20th century. Changes in daily temperature extremes can be influenced by changes in daily variability and changes in average maximum or minimum temperature. CSIRO modelling results for Australia indicate that future changes in variability are relatively small and the increases in average maximum and minimum temperature mainly determine the change in extremes.

5.3.2 Rainfall

Most models simulate an increase in extreme daily rainfall leading to more frequent heavy rainfall events *(CSIRO 2001)*. This can occur even where average rainfall decreases. Reductions in extreme rainfall occur where average rainfall declines significantly. Increases in extreme daily rainfall are likely to be associated with increased flooding. Where average rainfall increases, there would be more extremely wet years, and where average rainfall decreases there would be more dry spells. For example, summers in south-west NSW are expected to become 15% wetter and springs will become about 10% drier by 2030. The number of extremely dry springs more than doubles after 2020, as does the number of extremely wet summers.

Projected annual average ranges tend towards decrease in the south-west (–20% to +5% by 2030 and –60% to +10% by 2070, rounded to the nearest 5%), and in parts of the south-east and Queensland (–10% to +5% by 2030 and –35% to +10% by 2070). In some other areas, including much of eastern Australia, projected ranges are –10% to +10% by 2030, and –35% to +35% by 2070. The ranges for the tropical north (–5% to +5% by 2030 and –10% to +10% by 2070) represent little change from current conditions.

5.3.3 Tropical cyclones

While regional and decadal variations in the frequency of tropical cyclones have been observed worldwide, no significant global trends have been detected. Projections are difficult since tropical cyclones are not well resolved by global or regional climate models. Present indications are:

- regions of cyclone origin are likely to remain unchanged
- maximum wind-speeds may increase by 5–20% in some parts of the globe by the end of the century
- preferred paths and poleward extent may alter, but changes remain uncertain
- future changes in frequency will be modulated by changes in the El Niño Southern Oscillation.

Tropical cyclones are associated with the occurrence of oceanic storm surges, gales and flooding rains in northern Australia. The frequency of these events would rise if the intensity of tropical cyclones increases. Projected rises in average sea-level will also contribute to more extreme storm surges.

5.3.4 Variability

The increasing levels of greenhouse gas concentrations in the atmosphere are predicted to result in changes in daily, seasonal, inter-annual and decadal variability *(IPCC 2001c)*. Many models predict an increase in El Niño-like mean conditions in the tropical Pacific (which would have flow-on effects for Australia), although not all do *(IPCC 2001c)*. There are still severe limitations on the ability of global climate models to represent the full complexity of observed climate variability. Consequently, the estimates used in this report are of the expected mean future change of a given climate variable.

5.4 Direct and indirect effects

Global climate change would affect the health of human populations via diverse pathways. These would vary in their complexity, scale and directness. The timing of the various impacts would also differ – some would occur soon; others would be deferred. There would be both positive and negative impacts, although expert scientific reviews (IPCC 2001, National Assessment [US] 2000) assess that the latter would clearly predominate. This mainly negative impact reflects the fact that climatic change would alter many natural ecological and physical systems that are integral to Earth's life-support systems.

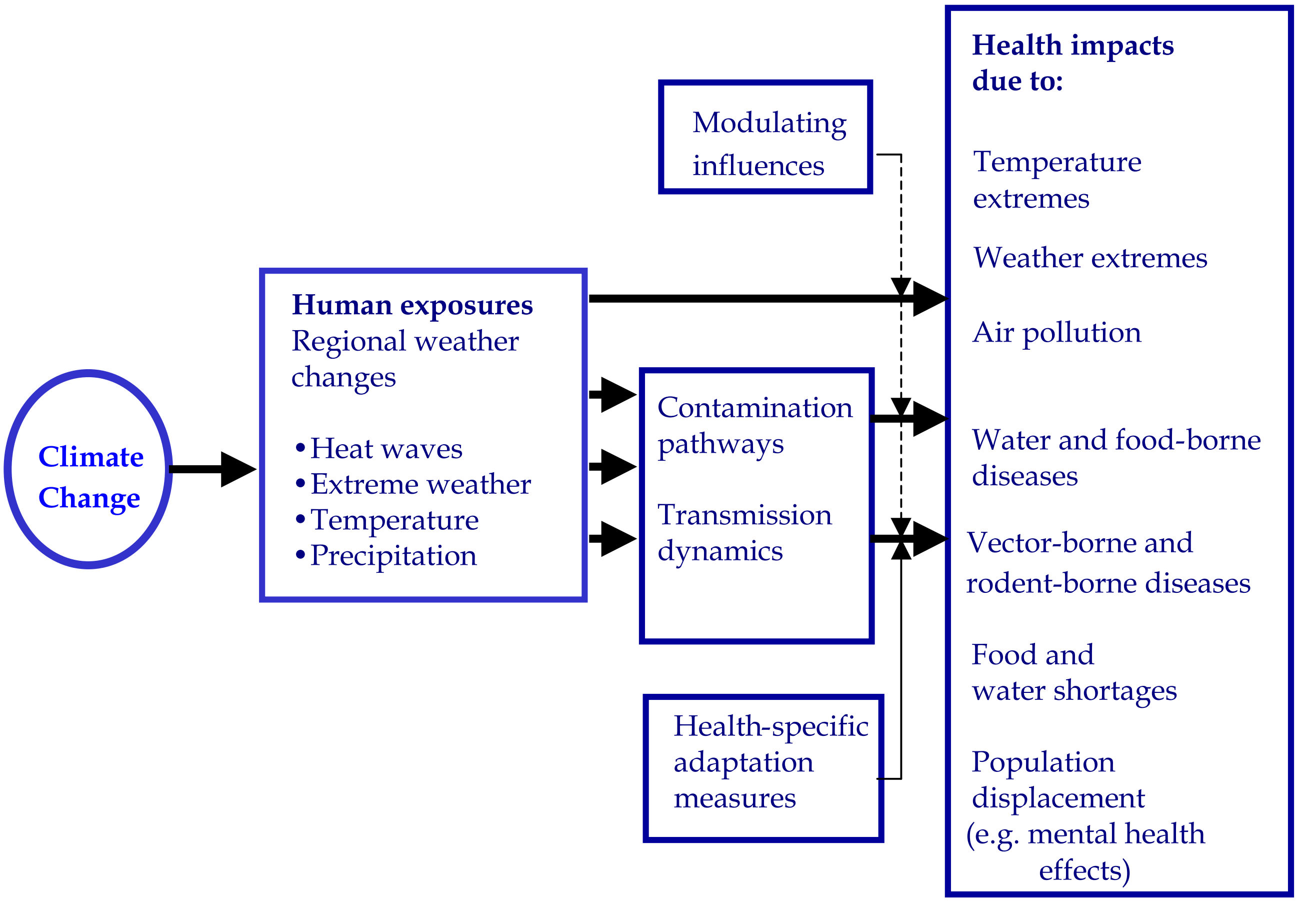
Figure 2 shows the main pathways and categories of health impact of climate change. The more direct impacts on health include those caused by changes in exposure to weather extremes (heatwaves, winter cold), those due to increases in other extreme weather events (floods, cyclones, storm-surges, droughts), and those due to a rise in production of certain air pollutants and aeroallergens (spores and moulds). In some countries, decreases in winter mortality due to milder winters may compensate for increases in summer mortality due to the increased frequency of heatwaves *(Langford and Bentham 1995, Rooney 1998)*. However, the extent of future change in the frequency, intensity and location of extreme weather events due to climate change remains uncertain.

Climate change will also affect human health via less direct mechanisms. These would include changes in the pattern of transmission of many infectious diseases – especially waterborne, food-borne and vector-borne diseases – and regional food productivity (especially cereal grains). In the longer term, and with considerable variation between populations because of geography and vulnerability, the indirect impacts may well have greater magnitude than the more direct impacts *(Epstein 1999, McMichael et al. 1996b)*.

Various integrated modelling studies have forecast that an increase in ambient temperature would cause, worldwide, net increases in the geographic distribution of particular vector organisms — such as malaria-transmitting mosquitoes — although some localised decreases may also occur.

Further, temperature-related changes in the life-cycle dynamics of both the vector species and the pathogenic organisms (flukes, protozoa, bacteria and viruses) would increase the potential transmission of many vector-borne diseases such as malaria (mosquito), dengue fever (mosquito) and leishmaniasis (sand-fly) – although schistosomiasis (water-snail) may undergo a net decrease in response to climate change *(Martens 1998a, Patz et al. 1996)*.

Figure 2 Pathways by which climate change affects human health, including local modulating influences and the feedback influence of adaptation measures (based on *Patz et al. 2000)*



Other types of modelling studies have estimated the impacts of climate change upon cereal grain yields (grain accounts for approximately two-thirds of world food energy). Globally, a slight downturn appears likely, but this would be greater in already food-insecure regions in South Asia, parts of Africa and Central America. Such downturns would increase the number of malnourished people by several tens of millions in the world at large – that is, by at least several percent against a current and projected total, without climate change, of between four hundred and eight hundred million.

Climatic change over the past quarter-century may already have had various initial impacts on some health outcomes. However, the time at which any such health impacts of climate change first become detectable depends particularly upon: (i) the sensitivity of response, and (ii) whether there is a threshold that results in a jump. Further, detectability is influenced by the availability of high-quality data, by the extent of background variability in the health-related variable under investigation, and by the number of plausible causes. Detection is thus a matter both of statistical power and of reasonable judgement, including pattern recognition, about attribution.

The first *detectable* changes in human health may well be alterations in the geographic range (latitude and altitude) and seasonality of certain vector-borne infectious diseases. Summer-time food-borne infections (e.g. salmonellosis) may show longer-lasting annual peaks. By contrast, the public health consequences of the disturbance of natural and managed food-producing ecosystems, of rising sea-levels and of population displacement for reasons of physical hazard, land loss, economic disruption and civil strife may not become evident for several decades.

6. General methods

6.1 Definition of exposure

For this assessment, a “risk factor” to human health relates to the future change in Australian climate predicted to occur due to increasing greenhouse gas emissions. The entire population is assumed to be “exposed” equally to climate change, although not all communities in Australia will experience the same rate of change. More rapid warming, for example, is predicted in the central parts of the country than in most of the coastal areas.

6.2 Representing the range of possible futures

6.2.1 Principles of representing uncertainty

Two main types of uncertainty exist in climate change risk assessment: social/economic pathways (predicting the path of future greenhouse gas emissions) and scientific accuracy (differences between model simulations of global and regional climate conditions). Population and economic growth, technological change, energy policies, and social behaviour will affect future levels of greenhouse gas emissions. Climate models are most uncertain in how they represent feedback effects, particularly those dealing with changes to cloud regimes, biological effects, and ocean-atmosphere interactions. The coarse spatial resolution of climate models also remains a limitation on their ability to simulate the details of regional climate change, particularly in mountainous coastal areas. Future climate change will also be influenced by other factors, largely unpredictable, such as changes in solar radiation, volcanic eruptions and natural variations within the climate system itself. Rapid climate change (abrupt and non-linear changes in physical systems that could be irreversible) in response to the enhanced greenhouse effect is possible, but its likelihood cannot be defined *(IPCC 2001c)*.

A range of possible future greenhouse gas emission levels is used in this risk assessment (“alternative emission scenarios”, discussed below). These scenarios do not show the full range of possible futures, but illustrate some of the possibilities within the current known range.

6.2.2 The alternative emission scenarios

The IPCC has published a set of forty greenhouse gas and sulfate aerosol emission scenarios for the 21st century *(IPCC 2000)*. They combine assumptions about demographic, economic and technological driving forces of future greenhouse gas and sulphur emissions. The effect of specific measures to reduce emissions, such as the Kyoto Protocol, is excluded. Each scenario represents a variation within one of four "storylines": A1, A2, B1 and B2.

A1 describes a world of very rapid economic growth, global population that peaks around 2050 and declines thereafter, and the rapid introduction of new and more efficient technologies. Within A1, there are three sub-groups distinguished by their technological emphasis: fossil fuel intensive (A1F1), non-fossil energy sources (A1T), and balanced across all energy sources (A1B).

The A2 storyline describes a world of regional self-reliance and preservation of local identities. Fertility patterns across regions converge slowly, leading to increasing population. Per capita economic growth and technological change is more fragmented and slower than other storylines.

The B1 storyline describes a convergent world with the same population as in A1, but with an emphasis on global solutions to economic, social and environmental sustainability, including the introduction of clean and resource-efficient technologies. The B1 storyline has an emphasis on local solutions to economic, social and environmental sustainability. Population increases at a rate lower than A2, with intermediate economic development, and less rapid and more diverse technological change than in A1 and B1.

Because of divergent views about the likelihood of each storyline amongst the experts who created them, probabilities were not assigned to the storylines. Equal probability cannot be assumed across the range, or greater probability in the middle of the range. When emissions and concentrations of greenhouse gas and sulphate aerosol are estimated, B1 is considered to be one of the best case scenarios (i.e., lowest emissions, and therefore a less dramatic rate of climate change) and A1F1 is one of the worst case scenarios (i.e., highest emissions, and fastest rate of change).

In this assessment, three alternative emission scenarios were used:

- **B1** – represents the **low** scenario of climate change
- **A1B** – represents the **mid** scenario of climate change
- **A1F1** – represents the **high** scenario of climate change

Throughout this report, these scenarios will be referred to as low, mid, and high.

6.2.3 The regional climate projections

General Circulation Models (GCMs) are used to simulate changes in temperature, precipitation and other climate variables at the global and regional scales as a function of increasing greenhouse gas concentrations and other drivers. These model results are used to project future changes under the alternative scenarios (i.e., different assumptions about future greenhouse gas emissions). While GCMs are valuable for modelling climate change at such scales, they are too coarse to capture factors that influence climate at the scale of individual countries (typically the resolution is 3.75^0 longitude and 2.5^0 latitude).

Current projections for the future changes in temperature and rainfall in the Australian region were prepared by CSIRO *(CSIRO 2001)*, and were provided through the OzClim software. This software uses local climate data, greenhouse gas emission scenarios, a range of climate sensitivities and down-scaled GCM patterns to generate country-scale scenarios of future climate change.

All models show an Australia-wide trend towards warming. There is wide variation, however, among the models representing future precipitation patterns. Some show large increases, and others large decreases. Two climate simulations were chosen for the Australian region, which provide a representative pattern of the spectrum of different precipitation projections – the CSIROMk2 (developed by the CSIRO), and ECHAM4 (from the Max Planck Institute for Meteorology, Hamburg). CSIROMk2 simulates wetter conditions in central Australia and the Top End, but drier conditions elsewhere. ECHAM4 simulates wetter conditions north of a diagonal line from Broome to Hobart, and much drier conditions in the west.

The two models used generated monthly estimates of the main climate variables (temperature, precipitation, humidity), for each cell of a regional grid. The cell size was 0.25^0 (approximately $25km^2$). The baseline climate used was for the period 1961 to 1990. The two future time points for which climate change was estimated were 2020 and 2050.

The CSIRO scenarios were used as the basis for four of the six quantitative analyses conducted for this assessment (dengue, deaths due to heat extremes, change in diarrhoeal disease, and deaths and injuries due to extreme rainfall and flooding). They were not used for the malaria or the sea-level rise analyses. In relation to the former, software incompatibilities prevented their use. For the latter, the modelling was conducted as part of a global risk assessment of the impact of sea-level rise, which used different climate data. The climate scenarios used in both these analyses are explained in the relevant sections.

6.2.4 The population projections

The population projections for 2020 and 2050 were derived from two data sets: (i) the Australian Bureau of Statistics Statistical Local Area Population Projections 1999-2019 (prepared by the ABS for the Commonwealth Department of Health and Ageing), and (ii) the Australian Bureau of Statistics Population Projections 1999-2101 *(Trewin 2000).* A combination of these two data sets was used to derive projections for both Statistical Local Areas (SLAs) and capital city/balance of state population groupings for 2020 and 2050. SLAs vary in size. In metropolitan regions, they may be equivalent to a cluster of suburbs. In rural Australia, they can average several hundreds of square kilometres in size.

Demographic assumptions for Capital City and Balance of State/Territory ABS 1999-2101 projections

The base population for these projections was the preliminary estimated resident population in each area, by single year of age and sex, at 30 June 1999. The assumptions for fertility, mortality, overseas migration and interstate migration are the same at the capital city and balance of State/Territory level as Series II outlined in ‘Population Projections Australia, 1999 to 2101 *(Trewin 2000).* Series II incorporates assumptions for Australia of 'low' fertility (a total fertility rate of 1.60 births per women from 2008), 'medium' overseas migration (an annual net overseas migration gain of 90,000) and 'medium' interstate migration. For mortality it was assumed that the 1986–1996 rate of improvement in life expectancy of 0.30 years per year for males and 0.22 years for females would continue for the next five years and then gradually decline, resulting in life expectancy at birth of 83.3 years for males and 86.6 years for females in 2051.

Demographic assumptions for the ABS SLA 1999-2019 projections

The base population for these projections was the preliminary estimated resident population in each SLA, by single year of age and sex, at 30 June 1999. The base population was projected annually by calculating the effect of births, deaths and migration within each age-sex group according to the specified Series II fertility, mortality and migration assumptions. These projections were produced in two stages. First, the resident population of each capital city and balance of State/Territory was projected by single year of age and sex. Second, the population of each SLA within each capital city and balance of State/Territory was projected by single year of age and sex, and constrained to sum to the respective capital city and balance of State/Territory projected population for each year. Appendix A is a table of 1999, 2020, and 2050 population projections for several major cities in Australia.

Method for extrapolation forward to 2020 and 2050

For the 2020 projections, a linear regression method (based on the period 2010 to 2019) was used to extrapolate the population of each SLA forward one year to 2020. Capital city population estimates for 2020 were taken from the Australian Bureau of Statistics (ABS) Population Projections 1999-2101 *(Trewin 2000).*

The 2050 SLA estimates were derived from the ABS 2050 Capital City and Balance of State projections *(Trewin 2000)*. The simplifying assumption was made that the change in population size for each Capital City and Balance of State projection would apply uniformly across all of the SLAs in that region. For example, if the total size of a capital city's population was projected to increase by 10% between 2019 and 2050, then it was assumed that each SLA within the city boundary would also increase in size by 10%. Similarly, if the Balance of State population estimate decreased by 5% at 2050, then the population size of each regional SLA in that state was reduced by 5%. The SLAs were constrained to sum to the respective Capital City and Balance of State projected populations for the 2050 year.

Nature of Projection Method

The nature of the projection method and inherent fluctuations in population dynamics mean that the projection results (particularly those for 2050) should be interpreted cautiously. The projections are not exact forecasts but illustrate changes that could occur in population size and distribution if the stated assumptions were to apply over the projection period. The unpredictability of migration trends could have a significant effect on projection results. For these reasons, assessment results at the SLA level were not presented, as this would incorrectly suggest a level of accuracy that cannot be guaranteed. The projections used in the thermal extremes calculations were taken from the ABS' projected city population distribution *(Trewin 2000).*

Although the base projections prepared by the ABS take account of land planning and other decisions known at the time the projections were derived, the ABS does not always have access to the policies or decisions of Commonwealth, State, and Local Governments, and businesses that would assist in the accurate forecasting of small area populations. The projections also do not allow for other non-demographic factors (e.g. economic factors, catastrophes, wars) that may affect future demographic behaviour.

6.3 Outcomes to be assessed

The health outcomes for quantitative risk assessment were selected on the basis of evidence of sensitivity to short-term climate variability, likely sensitivity to gradual climate change *(IPCC 2001b, c, McMichael et al. 2002)*, relative public health impact within Australia, and the availability of health risk assessment models for impact estimation (or feasibility of developing models in the time available). The health outcomes that constitute the formal quantitative component of the risk assessment are listed in Table 1.

Table 1 Summary of methods, exposure variables, and impact measurements used for the health outcomes that were quantitatively assessed

Health Outcome	Study populations	Exposures	Method	Health impact estimated
Thermal extremes mortality	10 Australian cities & 2 New Zealand cities	• max temperature (daily) • min temperature (daily)	Risk coefficient x exposure increase - change in relative risk	Attributable cold- and heat-related mortality in aged < 65
Flooding (inland)	Australia	• extreme rainfall (month)	Change in mean rainfall to baseline	Relative risk of exposure to extreme rainfall; annual incidence
Flooding (coastal)	Australia, New Zealand, Pacific Island States	• sea level • topography • flood defences	Topographic model - population distribution and flood defences	Annual population exposed to coastal flooding
Malaria	Australia	• temperature (week) • rainfall (week)	Geographic area suitable /unsuitable for maintenance of vector	Population living in potential malaria transmission zone
Dengue	Australia, New Zealand, Pacific Island States	• vapour pressure (annual)	Geographic area suitable /unsuitable for maintenance of vector	Population living in potential dengue transmission zone
Diarrhoeal diseases	Indigenous (Central Australia)	• mean temperature (annual)	Risk coefficient x exposure increase - change in incidence	Increase in incidence of cases from baseline

In addition to these health outcomes, there are others that are likely to be affected by climate change. For several reasons, including the indirect and complex pathways that operate between climate and disease, quantitative relationships have not yet been established, or modelling not conducted, on the following health outcomes:

- Air pollution and aeroallergen levels
- The rate of recovery of stratospheric depletion, affecting exposure to UV radiation
- Changes in the distribution and transmission of other vector borne-diseases (particularly Ross River virus disease, Murray Valley encephalitis, and Japanese encephalitis)
- Indirect effects on food production acting through plant pests, diseases, drought, and excess rainfall, and consequent flow-on effects to rural communities due to regional economic downturn.

6.4 Methods for estimating risk factor-disease relationships

For the estimation of the future effects of climate on disease, it was assumed that the current relationship between climate and health outcomes would remain the same in the future. This approach assumes that populations, vectors, pathogens etc. will respond in the same manner to climate in the future as at present. This is clearly a simplification, as it is highly likely that human populations, in particular, will influence both the exposure of individuals and populations to climate hazards and their impacts *(IPCC 2001b, Woodward et al. 1998).* This uncertainty has been reduced, to an extent, by including expected future changes in population size.

For some health outcome assessments, models incorporate the effects of existing risk modifiers into the baseline estimate of the climate-disease relationships. For example, the CLIMEX model used in the estimate of malaria distribution is based on current observed distribution of the mosquito in Australia. This distribution has already been modified by the influence of human behaviour (through vector control, and infrastructure changes). This model captures the effect of these influences on the current climate relationship, but it does not attempt to model future changes in these influences (e.g. reduced public health control).

7. HEALTH IMPACTS STUDIED

7.1 Temperature-related deaths

7.1.1 Reason for consideration

Heat-related deaths are the result of prolonged exposure to ambient heat, which can cause heat exhaustion, cramps, heart attacks and stroke. Those most vulnerable include the elderly *(Guest et al. 1999)*, people under intense physical stress, and those with cardiovascular disease. This vulnerability relates to a decreased capacity to increase cardiac output as a cooling mechanism. The temperature at which sweating (i.e., cooling) begins also increases with age *(Coates 1996)*. Over the last 50 years, warming in the Australian region has occurred principally in the form of rising minimum temperatures, with fewer cold extremes. Daytime maximum temperatures have risen less than night-time minimum temperatures. This trend is projected to continue because of greenhouse 'forcing'. Global climate change is expected to bring an increase in the frequency and intensity of heatwaves, warmer summers and milder winters *(Kovats et al. 2001)*.

Previous research

In temperate countries, there is a U-shaped relationship between temperature and mortality, with a minimum number of deaths at moderate temperatures, and an increase in deaths during hot weather as well as cold weather *(Kunst et al. 1993, Martens 1998b)*. Excess winter mortality appears to be greatest in countries with mild winters *(Keatinge et al. 1997)*. In New Zealand, heart disease death rates are up to 35% higher at the winter peak compared to the summer low *(Marshall et al. 1988)*. Seasonal variation is even greater (over 50% variation) among the elderly and for deaths from respiratory causes, but possible explanatory factors such as other meteorological variables or air pollution were not analysed in this study. Air pollution and extremes of temperature are each associated with increases in mortality from all causes, with stronger effects on respiratory and/or cardiovascular mortality.

Local studies of daily deaths in relation to temperature in New Zealand have been conducted in Christchurch *(Hales et al. 2000)* and Auckland *(Cockburn 2001)*. In Christchurch, daily maximum temperatures average 20°C in summer but occasionally exceed 35°C. After removing seasonal effects using a regression method, mortality was found to be at a minimum on days where the temperature was between about 12 and 20°C *(Hales et al. 2000)*. There was a correlation between daily temperature and mortality on hot days, above 20°C, whereas the correlation between cold days and mortality was not statistically significant. The effect of temperature on mortality on the day of death and one to two days prior to death was investigated. The strongest effect was seen on the day of death, where mortality from all causes increased by about 1% per degree Celsius for days above 20°C.

In Auckland, daily maximum temperatures rarely reach 29°C. Cockburn investigated the effect of temperature on mortality in Auckland on the day of death and up to seven days prior to death *(Cockburn 2001)*. When seasonal effects were removed using a monthly running mean, mortality from all causes increased following cold weather, after a lag of four days. In summer, mortality from respiratory causes increased following hot weather, but to a less marked extent. Guest and others *(Guest et al. 1999)* studied the impact of climate on temperature-related deaths between 1979 and 1990 in five capital cities in Australia.

They predicted that heat-related mortality would increase, but that it would be offset by a reduction in cold-related mortality. The overall net reduction of daily temperature-associated mortality by 2030 was estimated at 10% *(Guest et al. 1999)*.

7.1.2 Method of analysis

In the analysis for this risk assessment, the baseline annual number of temperature-attributable deaths was calculated for ten major Australian cities and two New Zealand cities. The number of deaths due to temperature in the future was estimated, based on models of projected climate change. The results are presented with and without expected changes in population size and age distribution, so that the climate and changing population structure effects can be separately identified.

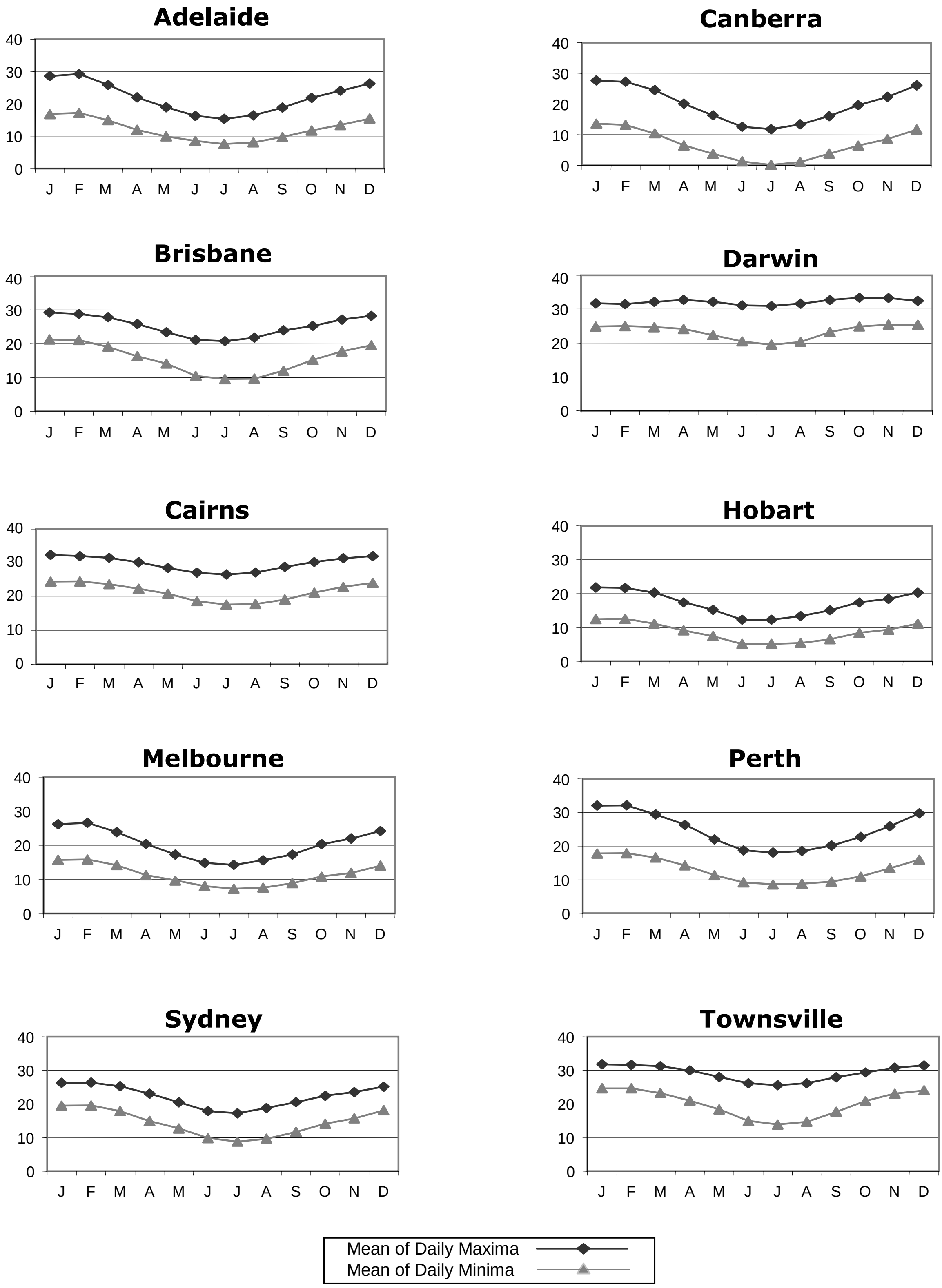
The populations living in the major cities of Adelaide, Auckland, Brisbane, Cairns, Canberra, Christchurch, Darwin, Hobart, Melbourne, Sydney, Perth, and Townsville were studied. For each city all-cause mortality was examined in relation to ambient maximum and minimum temperatures, after adjusting for the effect of air pollution.

Data

Bureau of Meteorology observations of daily maximum and minimum temperature were obtained for each Australian city for the years 1990 to 1999. The Sydney, Melbourne, Adelaide and Hobart data came from central city observations. The other Australian cities in the study do not have readily available continuous, high-quality meteorological records from the central city area; data from these cities came from observations taken at airport stations. Over a longer period, the effect of urban heating in the centre relative to the outskirts may skew the overall temperature picture for a city. However, given that this study spans a short period (ten years) and that a separate analysis was conducted for each city, this was not considered to be a problem. In general, a warm day on the outskirts will also be a warm day in the centre. The variations from day to day at the airport are likely to be representative of the day to day variations in the urban centre, even though the latter will be consistently several degrees higher (due to the "heat-island" effect, where cities experience higher daytime temperatures, and sustain higher night-time temperatures). It is likely that the estimates for those cities underestimate the true effect of heat. Figure 3 presents the mean daily temperature profiles for each of the Australian cities, for the years 1990 to 1999. There were very few missing data. Where these occurred, data were imputed from surrounding values. The NZ National Institute of Water and Atmospheric Research provided weather data for the two New Zealand cities in the study, for the period June 1988 to December 1997.

The Australian Institute of Health and Welfare provided monthly all-cause mortality for the years 1997 to 1999 inclusive, for the 65+ age groups (that group most vulnerable to the effect of temperature). The Australian Bureau of Statistics classification of city boundaries was used to define the geographic extent of each city. Mean annual mortality figures for each city were derived to provide the "baseline". New Zealand mortality data were acquired from the NZ Health Information Service.

Figure 3 Mean daily temperature profiles for Australian cities, 1990 to 1999 (Bureau of Meteorology)



Dose-response relationship

Poisson multiple regression analysis of the relationships between daily all-cause mortality in people aged over 65 years, daily maximum and minimum temperatures, and air pollution levels was undertaken for two cities in the study (Auckland and Christchurch). The data were analysed by Kjellstrom and Shrestha (to be published, 2002). PM_{10} (a measure of particulate pollution), seasonal patterns of mortality, and population size were used as explanatory variables in the model. Seasonal patterns of mortality were controlled using a sinusoidal wave function. Residuals from the model were calculated for each day.

The relationship between mortality and temperature can be described as having a "U-shaped pattern", in which a reduction in mortality attributable to temperature is observed until a threshold is reached, after which there is a linear increase in the relationship between temperature and deaths. The Christchurch regression analysis showed that, at the minimum temperature end, temperature attributable mortality increased as temperatures dropped below 0°C at a rate of 0.8% per degree. At the maximum temperature end, temperature-attributable mortality started at 28°C and increased by 3% per degree above that. These dose-response relationships reflect the independently remaining effects after air pollution effects had been accounted for.

Given time constraints, the Christchurch threshold values were used in the calculation of mortality for the temperate cities of Adelaide, Canberra, Hobart, Melbourne, Brisbane and Perth. A preliminary analysis for Brisbane by Rod Simpson and others (unpublished data) showed the heat threshold from Christchurch (i.e., 28°C) also applied for Brisbane, with no cold threshold identifiable. The dose-response values for Sydney were prepared by Geoff Morgan (Southern Cross Institute). These data showed an increase in mortality as daily maximum temperatures increased above 20°C, with a 1% increase in deaths per degree above that. The dose-response values for the tropical cities of Darwin and Cairns were prepared by Rupendra Shrestha (New Zealand Environmental and Occupational Health Research Centre). He found that attributable mortality increased by 10% per degree increase in maximum temperature above 34°C. No threshold was evident for minimum temperatures. This dose-response result was used for the calculation of Townsville heat-related mortality.

Calculation of attributable deaths

Future maximum and minimum temperature increases were derived for each city area for the years 2020 and 2050, using the three alternative climate scenarios and two different model projections provided by the CSIRO (see Section 6.2). The Australian Bureau of Statistics classification of city boundaries was used to define the geographic extent of a city, and future increases in temperature were averaged for each of these areas. The future projections were calculated separately with and without adjustment for the projected change in population size in the 65+ age group (city increases or decreases in the future size of this group were taken from Australian Bureau of Statistics projections – see Section 6.2 and the table at Appendix A). It was assumed that the background mortality rate in the future years would remain the same as in the baseline year.

The calculation of baseline and future deaths temperature-attributable deaths was:

Baseline Deaths $A = [\Sigma (DR \times T_{1\text{-}x})] \times M$
where,
A......... annual temperature-attributable deaths
DR...... dose-response relationship calculated from daily temperature values (percent increase in mortality per degree Celsius temperature change above/below threshold)
T......... frequency of days above/below threshold temperature (from 1990-1999)
M........ mean annual all-cause mortality, per 65+ age group (average of 1997-1999)

Future Deaths $A = [\Sigma (DR \times T_{1\text{-}x})] \times M \times P$
where,
A......... annual additional temperature-attributable deaths
DR...... dose-response relationship calculated from daily temperature values (percent increase in mortality per degree Celsius temperature change above/below threshold)
T......... frequency of days over/below threshold temperature (baseline frequency shifted according to projected increase in max. and min. temperatures)
M........ mean annual all-cause mortality, per 65+ age group (average of 1997-1999)
P......... proportional population change, relative to baseline

7.1.3 Findings

Table 2 shows results for all-cause temperature-attributable deaths in people aged 65 years and older in six of the temperate Australian cities. Results are categorised into baseline deaths (1997 to 1999 period), estimated deaths in 2020, and in 2050. The results are provided for the three alternative climate scenarios (low, mid, and high emissions) and for the two regional model simulations (CSIROMk2 and ECHAM4). Table 3 presents the results for the three tropical cities. Table 4 presents the results for Canberra, the only Australian city in the study that recorded deaths attributable to cold temperatures. Figure 5 is a graphical prediction of the results for the Australian cities at the baseline year, 2020, and 2050. The figure shows results for the mid scenario and baseline population values. For the New Zealand cities, Tables 5 & 6 show results for heat and cold deaths. All results assume no adaptation will occur by populations to the projected increases in temperatures.

Heat-related deaths in temperate Australian cities (Tables 2 & 4) for people aged over 65 years

Assuming no change in population size or structure

Baseline Year

- The highest number of temperature-related deaths per capita in the 65+ age-group was predicted for the cities of Perth and Adelaide. In the baseline year (an average of the period 1997-1999) temperature-attributable death rates were estimated to be: Perth (199/100,000); Adelaide (127/100,000); Brisbane (77/100,000); Melbourne (70/100,000); Canberra (56/100,000); Sydney (37/100,000); and Hobart (19/100,000).
- Canberra was the only city for which deaths were attributed to cold temperatures (an average of 3 deaths per year).
- The estimated number of annual heat-related deaths for all the temperate cities in the study was 1115.

2020

- The “high” scenario predicted a 0.5°C maximum temperature increase for all cities except Hobart. A 5-41% increase in the mortality burden was predicted for the temperate cities, relative to the baseline. The largest increases were predicted for Brisbane (41%) and Sydney (34%).

2050

- The range of maximum temperature increases predicted across the cities was between 0.55 and 2.35°C. Relative to the baseline, Brisbane and Sydney were predicted to have the greatest percentage increases in mortality (164% and 149% respectively for the high scenario).
- The range of minimum temperature increases for Canberra was 0.73 to 2.24°C. Cold-related deaths in Canberra were predicted to have decreased by this point, but one or two a year were still predicted.

Accounting for projected changes in population size and structure (see table at Appendix A)

Baseline Year

- Relative to the baseline, the absolute number of annual heat-related deaths was predicted to increase substantially. Much of the predicted increase in future deaths was likely to be due to the effect of an ageing population, with the effect due to increased warming expected to comprise a smaller fraction (see Figure 4 for a diagrammatic explanation of the contribution of the effects of climate and ageing on the future heat-related mortality projections).

2020

- The estimated number of annual heat-related deaths for all the temperate cities in 2020 was between 2300 and 2500.

2050

- The heat-related mortality rates were predicted to increase substantially for all cities by 2050: Perth (226–279/100,000); Adelaide (143–196/100,000); Brisbane (116–204/100,000); Melbourne (84–112/100,000); Canberra (72–107/100,000); Sydney (50–92/100,000); and Hobart (22–29/100,000), after accounting for projected changes in age distribution.
- Annual estimates for Brisbane were of between 800 and 1400 deaths (134 baseline), for Sydney of 700 to 1300 deaths (176 baseline), for Melbourne of 1000 to 1300 deaths (baseline 289), for Perth of 1300 to 1500 (294 baseline), and for Adelaide of 500 to 700 (200 baseline).
- The estimated number of annual heat-related deaths for all the temperate cities in 2050 was between 4300 and 6300.

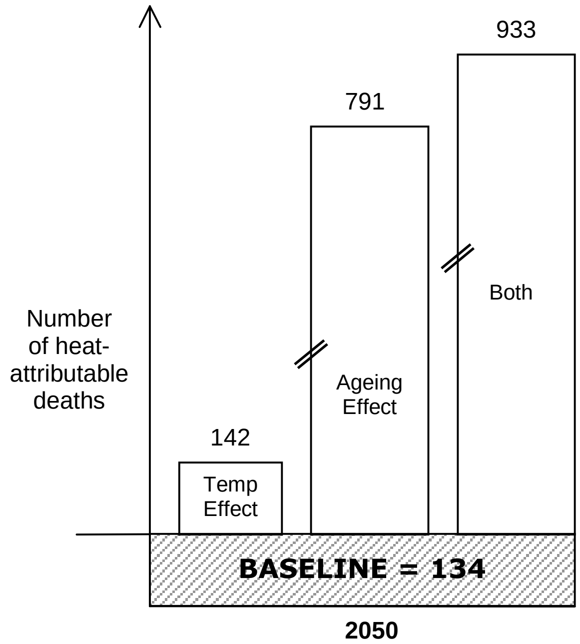
Heat-related deaths in tropical Australian cities (Table 3) for people aged over 65 years

Assuming no change in population size or structure

Baseline

- The annual baseline death rates in the 65+ age group were estimated to be: Darwin (59/100,000); Townsville (33/100,000); and Cairns (12/100,000).
- The estimated number of heat-related deaths for all the three tropical cities at the baseline was estimated to be six per year.

Figure 4 Temperature increase and ageing effect components of the total number of deaths attributable to heat for Brisbane, under the "mid" scenario and CSIROMk2 model for 2050 (data from Table 2)*



* The baseline number of deaths attributable to heat each year were 134. With an estimated increase in temperature of 1.64oC, an additional 142 deaths per year were predicted (assuming the population stayed the same as at 1999). If temperatures did not change, an additional 791 heat-related deaths were predicted for 2050 (due to the projected increase in people aged over 65). When the effect of both temperature and ageing were accounted for, an additional 933 deaths were predicted for Brisbane in the year 2050, relative to the present. In total, an average of 1067 heat-related deaths a year were predicted in 2050, compared to the current estimation of 134 deaths per year.

2020

- The "high" scenario predicted a maximum temperature increase of between 0.61°C and 0.76°C in the three cities. Relative to the baseline, an increase of 67-200% in deaths was predicted (although absolute figures were small).

2050

- All scenarios predicted an increase in maximum temperatures of between 0.77°C and 2.56°C. The greatest mortality increases were predicted for Darwin, relative to the baseline (between 200–900%).

Accounting for projected changes in population size and structure (see table at Appendix A)

2020

- The estimated number of heat-related deaths for all the three tropical cities was predicted to be between 20 and 28 per year.

2050

- Absolute heat-related deaths were predicted to rise substantially for Darwin (37 to 126 deaths per year), from a baseline of 2 per year.
- Annual heat-related death rates were predicted to increase substantially for all cities: Darwin (177–602/100,000); Townsville (56–192/100,000); and Cairns (27–63/100,000).
- The estimated number of heat-related deaths for all the three tropical cities in the over 65 agegroup was predicted to be between 58 and 186 a year by 2050.

Heat-related deaths in the New Zealand cities (Tables 5 & 6) for people aged over 65 years

- Four deaths per year were predicted to be due to heat in Auckland, and two per year due to cold. For a temperature increase of 2-3°C, the number of cold-related deaths was predicted to diminish to zero. Meanwhile, the number of heat deaths was predicted to increase to 53 (at +3°C). This represents a net increase in the temperature-related mortality burden of about eight-fold.
- Ten deaths per year were predicted to be due to heat in Christchurch, and two per year due to cold. The number of cold-attributable deaths was predicted to diminish to zero with a 1°C increase in temperature. Heat-attributable deaths were predicted to increase to 35 (at 3°C), or about three-fold.

7.1.4 Interpretation

These findings indicate that: (i) after adjusting for the effect of air pollution, thermal extremes currently contribute to the deaths of approximately 1121 people a year in the Australian cities and 18 people a year in the New Zealand cities studied, and (ii) climate changes are predicted to increase the overall number of temperature-related deaths in all the cities studied in future, assuming no human adaptation to these changes.

Two previous studies in the Australian and New Zealand region *(Cockburn 2001, Guest et al. 1999)* indicated that expected increases in summer mortality due to global climate change would be roughly equalised by corresponding decreases in winter mortality. In the current analysis, the estimated increases in heat-related deaths were predicted to be far greater than the decreases in cold-related deaths. This different finding may relate to the fact that the previous studies mentioned were not able to adjust for the effect of air pollution. Air pollution is higher in urban areas and, typically, in winter, due to additional particulate pollution from home heating *(Kjellstrom and Shrestha, in preparation)*. In temperate zone cities, daily mortality is also much higher in winter than summer. Therefore, if the health effect of temperature is analysed without accounting for air pollution, cold temperatures will appear to have a greater effect on mortality than is really the case. After adjusting for air pollution, it was estimated that only a very small number of cold-related deaths currently occur in, for example, Auckland (2/year), Canberra (3/year), and Christchurch (2/year). These cities may experience positive effects from a reduced number of cold winter days in the short-term, but in the medium- to long-term these health gains are predicted to be outnumbered by the additional heat-related deaths. Additionally, the current analysis has used the most recent general circulation model (GCM) estimates: these predict a greater degree of future warming than the earlier GCM estimates used by the aforementioned studies.

The cities in this analysis cover a broad range of latitude, with much variation in average seasonal temperatures. The high number of deaths per capita in Perth and Adelaide relates to the high frequency with which maximum temperatures above 40°C are recorded from December through to March. Conversely, the cities in the tropical zone (Darwin, Cairns, Townsville, and to a lesser extent Brisbane) recorded the lowest baseline rates, and have far fewer days above 32°C. Although the tropical cities have high average maxima, the maximum temperatures across a typical summer month are relatively stable (i.e., the maximum temperature fluctuates very little over the summer period), and maximum temperatures typically remain in the low thirties. In Perth and Adelaide, however, the monthly average maxima for December and January are approximately the same as for the tropical cities (low thirties), but within an average month great temperature fluctuations can occur in these cities, including days in the high thirties and low forties.

The high rates estimated for Darwin in the 2050s in part relate to the fact that this city was the only one for which an increase of 3°C was predicted by that year.

Adaptive measures include development of community-wide heat emergency plans, the development of a heat-forecasting systems, better heat-related illness management plans, and better education on behavioural changes *(Patz et al. 2000)*. The extent to which population acclimatisation and adaptation (through increased use of air conditioners, additional intake of fluids, changed work hours, better insulation and building design etc) will affect these figures has not been calculated. Some studies have suggested that, even if people acclimatise to the increased warmth, the rapid pace of predicted climate change is likely to mean that summer mortality would increase markedly anyway *(Kalkstein and Greene 1997)*, depending on the scale at which people are able to adapt (i.e., annual, or longer). Nevertheless, level of socio-economic status can be expected to influence a population's capacity to adapt, and this aspect of the future relationship warrants further research. Indeed, given that the world is now apparently committed to undergoing some degree of climate change, no matter what, there is a need to consider, and evaluate, adaptive strategies in relation to many different types of risks to health.

Table 2 Annual all-cause deaths in people aged 65 years and older attributable to heat in six temperate Australian cities (calculated for alternative emission scenarios [high, mid, and low] and for two regional model simulations [CSIROMk2 and ECHAM4])

Scenarios		Adelaide				Brisbane				Hobart			
		Temp △	Pop △	No Pop △		Temp △	Pop △	No Pop △		Temp △	Pop △	No Pop △	
		°C	Deaths	Deaths	% inc.	°C	Deaths	Deaths	% inc.	°C	Deaths	Deaths	% inc.
Baseline (1999)		-	-	200	-	-	-	134	-	-	-	5	-
2020													
High	*CSIROMk2*	0.67	371	230	15	0.70	387	189	41	0.48	8	5	0
	ECHAM4	0.46	356	221	10	0.68	383	187	40	0.44	8	5	0
Mid	*CSIROMk2*	0.51	359	223	11	0.54	361	176	31	0.36	8	5	0
	ECHAM4	0.36	348	216	8	0.52	358	175	31	0.34	8	5	0
Low	*CSIROMk2*	0.38	350	217	9	0.40	339	165	23	0.27	8	5	0
	ECHAM4	0.27	342	212	6	0.39	337	165	23	0.25	8	5	0
2050													
High	*CSIROMk2*	2.24	664	311	56	2.35	1368	354	164	1.60	14	7	40
	ECHAM4	1.56	585	274	37	2.27	1331	344	157	1.47	13	7	40
Mid	*CSIROMk2*	1.56	585	274	37	1.64	1067	276	106	1.12	12	6	20
	ECHAM4	1.09	533	249	25	1.58	1044	270	101	1.03	12	6	20
Low	*CSIROMk2*	0.84	507	237	19	0.88	785	203	51	0.60	10	6	20
	ECHAM4	0.58	482	226	13	0.85	776	201	50	0.55	10	6	20

Scenarios		Melbourne				Perth				Sydney			
		Temp △	Pop △	No Pop △		Temp △	Pop △	No Pop △		Temp △	Pop △	No Pop △	
		°C	Deaths	Deaths	% inc.	°C	Deaths	Deaths	% inc.	°C	Deaths	Deaths	% inc.
Baseline (1999)		-	-	289	-	-	-	294	-	-	-	176	-
2020													
High	*CSIROMk2*	0.63	601	333	15	0.53	689	327	11	0.60	402	227	29
	ECHAM4	0.65	604	335	16	0.50	685	325	11	0.70	417	235	34
Mid	*CSIROMk2*	0.48	582	323	12	0.40	672	319	9	0.46	381	215	22
	ECHAM4	0.50	584	324	12	0.38	670	318	8	0.54	392	221	26
Low	*CSIROMk2*	0.36	566	314	9	0.30	658	313	6	0.35	364	205	16
	ECHAM4	0.37	568	315	9	0.29	657	312	6	0.40	372	210	19
2050													
High	*CSIROMk2*	2.10	1293	455	57	1.77	1548	412	40	2.02	1151	384	118
	ECHAM4	2.19	1318	463	60	1.68	1524	405	38	2.35	1312	438	149
Mid	*CSIROMk2*	1.46	1136	399	38	1.23	1404	373	27	1.41	928	309	76
	ECHAM4	1.53	1152	405	40	1.17	1388	369	26	1.64	1011	337	91
Low	*CSIROMk2*	0.78	980	344	19	0.66	1262	335	14	0.75	717	239	36
	ECHAM4	0.82	988	347	20	0.63	1254	334	14	0.88	749	250	42

"Temp △": refers to the projected change in maximum temperatures.

"Pop △": the future attributable mortality burden is presented, assuming a larger, older population.

"No Pop △": the future attributable mortality burden and percentage increase in mortality burden from baseline are presented, without accounting for the projected changes in population structure (i.e., based on 1999 population estimates).

Table 3 Annual all-cause deaths in people aged 65 years and older attributable to heat in three tropical Australian cities

Scenarios		Cairns				Darwin				Townsville			
		Temp ∆	Pop ∆	No Pop ∆		Temp ∆	Pop ∆	No Pop ∆		Temp ∆	Pop ∆	No Pop ∆	
		°C	Deaths	Deaths	% inc.	°C	Deaths	Deaths	% inc.	°C	Deaths	Deaths	% inc.
Baseline (1999)		-	-	1	-	-	-	2	-	-	-	3	-
2020													
High	*CSIROMk2*	0.70	5	2	100	0.64	15	5	150	0.73	7	5	67
	ECHAM4	0.61	5	2	100	0.76	16	6	200	0.65	6	5	67
Mid	*CSIROMk2*	0.53	5	2	100	0.49	13	5	150	0.56	6	4	33
	ECHAM4	0.47	5	2	100	0.59	14	5	150	0.49	6	4	33
Low	*CSIROMk2*	0.40	4	2	100	0.37	11	4	100	0.42	6	4	33
	ECHAM4	0.35	4	2	100	0.44	12	4	100	0.37	5	4	33
2050													
High	*CSIROMk2*	2.34	26	5	400	2.13	98	16	700	2.45	34	18	500
	ECHAM4	2.07	22	5	400	2.56	126	20	900	2.17	28	14	367
Mid	*CSIROMk2*	1.63	18	4	300	1.49	66	11	450	1.71	20	10	233
	ECHAM4	1.50	17	3	200	1.76	80	13	550	1.51	18	9	200
Low	*CSIROMk2*	0.87	12	2	100	0.80	37	6	200	0.91	11	5	67
	ECHAM4	0.77	11	2	100	0.96	41	7	250	0.81	10	5	67

Table 4 Annual all-cause deaths in people aged 65 years and older attributable to heat and cold in Canberra

Scenarios		Heat Deaths				Cold Deaths				Net Deaths			
		Temp ∆	Pop ∆	No Pop ∆		Temp ∆	Pop ∆	No Pop ∆		Temp ∆	Pop ∆	No Pop ∆	
		°C	Deaths	Deaths	% inc.	°C	Deaths	Deaths	% inc.	°C	Deaths	Deaths	% inc.
Baseline (1999)		-	-	14	-	-	-	3	-	-	-	17	-
2020													
High	*CSIROMk2*	0.65	40	17	21	0.58	6	3	0	-	46	20	18
	ECHAM4	0.71	41	17	21	0.67	6	3	0	-	47	20	18
Mid	*CSIROMk2*	0.50	38	17	21	0.45	7	3	0	-	45	19	12
	ECHAM4	0.55	39	17	21	0.51	6	3	0	-	45	20	18
Low	*CSIROMk2*	0.37	37	16	14	0.34	7	3	0	-	44	19	12
	ECHAM4	0.41	37	16	14	0.38	7	3	0	-	44	19	12
2050													
High	*CSIROMk2*	2.18	88	25	79	1.96	5	1	-67	-	93	27	59
	ECHAM4	2.40	92	27	93	2.24	4	1	-67	-	97	28	65
Mid	*CSIROMk2*	1.52	75	21	50	1.37	7	2	-33	-	81	23	35
	ECHAM4	1.67	77	22	57	1.56	6	2	-33	-	84	24	41
Low	*CSIROMk2*	0.81	62	18	29	0.73	9	3	0	-	71	20	18
	ECHAM4	0.89	63	18	29	0.84	8	2	-33	-	72	21	24

"Temp ∆": refers to the projected change in maximum temperatures. For Canberra, for the heat deaths calculations, Temp ∆ is the projected change in max. temperatures. For the cold deaths calculations, Temp ∆ is the projected change in min. temperatures.

"Pop ∆": the future attributable mortality burden is presented, assuming a larger, older population.

"No Pop ∆": the future attributable mortality burden and percentage increase in mortality burden from baseline are presented, without accounting for the projected changes in population structure (i.e., based on 1999 population estimates).

Figure 5 Predicted heat-related deaths in 10 Australian cities at the baseline year (1999), 2020, and 2050 (for the mid scenario and for baseline population values)

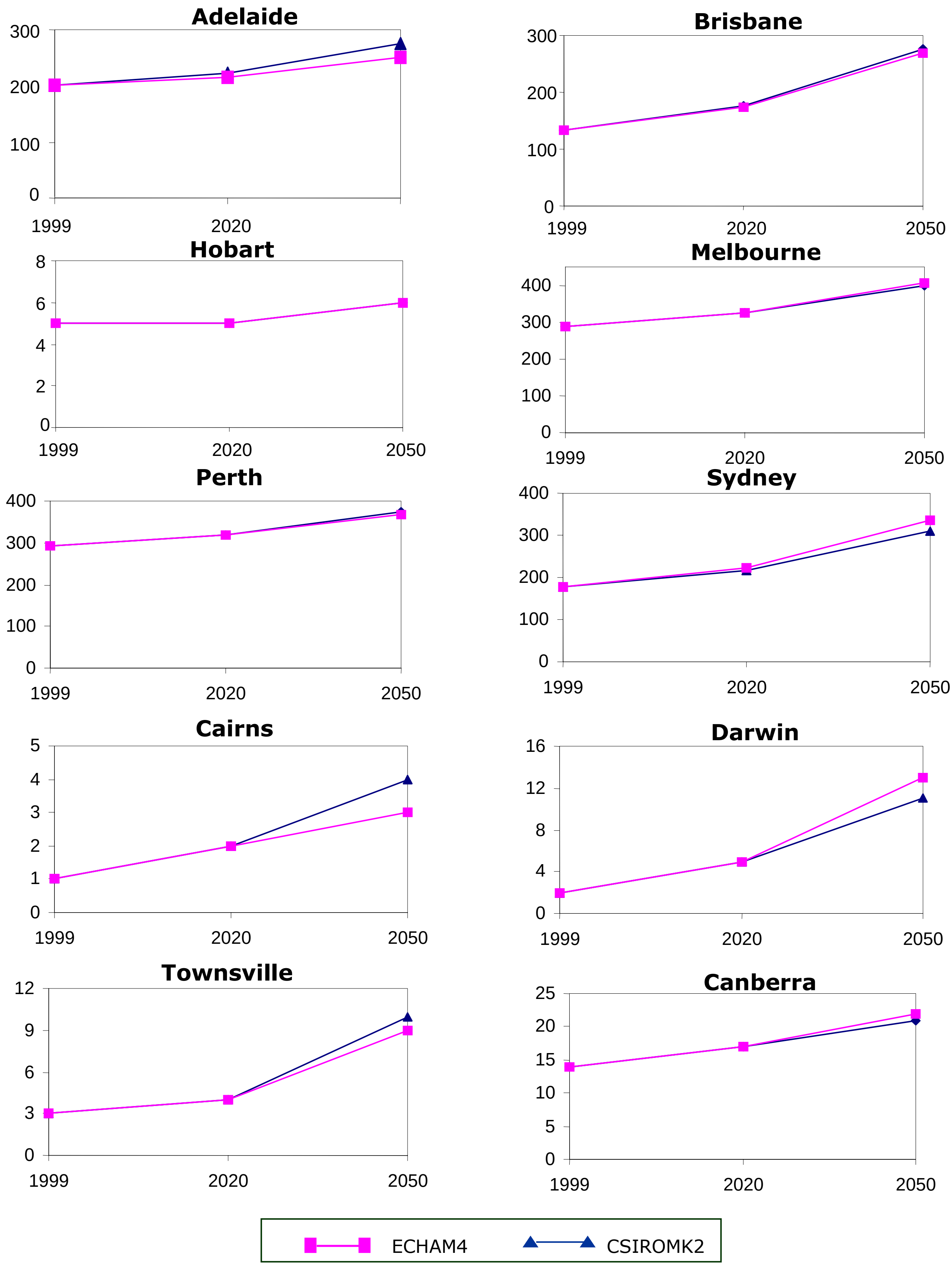


Table 5 Annual all-cause deaths in people aged 65 years and older attributable to heat in Auckland, New Zealand

Temperature °C	Temperature-related deaths*		% Increase in mortality**
	Heat	*Cold*	
Baseline ***	4	2	-
+ 1	12	1	117%
+ 2	27	<1	350%
+ 3	53	<1	783%

* All estimates used the baseline population (no increase in population over the 50 years was assumed).
** Relative to the baseline mortality.
*** Annual figure derived from the period 1989 to 1997.

Table 6 Annual all-cause deaths in people aged 65 years and older attributable to heat in Christchurch, New Zealand

Temperature °C	Temperature-related deaths*		Increase in mortality**
	Heat Deaths	*Cold Deaths*	
Baseline ***	10	2	-
+ 1	16	1	41%
+ 2	24	<1	100%
+ 3	35	<1	292%

* All estimates used the baseline population (no increase in population over the 50 years was assumed).
** Relative to the baseline mortality.
*** Annual figure derived from the period 1989 to 1997.

7.2 Deaths and injuries from extreme rainfall and flooding

7.2.1 Reason for consideration

The frequency of extreme rainfall events is expected to increase almost everywhere in the world *(IPCC 2001a)*. In Australia, the flooding of rivers following heavy rainfall is the most common form of flooding *(Bureau of Meteorology 2002)*. River floods in inland areas of central and western New South Wales and Queensland, as well as parts of Western Australia, can spread for thousands of square kilometres and may last for weeks or even months. Flash flooding usually results from relatively short intense bursts of rainfall, commonly from thunderstorms. This flooding can occur in most parts of the country, but is a particularly serious problem in urban areas where drainage systems may not cope, in hilly or mountainous areas of inland rivers, in rivers draining to the coast, and in very small creeks and streams. Flash floods tend to be quite local, and early warning can be hampered by their rapid onset.

Substantial research on flood fatalities in Australia has been conducted by Coates *(Coates 1996)*. Flood-risk seasons change with location *(Coates 1999)*, reflecting the dominant seasonal rainfall patterns of a region, the timing of tropical cyclones, monsoons and tropical depressions *(Suppiah 1992)*. In northern Australia, most of the big floods occur in summer or early autumn in association with tropical cyclones or intense monsoonal depressions. Outside the tropics, coastal areas of eastern Australia receive most flood rains from "east coast lows" that develop over the Tasman Sea *(Bureau of Meteorology 2002)*.

In the southern states, flooding is mostly a winter-spring phenomenon, associated with unusually frequent low pressure systems and fronts. Flooding, unlike drought, is often localised, and therefore not closely tied to broad-scale influences like the El Niño-Southern Oscillation phenomenon *(Bureau of Meteorology 2002)*. Even so, over much of Australia flooding is more likely than usual during La Niña years, and less likely in El Niño years *(Bureau of Meteorology 2002)*. The La Niña years of 1916, 1917, 1950, 1954–1956, and 1973–1975, were accompanied by some of the worst and most widespread flooding in the country this century.

Historically, most deaths in Australia have occurred in Queensland in February, in NSW in the months of February and June, and in Victoria in August, September, and October *(Coates 1999)*.

Impacts of Flooding

Flooding can cause immediate, medium-term, and longer-term effects on communities. The immediate health effects include deaths and injuries by drowning or from being hit by heavy or sharp objects. At least 2213 people were estimated to have died in floods during the period 1788 to 1996 *(Coates 1999)*, an average of 10.5 deaths per year. There has been an overall decrease in flood fatalities in Australia since the 1850s. Deaths due to flooding were much higher in the early days of European settlement of Australia, when knowledge of the landscape and climate patterns of the country were less developed (for example 36% of the 250 people living in Gundagai were killed in 1852) *(Coates 1999)*.

Improvement in flood mitigation infrastructure, better warning systems and rescue services have also led to a general decline in deaths *(Coates 1999)*. This contrasts with the USA, where flood death rates have not decreased over time, and floods are the main cause of natural hazard disasters *(Noji 1997)*. No major flood disaster (i.e., with more than several people killed in a single event) has occurred in Australia since 1955, when 24 deaths were recorded in Singleton and Maitland NSW *(Coates 1999)*. Even so, current flood fatalities are still significant, representing a large proportion of natural-hazard fatalities in Australia, possibly equal with tropical cyclones, following heatwaves (Table 7). In New Zealand, approximately one drowning a year is recorded by the New Zealand Health Information Service as due to "floods and civil emergencies" *(Woodward et al. 2001)*, but this is almost certainly an under-estimate.

Table 7 Fatalities in Australia caused by some natural hazards

Natural Hazard	Period covered	Total Fatalities
Heatwaves	1803 – 2002	4336
Floods	1788 – 2002	2231
Tropical cyclones	1827 – 2002	1906-2355*
Bushfires	1827 – 2002	682
Lightning strikes	1803 – 2002	652
Landslides	1803 – 2002	50

* Maximum and minimum estimates.
Source: adapted from Coates 1996, EM-DAT database (OFDA/CRED 2002) and Emergency Management Australia 2002.

Medium-term effects of flooding relate to the possibility of increased water-borne diseases, although the evidence for this is inconclusive. Potentially, floods may disrupt water purification and sewage disposal systems *(Kovats et al. 1999)*, and minimising disease risk relies on well-maintained flood control and sanitation infrastructure, as well as public health surveillance and disease prevention *(Kovats et al. 2001)*.

There is some evidence of long-term health impacts for people affected by natural disasters. While most people maintain adequate recuperative strategies and return to a state of normalcy following a disaster *(Green 1991, Lazarus and Folkman 1984)*, there is increasing evidence that a proportion do not. Flood victims frequently report feeling depressed and isolated *(Tapsell 2000)*. Heightened psychological stress has been suggested for the increased number of visits that people affected by the Brisbane floods made to medical providers *(Abrahams et al. 1976)*. Some 15-20% of people affected by a natural disaster in one study were found to have symptoms of post-traumatic stress disorder *(Beck and Franke 1996)*, and 50 suicides were attributed to flood effects in Poland in 1997 *(Kovats et al. 1999)*. Providing social support for the process of cleaning up, making repairs, and insurance claims has been shown to significantly lower illness burdens after natural disasters *(Lutgendorf et al. 1995)*.

7.2.2 Method of analysis

Intense rainfall and inland flooding have been poorly researched *(Pielke 1999)*. Only one study has attempted to model intense rainfall as a health exposure, and to estimate the magnitude of health impacts. McMichael, Campbell-Lendrum and others *(McMichael et al. 2002)*, in their estimation of the global burden of disease relating to climate change, made an assumption that the frequency of health impacts will be determined by the temporal distribution of rainfall at the local level (i.e., not only by the average amount of rain over an extended period, but by the peak amount falling in a week, day or hour). It will also be modulated by topography, and the social aspects of vulnerability *(Kundzewicz and Kaczmarek 2000)*. They made the *a priori* assumption that flood frequency is proportional to the frequency with which monthly rainfall exceeds the 1 in 10 year limit (i.e., upper 99.2% percentile) of the baseline climate. They also assumed that determinants of vulnerability would be distributed evenly throughout the population of a region – so that the change in relative risk of health impacts would be proportional to the per capita change in absolute risk of experiencing such an extreme event.

The method of McMichael and Campbell-Lendrum was adopted for this analysis, with some minor adjustments. A longer time series of baseline rainfall observations was provided by the CSIRO for this analysis. This enabled a more precise estimate of the baseline mean and variability. The 99.2 percentile for the 'baseline climate' was estimated for each 0.25 by 0.25 degree grid cell in Australia, using means and standard deviations derived from 1961 to 1970 observed monthly rainfall (120 months). Time constraints did not permit an analysis of the standard thirty year "climate normal" period (i.e., 1961 to 1990). Monthly projected data for the future climate scenarios at 2020 and 2050 were used to estimate the change in frequency with which a '1 in 10 year event' (i.e., 1 in 120 month) would occur.

The difference between the projected future rainfall mean and the previously defined '1 in 120 month limit' was calculated by:

$$((X_1 + 2.41 * u_1) - X_2)/u_1$$

X_1, u_1 = mean and intra-annual deviation of monthly rainfall from 1961-1970
X_2 = mean under new scenario (12 months of values)

The probability that this difference would be exceeded in any one month under the projected future rainfall distribution was taken from probability tables. This probability was divided by the frequency of occurrence under the baseline scenario (=0.008) to give the relative frequency with which the 1 in 120 month limit would be exceeded for each future climate scenario.

The measure of "exposure risk" (or flood risk) is the relative frequency with which each person in a grid cell area is predicted to experience 1 in 10 year rainfall events in 2020 and 2050. A value of "1" indicates no change in risk; values greater or less than 1 indicate higher and lower risk than the baseline respectively (the baseline climate period is 1961-1970). The exposure risk results were weighted by the population in each SLA, and then averaged across Statistical Division regions. State estimates were obtained from a weighted population average of the Statistical Division figures.

The main limitation of this method is that it assumes that future rainfall variability will remain the same as present. Future changes in rainfall variability cannot currently be projected with any reliability or accuracy by GCMs, and consequently were not available for this analysis. Based on patterns from current global climate models, it is likely that future increases in mean rainfall would lead to increased variability. Conversely, future decreases in the mean rainfall are likely to lead to reduced variability. Climate change models for the Australian region present mixed estimates of mean changes in future rainfall. Of the two models used for this study, CSIROMk2 simulates wetter conditions in central Australia and the Top End, but drier conditions elsewhere. ECHAM4 simulates wetter conditions north of a diagonal line from Broome to Hobart, and much drier conditions in the west.

Baseline Rates

The exposure risks for each state were applied to the baseline estimated rate of deaths and injuries attributable to extreme rainfall events. Death and injury rates were calculated from data derived from two sources: the EM-DAT database *(OFDA/CRED 2002)*, and the Emergency Management Australia database *(Emergency Management Australia 2002)*. The EM-DAT database records numbers of deaths and injuries attributed to each natural disaster reported by the media or aid agencies in the last 100 years. This is the most comprehensive global data source available on the current health impacts of natural disasters. Disasters are defined as events which resulted in at least one of the following conditions: (1) >10 people killed, (2) >200 injured, or (3) a call for international assistance.

The Emergency Management Database is the principal ongoing collection of natural disaster events in Australia. In general, it provides more details about where an event occurred. The two data sets were combined to maximise the available information on place, time and climatic conditions relating to deaths and injuries. Death and injury data for the period 1970 to 2001 were collected (representing the baseline period for the health outcome). Reported deaths due to flood and severe storms were counted, but those due to tropical cyclones were not. Deaths at sea due to severe storms were also not counted. Data were checked for duplication and other inconsistencies.

Reported deaths and injuries from the two datasets were summed to estimate the national and state rates for the period (Table 8 & 9), based on relevant state and national population figures for the period 1970-2001. The annual state and national baseline incidence of death and injury was estimated by dividing the average annual records of these outcomes over the 32 years by the mid-period state population – 1985 (Table 8 & 9).

The estimation of rates is necessarily approximate, as not all events record the precise region where the event occurred. Deaths or injuries from events that crossed more than one state boundary were apportioned based on locational information in the records, or divided evenly between the relevant States when no information was available. The future estimates of deaths and injuries assume that GDP will remain the same as for the baseline period, and no adaptation to changing conditions is accounted for.

Table 8 Estimated fatalities related to flooding in Australia, for the period 1970 to 2001

State	Total Deaths	% of total	Average annual deaths (period)	Average annual fatality rate, per 1 000 000 (period)
NSW	97	49	3.1	0.57
QLD	61	31	2.0	0.77
NT	14	7	0.5	3.04
SA	8	4	0.3	0.19
ACT	7	4	0.2	0.90
WA	6	3	0.2	0.14
VIC	6	3	0.2	0.05
TAS	1	1	0.0	0.07
National	200	100%	6.5	0.41

Table 9 Estimated injuries related to flooding in Australia, for the period 1970 to 2001

State	Total Injuries	% of total	Average annual injuries (period)	Average annual injury rate per 1 000 000 (period)
QLD	527	54	17.0	6.61
NSW	336	34	10.8	1.98
VIC	46	5	1.5	0.36
NT	40	4	1.3	8.69
TAS	15	2	0.5	1.09
SA	10	1	0.3	0.24
ACT	0	0	0.0	0.00
WA	0	0	0.0	0.00
National	974	100	31.4	1.99

7.2.3 Findings

The relative risk of an extreme rainfall event (relative to baseline climate) are presented in map form for each of the climate scenarios and time points (Figures 6–11). These values are the raw grid cell estimates, not weighted by population distribution. The relative risks are categorised into: 0-1 (i.e., less than baseline), 1-2, 2-3, 3-4, 4-5, and 5-18.

The flood risk results are also provided in tabular format, with the grid cell values summarised into Statistical Division (SD) regions. These figures are weighted by the future projected population in each SLA, and then averaged across the SDs (Tables 10 & 11). Figure 12 is a map of the Australian Statistical Divisions.

Tables 12 & 13 present the relative risk of death and injury due to flooding for Australian States in 2020 and 2050. Table 14 gives the predicted national annual incidence of deaths and injuries due to flooding per 100,000 people, for the baseline period, 2020, and 2050, and for the alternative climate scenarios. Table 15 presents the predicted annual incidence of deaths and injuries due to flooding for individual States.

Results can be summarised as follows:

1970-2001 baseline period (Tables 8 & 9)

On average, nearly half the deaths occurred in New South Wales during the baseline period, and one third in Queensland. After accounting for population size differences, the highest incidences were in the Northern Territory (3.04/1,000,000) and the ACT (0.9/1,000,000). Six of the seven deaths in the ACT were recorded in 1974 however; given infrastructure changes in that city since then, this figure is unlikely to remain as high in future. The overall national rate was 0.41/1,000,000.

More than half of all injuries occurred in Queensland (527), and one third in New South Wales (336). The annual incidence of flood-related injuries was highest in the Northern Territory (8.69/1,000,000) and Queensland (6.61/1,000,000).

2020 scenarios (Figures 6-8 and Tables 10, 12 & 14)

The risk of flood deaths and injuries was predicted to increase for nearly all States by 2020. For New South Wales, Victoria, Northern Territory, Queensland, and Tasmania increases of between 40% and 138% were estimated relative to baseline risk. Western Australia and South Australia had minor predicted increases or decreases in risk under all scenarios except for the "high" one (ECHAM4), where increases of 25% and 37% respectively were predicted.

There was significant variation in flood risk within many States, reflecting the influence of topography, altitude, and coastal proximity on rainfall changes. In Queensland, all Statistical Divisions were predicted to have an increased risk of flooding by 2020, although the regions in the north and west showed the greatest increases (200 to 385%). The south of New South Wales that borders the Murray River had a predicted increase in risk of +120 to +240%. In Tasmania, Hobart had a predicted 116-224% increased risk, whereas Launceston and other areas in the northeast (where drying has been projected to occur) had a reduced risk (-12 to -38%). The risk of flood events in parts of south-western Victoria, where drying has also been predicted, may be reduced by -35%.

For the country as a whole, flood risk was predicted to increase by between +39% and +97%. This translated to a predicted annual increase in the incidence of deaths to 5.7 – 8.1 per 10 million people by 2020 (up from the 1970 to 2001 annual average of 4.1). The annual incidence of injuries was predicted to increase to between 27.7 and 39.1 per 10 million people (from the 1970 to 2001 annual average of 19.9), depending on the future climate scenario.

2050 scenarios (Figures 9-11 and Tables 11, 13 & 14)

With minor exceptions, the flood risk estimates were lower for all States under all scenarios by 2050 compared to 2020. Nonetheless, flood risk was still predicted to be higher than during the baseline period for all States except Western Australia and South Australia. These latter States were predicted to have up to 46% less flood risk. The Murray River regions of southern NSW, the north and west of Queensland, and the south of Tasmania were predicted to have risk estimates of between +100 and +200%. At the state level, increase in flood risk estimates was high for New South Wales (+53 to +75%), Northern Territory (+48 to +58%), and Queensland (+31 to +82%). Flood risk estimates were generally highest for the "low" emission scenarios and lowest for the "high" scenarios.

The national relative risk of deaths and injuries was predicted to be lower than in 2020, but still higher than the baseline period by +29 to +48%. The annual incidence of deaths was predicted to increase from 4.1 per 10 million people (the baseline annual average) to 5.3 – 6.1 per 10 million people, and the incidence of injuries to increase from 19.9 per 10 million people to 25.6 – 29.5 per 10 million people.

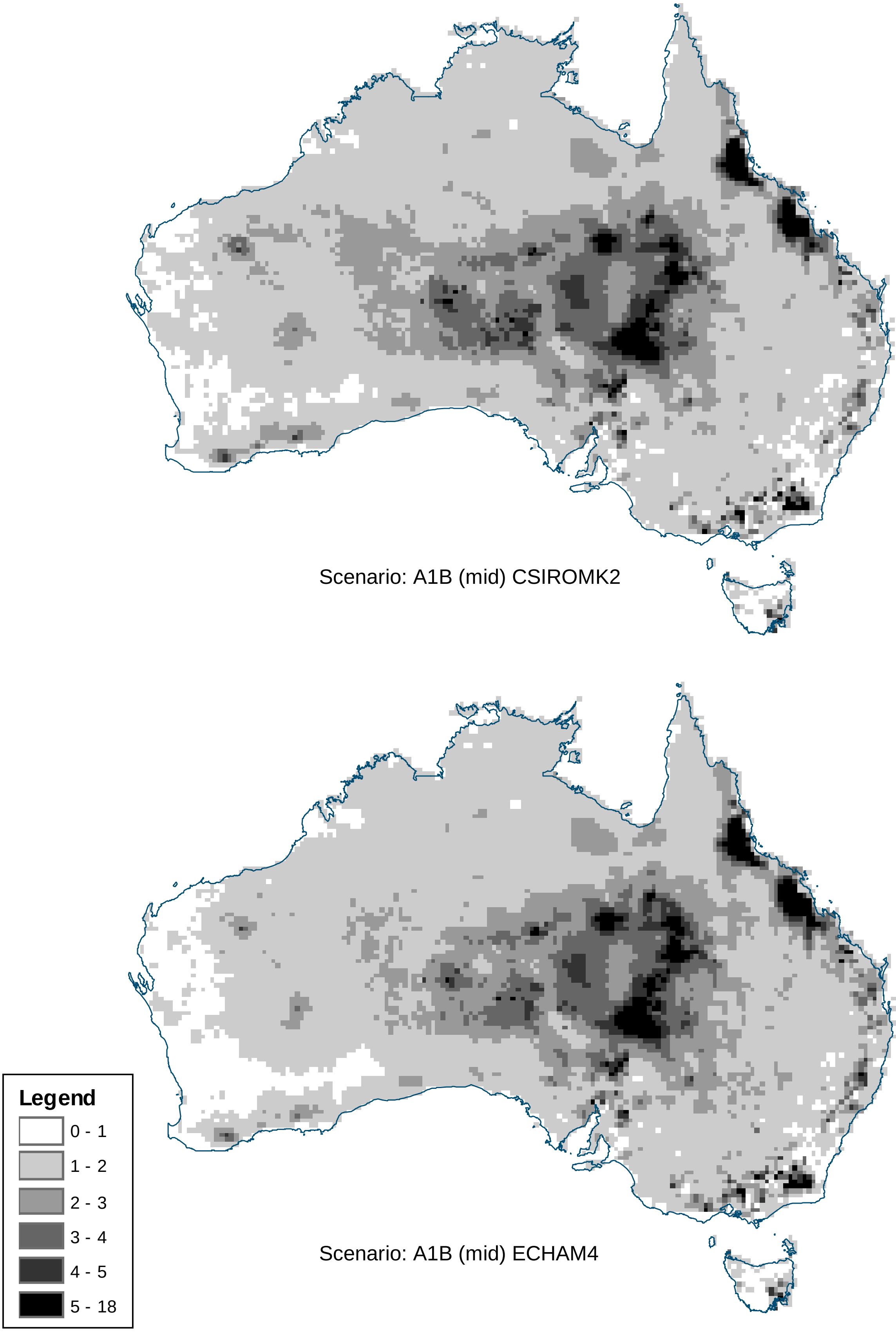


Figure 6 Estimates of the flood risk in **2020**, relative to baseline, for the mid emission scenarios

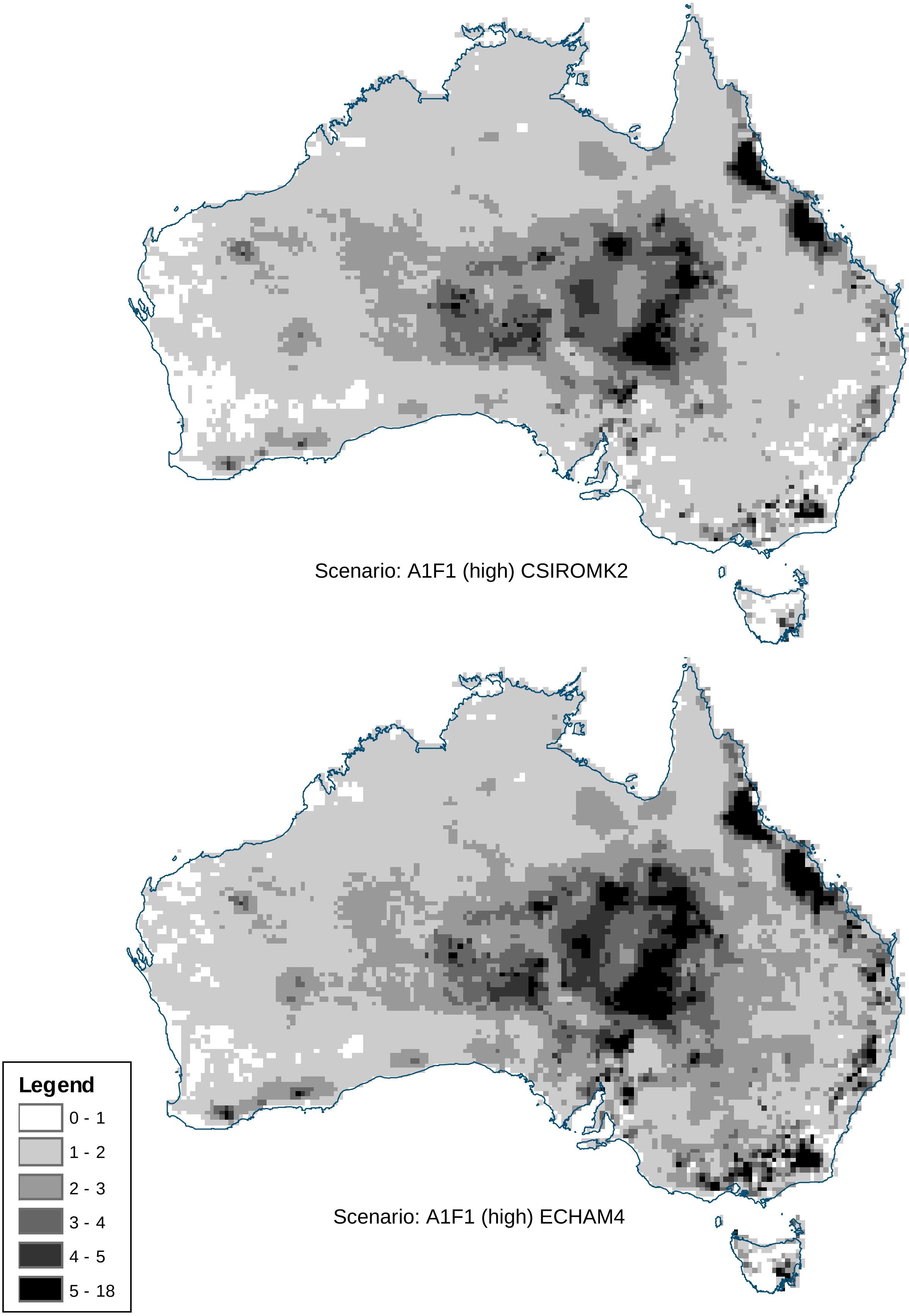


Figure 7 Estimates of flood risk in **2020**, relative to baseline, for the high emission scenarios

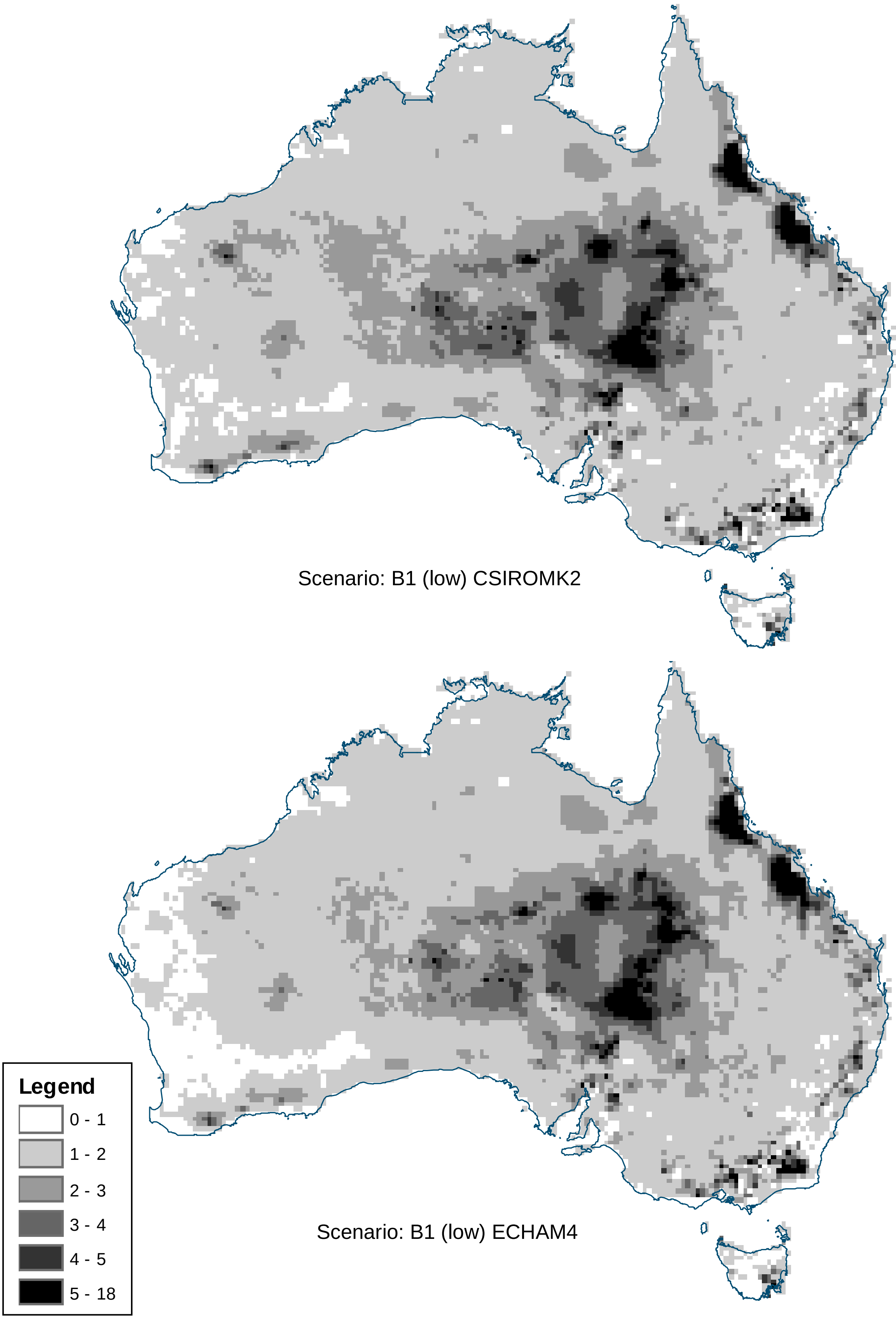


Figure 8 Estimates of flood risk in **2020**, relative to baseline, for the low emission scenarios

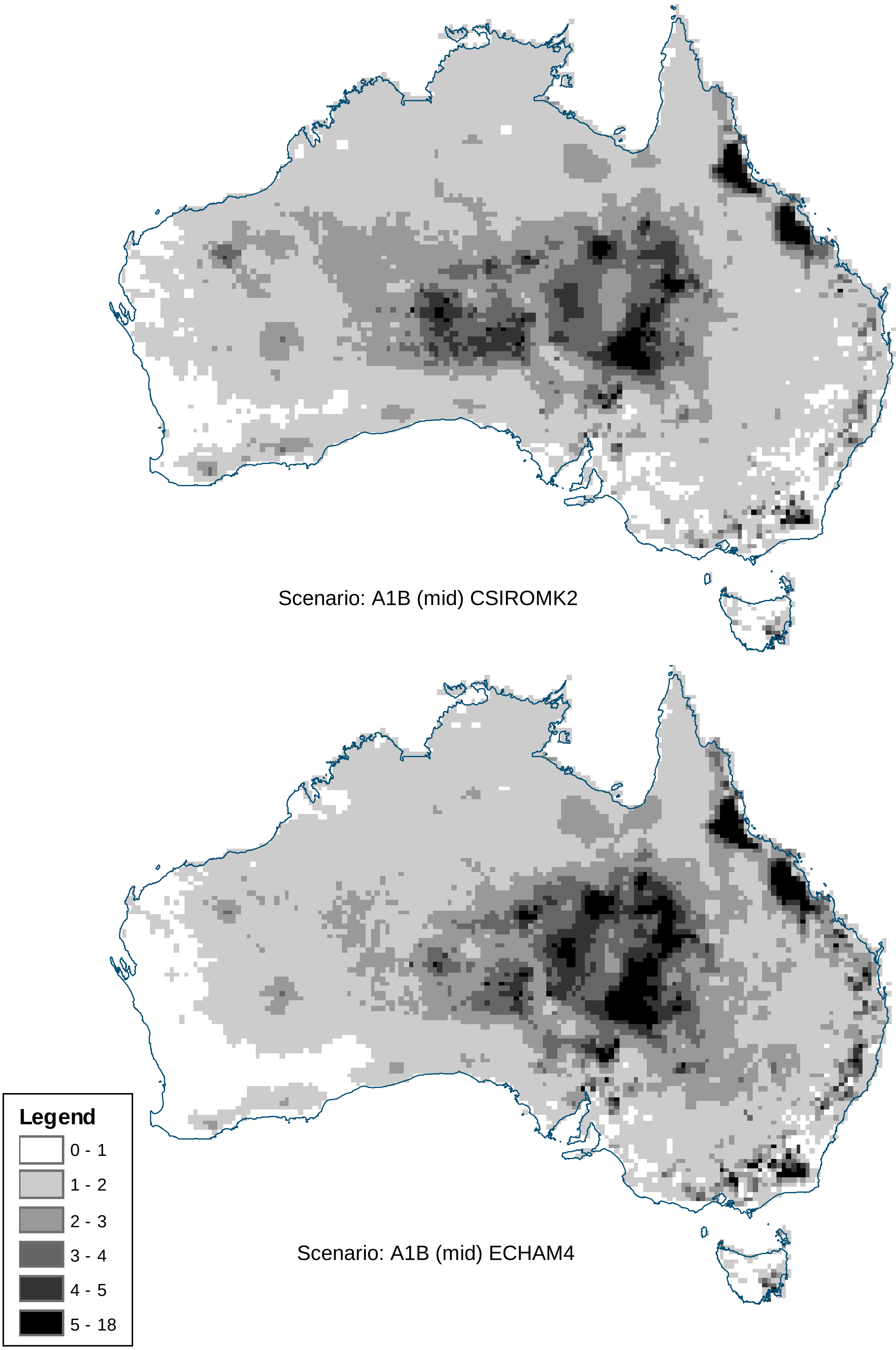


Figure 9 Estimates of flood risk in **2050**, relative to baseline, for the mid emission scenarios

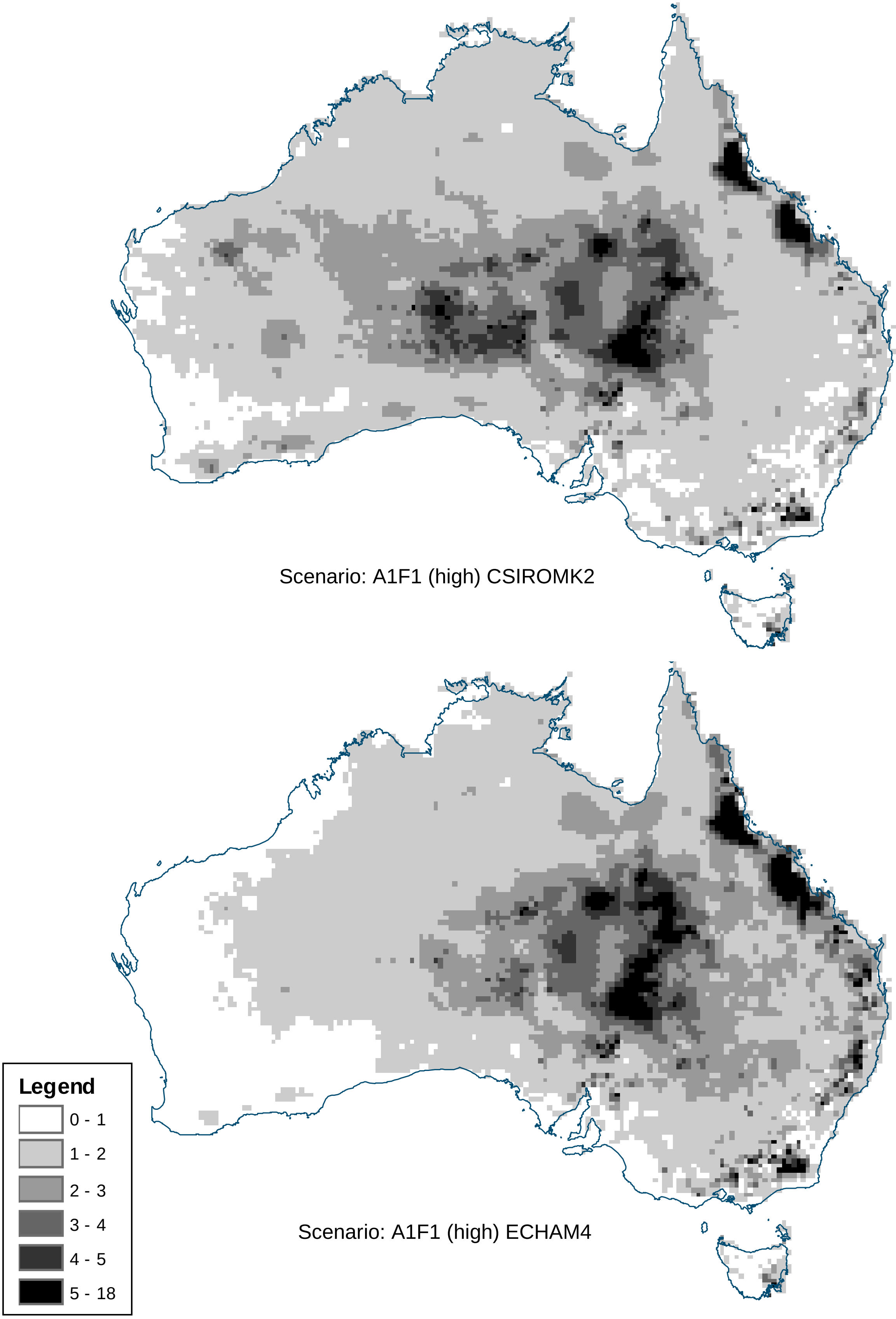


Figure 10 Estimates of flood risk in **2050**, relative to baseline, for the high emission scenarios

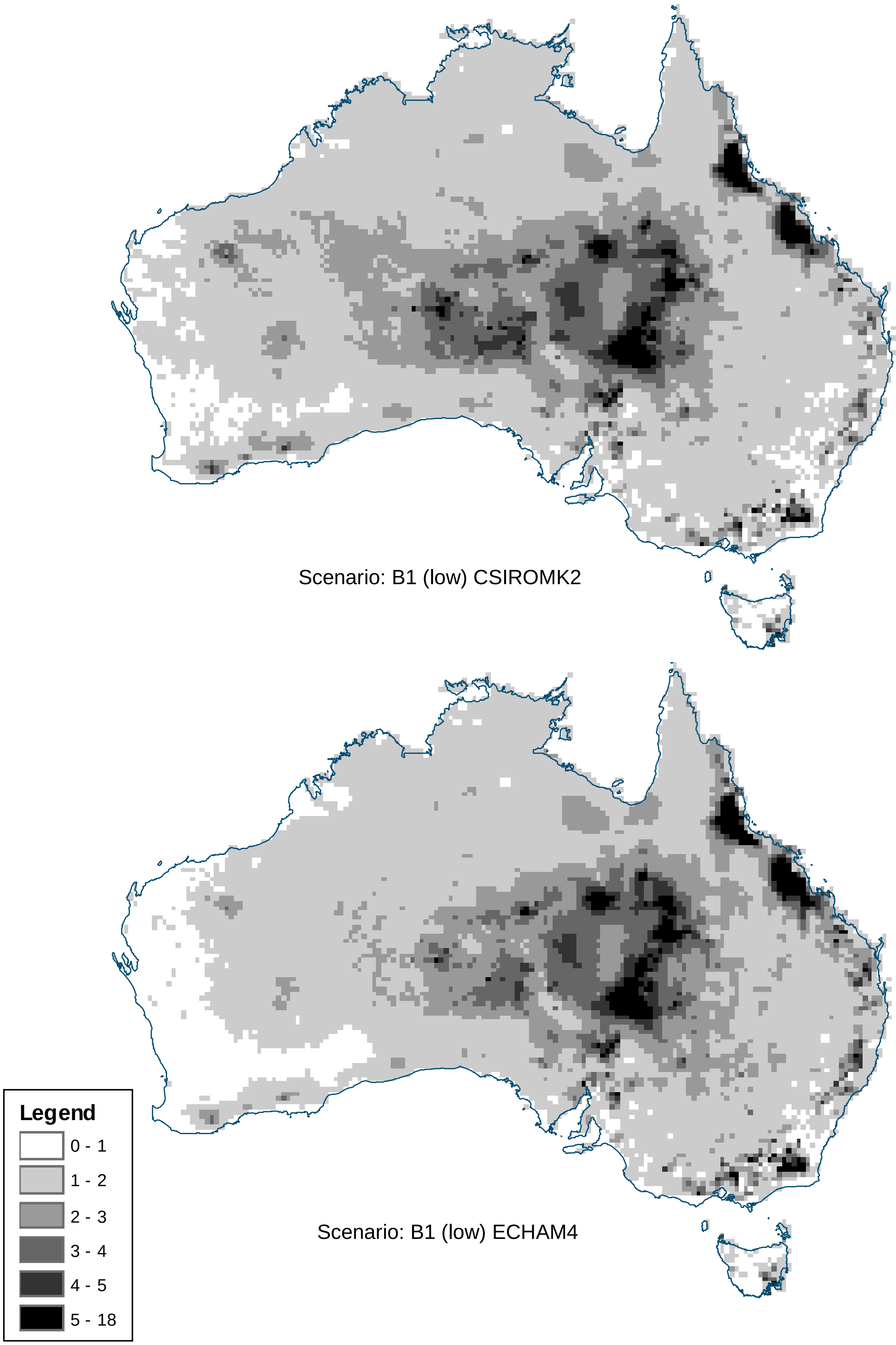


Figure 11 Estimates of flood risk in **2050**, relative to baseline, for the low emission scenarios

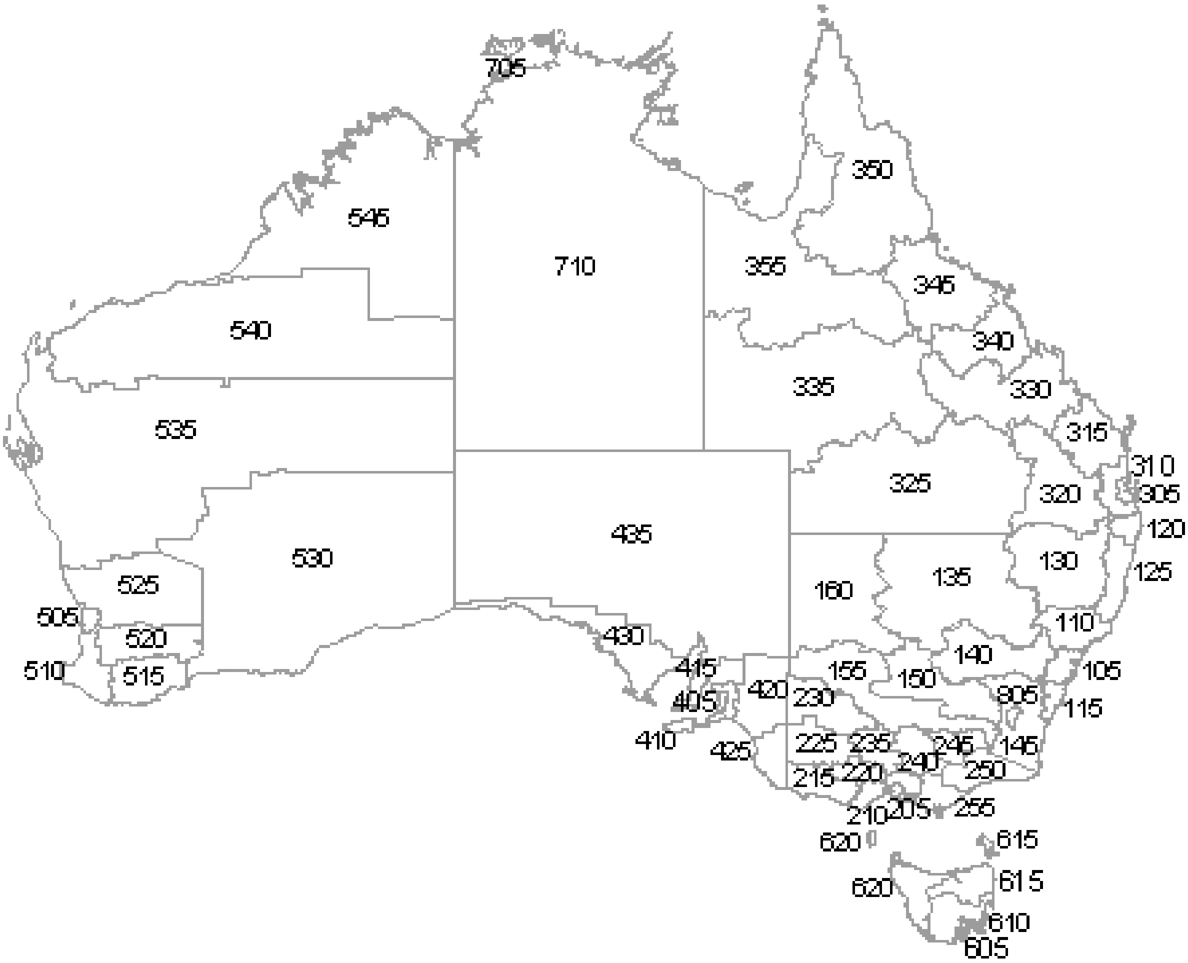


Figure 12 Australian Statistical Divisions. Numbers refer to the Australian Standard Geographical Classification number for each Statistical Division

Table 10 Flood risk in **2020** for Statistical Division (SD) regions**,** relative to baseline climate (results weighted by the projected population in each SD)

State	SD	Mid		High		Low	
		CSIROMk2	ECHAM4	CSIROMk2	ECHAM4	CSIROMk2	ECHAM4
NSW	105	1.67	1.70	1.66	2.16	1.70	1.69
	110	2.07	2.13	2.07	2.96	2.03	2.12
	115	0.95	0.97	0.95	1.22	0.97	0.97
	120	1.25	1.35	1.24	1.82	1.29	1.33
	125	1.29	1.37	1.28	1.77	1.30	1.35
	130	1.61	1.77	1.60	2.29	1.59	1.74
	135	1.26	1.38	1.25	1.80	1.28	1.36
	140	1.31	1.41	1.30	1.90	1.35	1.39
	145	1.32	1.42	1.30	1.97	1.33	1.41
	150	1.57	1.71	1.54	2.42	1.67	1.70
	155	2.64	2.89	2.56	4.31	2.90	2.89
	160	1.81	1.91	1.78	2.37	1.80	1.91
Vic.	205	1.29	1.36	1.25	2.12	1.32	1.38
	210	2.17	2.22	2.10	3.47	2.24	2.26
	215	0.88	0.88	0.86	1.30	0.97	0.91
	220	2.05	2.14	1.97	3.22	2.17	2.18
	225	0.68	0.72	0.65	1.04	0.73	0.73
	230	1.43	1.52	1.39	2.08	1.48	1.54
	235	1.73	1.85	1.67	2.74	1.84	1.87
	240	2.13	2.31	2.05	3.52	2.28	2.33
	245	2.77	3.06	2.68	4.65	3.08	3.07
	250	1.54	1.63	1.50	2.41	1.57	1.63
	255	1.81	1.89	1.76	3.11	1.88	1.91
Qld	305	1.22	1.33	1.20	1.62	1.21	1.31
	310	1.32	1.44	1.31	1.84	1.34	1.42
	315	1.82	2.03	1.79	2.55	1.81	2.00
	320	1.59	1.80	1.57	2.26	1.55	1.76
	325	1.64	1.77	1.62	2.13	1.63	1.75
	330	2.07	2.30	2.03	2.76	2.08	2.28
	335	2.49	2.64	2.47	3.03	2.49	2.62
	340	2.33	2.54	2.31	2.96	2.34	2.51
	345	2.45	2.65	2.43	2.99	2.46	2.61
	350	3.06	3.21	3.06	3.85	3.06	3.17
	355	2.00	2.07	2.00	2.23	1.98	2.05
SA	405	0.81	0.81	0.79	1.14	0.88	0.83
	410	1.07	1.07	1.02	1.52	1.05	1.09
	415	1.33	1.34	1.29	1.95	1.44	1.38
	420	1.49	1.54	1.44	2.15	1.56	1.57
	425	1.11	1.09	1.07	1.52	1.26	1.12
	430	1.07	1.07	1.04	1.45	1.19	1.09
	435	2.13	2.17	2.08	2.99	2.20	2.21
WA	505	1.09	0.97	1.07	1.27	1.26	1.02
	510	0.99	0.89	0.97	1.17	1.13	0.93
	515	1.30	1.16	1.26	1.57	1.45	1.22
	520	1.08	0.96	1.06	1.23	1.21	1.01
	525	0.86	0.76	0.85	0.96	0.98	0.80
	530	1.50	1.33	1.50	1.68	1.57	1.37
	535	0.71	0.64	0.71	0.77	0.78	0.66
	540	1.31	1.17	1.32	1.25	1.33	1.19
	545	1.32	1.23	1.33	1.27	1.31	1.24
Tas.	605	2.18	2.20	2.16	3.24	2.19	2.22
	610	1.39	1.40	1.37	2.05	1.43	1.41
	615	0.63	0.63	0.62	0.88	0.69	0.64
	620	1.05	1.03	1.04	1.53	1.16	1.04
NT	705	1.30	1.27	1.31	1.29	1.29	1.27
	710	1.88	1.86	1.89	1.99	1.87	1.86
ACT	805	0.77	0.82	0.76	1.07	0.75	0.82

Table 11 Flood risk in **2050** for Statistical Division (SD) regions**,** relative to baseline climate (results weighted by the projected population in each SD)

State	SD	Mid		High		Low	
		CSIROMk2	ECHAM4	CSIROMk2	ECHAM4	CSIROMk2	ECHAM4
NSW	105	1.65	1.80	1.65	1.78	1.66	1.71
	110	2.05	2.23	2.05	2.34	2.07	2.17
	115	0.93	1.01	0.93	0.99	0.95	0.97
	120	1.18	1.51	1.18	1.60	1.23	1.40
	125	1.25	1.52	1.25	1.61	1.28	1.41
	130	1.53	2.07	1.53	2.26	1.58	1.86
	135	1.19	1.67	1.19	1.71	1.24	1.44
	140	1.24	1.69	1.24	1.67	1.29	1.45
	145	1.19	1.52	1.19	1.52	1.28	1.44
	150	1.38	1.93	1.38	1.80	1.51	1.72
	155	2.15	3.21	2.15	2.82	2.48	2.87
	160	1.63	2.01	1.63	1.94	1.75	1.92
Vic.	205	1.04	1.25	1.04	1.14	1.21	1.31
	210	1.76	1.97	1.76	1.70	2.03	2.11
	215	0.71	0.76	0.71	0.61	0.83	0.82
	220	1.60	1.95	1.60	1.66	1.90	2.04
	225	0.51	0.64	0.51	0.53	0.62	0.68
	230	1.17	1.50	1.17	1.37	1.34	1.49
	235	1.35	1.78	1.35	1.56	1.60	1.79
	240	1.67	2.34	1.67	2.07	1.98	2.27
	245	2.20	3.39	2.20	2.94	2.59	3.03
	250	1.33	1.63	1.33	1.56	1.47	1.62
	255	1.50	1.78	1.50	1.59	1.71	1.83
Qld	305	1.14	1.41	1.14	1.58	1.19	1.37
	310	1.23	1.56	1.23	1.71	1.30	1.49
	315	1.62	2.10	1.62	2.44	1.75	2.10
	320	1.45	1.99	1.45	2.36	1.55	1.89
	325	1.52	1.94	1.52	2.05	1.60	1.82
	330	1.81	2.31	1.81	2.69	1.98	2.37
	335	2.33	2.82	2.33	2.88	2.44	2.68
	340	2.19	2.57	2.19	3.04	2.29	2.63
	345	2.33	2.73	2.33	3.20	2.41	2.75
	350	3.04	3.27	3.04	3.70	3.06	3.30
	355	1.98	2.23	1.98	2.24	2.00	2.10
SA	405	0.65	0.70	0.65	0.56	0.76	0.76
	410	1.02	1.52	0.84	0.72	0.98	0.98
	415	1.05	1.19	1.05	0.93	1.24	1.26
	420	1.17	1.36	1.17	1.15	1.38	1.46
	425	0.89	0.92	0.89	0.71	1.04	1.00
	430	0.89	1.01	0.89	0.79	1.01	1.01
	435	1.79	2.12	1.79	1.72	2.02	2.08
WA	505	0.96	0.74	0.96	0.51	1.05	0.87
	510	0.85	0.67	0.85	0.47	0.95	0.79
	515	1.06	0.80	1.06	0.55	1.22	1.01
	520	0.94	0.73	0.94	0.49	1.04	0.85
	525	0.78	0.63	0.78	0.43	0.84	0.69
	530	1.49	1.19	1.49	0.86	1.50	1.22
	535	0.70	0.60	0.70	0.44	0.70	0.60
	540	1.37	1.21	1.37	0.85	1.33	1.10
	545	1.38	1.23	1.38	1.04	1.34	1.19
Tas.	605	2.00	2.08	2.00	1.97	2.13	2.16
	610	1.28	1.36	1.28	1.25	1.35	1.37
	615	0.59	0.65	0.59	0.58	0.62	0.62
	620	0.98	1.02	0.98	0.85	1.03	0.99
NT	705	1.35	1.29	1.35	1.23	1.32	1.26
	710	1.92	1.95	1.92	1.84	1.90	1.86
ACT	805	0.70	0.87	0.70	0.91	0.75	0.84

Table 12 Risk of death and injury due to flooding in **2020** for Australian States, relative to baseline (RR = 1.0 for no change in risk; >1 = increase in RR; <1 = decrease in RR)

State	**Mid**		**High**		**Low**	
	CSIROMk2	ECHAM4	CSIROMk2	ECHAM4	CSIROMk2	ECHAM4
NSW	1.57	1.63	1.57	2.12	1.60	1.62
VIC	1.46	1.53	1.41	2.38	1.51	1.55
Qld	1.40	1.53	1.39	1.84	1.40	1.51
SA	0.97	0.98	0.94	1.37	1.04	1.00
WA	1.09	0.97	1.07	1.25	1.24	1.02
Tas.	1.42	1.43	1.41	2.09	1.47	1.44
NT	1.54	1.51	1.55	1.58	1.52	1.51
National	1.41	1.47	1.39	1.97	1.45	1.47

Table 13 Risk of death and injury due to flooding in **2050** for Australian States, relative to baseline (RR = 1.0 for no change in risk; >1 = increase in RR; <1 = decrease in RR)

State	**Mid**		**High**		**Low**	
	CSIROMk2	ECHAM4	CSIROMk2	ECHAM4	CSIROMk2	ECHAM4
NSW	1.53	1.75	1.53	1.75	1.56	1.65
VIC	1.17	1.44	1.17	1.29	1.36	1.49
Qld	1.31	1.60	1.31	1.82	1.37	1.58
SA	0.80	0.90	0.78	0.69	0.91	0.91
WA	0.97	0.76	0.97	0.54	1.05	0.87
Tas.	1.31	1.38	1.31	1.26	1.39	1.40
NT	1.58	1.56	1.58	1.48	1.55	1.50
National	1.29	1.48	1.29	1.48	1.37	1.47

Table 14 Predicted national annual incidence of deaths and injuries due to flooding, per 1,000,000 people, for the baseline period, 2020, and 2050, using alternative emission scenarios

Baseline (1970-2001)		**Climate Scenario**		**2020**		**2050**	
Death	**Injury**			**Death**	**Injury**	**Death**	**Injury**
0.41	1.99	Mid	*CSIROMk2*	0.58	2.81	0.53	2.56
			ECHAM4	0.60	2.93	0.61	2.95
		High	*CSIROMk2*	0.57	2.77	0.53	2.56
			ECHAM4	0.81	3.91	0.61	2.94
		Low	*CSIROMk2*	0.59	2.88	0.56	2.73
			ECHAM4	0.60	2.93	0.60	2.92

Table 15 Predicted annual incidence of deaths and injuries, per 1,000,000 people, caused by flooding, for the baseline period, 2020, and 2050, using alternative emission scenarios

Baseline (1970-2001)		State	Scenario		2020		2050	
Death	Injury				Death	Injury	Death	Injury
0.57	1.98	NSW *	Mid	*CSIROMk2*	0.90	3.12	0.87	3.03
				ECHAM4	0.93	3.23	1.00	3.46
			High	*CSIROMk2*	0.89	3.10	0.87	3.03
				ECHAM4	1.21	4.20	1.00	3.46
			Low	*CSIROMk2*	0.91	3.17	0.89	3.09
				ECHAM4	0.92	3.21	0.94	3.27
0.05	0.36	VIC	Mid	*CSIROMk2*	0.07	0.52	0.06	0.42
				ECHAM4	0.08	0.55	0.07	0.52
			High	*CSIROMk2*	0.07	0.51	0.06	0.42
				ECHAM4	0.12	0.86	0.06	0.46
			Low	*CSIROMk2*	0.08	0.54	0.07	0.49
				ECHAM4	0.08	0.56	0.07	0.53
0.77	6.61	Qld	Mid	*CSIROMk2*	1.08	9.28	1.01	8.68
				ECHAM4	1.18	10.10	1.23	10.57
			High	*CSIROMk2*	1.07	9.18	1.01	8.68
				ECHAM4	1.42	12.19	1.40	12.05
			Low	*CSIROMk2*	1.08	9.25	1.06	9.09
				ECHAM4	1.16	9.97	1.22	10.44
0.19	0.24	SA	Mid	*CSIROMk2*	0.18	0.23	0.15	0.19
				ECHAM4	0.19	0.23	0.17	0.22
			High	*CSIROMk2*	0.18	0.23	0.15	0.19
				ECHAM4	0.26	0.33	0.13	0.17
			Low	*CSIROMk2*	0.20	0.25	0.17	0.22
				ECHAM4	0.19	0.24	0.17	0.22
0.14	0.00	WA	Mid	*CSIROMk2*	0.15	0.00	0.14	0.00
				ECHAM4	0.14	0.00	0.11	0.00
			High	*CSIROMk2*	0.15	0.00	0.14	0.00
				ECHAM4	0.18	0.00	0.08	0.00
			Low	*CSIROMk2*	0.17	0.00	0.15	0.00
				ECHAM4	0.14	0.00	0.12	0.00
3.04	8.69	NT	Mid	*CSIROMk2*	4.68	13.37	4.82	13.77
				ECHAM4	4.59	13.11	4.74	13.55
			High	*CSIROMk2*	4.70	13.43	4.82	13.77
				ECHAM4	4.79	13.69	4.50	12.87
			Low	*CSIROMk2*	4.63	13.24	4.72	13.49
				ECHAM4	4.59	13.13	4.57	13.06
0.07	1.09	Tas.	Mid	*CSIROMk2*	0.10	1.55	0.09	1.43
				ECHAM4	0.10	1.56	0.10	1.50
			High	*CSIROMk2*	0.10	1.53	0.09	1.43
				ECHAM4	0.15	2.28	0.09	1.38
			Low	*CSIROMk2*	0.10	1.61	0.10	1.51
				ECHAM4	0.10	1.57	0.10	1.52

* NSW results include ACT estimates.

7.2.4 Discussion

This analysis suggests that if global climate change affects rainfall patterns as predicted, extreme rainfall events may increase in all States by 2020. Annual flood-related deaths and injuries are predicted to increase by up to 240%, depending on the state and the climate scenario. The estimated state baseline rates are fairly crude, given that flood death reporting is often not geographically detailed and may be incomplete. Nonetheless, the results are likely to represent an order of magnitude estimate.

Not all the country was predicted to be evenly exposed. If global climate change increases to the levels suggested by the "high" emission scenarios, some parts of Australia are projected to have lower rainfall in future. In general, southwest Western Australia and and the populated areas of South Australia are predicted to have much lower relative risks than the other States. However, many other regions, such as the Murray River area of southern New South Wales, the north and west of Queensland, and the south of Tasmania, are expected to have a substantial increase in flood risk by 2020 that is not predicted to be greatly reduced by 2050.

Floods have important effects on health through social and economic impacts, although these secondary effects are not yet well quantified. Effects on human health may include repercussions arising from vulnerabilities in the agricultural sector (such as changing crop suitability and enhanced spread of some agricultural pests), on water resources (such as impacts on water availability and quality, agricultural irrigation and power generation), and impacts on the coastal zone (such as loss of land, and damage to infrastructure resulting from coastal erosion and flooding). The direct costs of agricultural, housing, and infrastructure losses represent costs to individuals, communities, state governments, and the insurance industry.

Table 16 summarises the estimated costs relating to flood damage in Australia and States for the period 1970 to 2001. Annual costs for the country were $454 million. At the state level, New South Wales incurred almost half the costs during this period (an average of $208 million per year), and Queensland around one third ($157 million per year).

Of the records available since 1790, the greatest proportion of flood-related deaths in Australia has been reported in people aged under 25 and over 59, reflecting increased risk with immobility, and a greater propensity for risk-taking in young adults *(Coates 1999)*. Historically, males have been at much higher risk than females (the overall male to female death ratio since 1790 has been calculated as 4 to 1), although this is reportedly decreasing *(Coates 1999).*

Table 16 Estimated costs related to flooding in Australia, for the period 1970 to 2001

State	Total costs ($m) *	Total (%)	Costs per year ($m)
NSW	6 447	46	208
QLD	4 865	35	157
VIC	1 267	9	41
SA	558	4	18
NT	529	4	17
TAS	225	2	7
WA	189	1	6
ACT	0.25	0	0.008
National	14 080	100	454

* Derived from the EM-DAT and EMA databases.

For this analysis, there were insufficient data to derive regional estimates of the relative vulnerability of different age groups and sexes to the impacts of flooding for this study. All age groups and both sexes were assumed to be equally at risk. However, it is more likely that certain sub-groups would have higher or lower relative risks than the overall population risk that was calculated for the States.

The vulnerability to drowning is clearly strongly dependent on infrastructure, lifestyle, attitudes towards perceived risks, and future settlement trends (e.g. building in flood-prone areas). This vulnerability is likely to change significantly over the time scales considered in this report, and future research into possible adaptation measures is suggested.

7.3 The impact of sea-level rise

7.3.1 Reason for consideration

Sea levels are predicted to rise worldwide by 0.09 to 0.88m (central value 0.48m) in the period 1990 to 2100, based on the SRES scenarios *(IPCC 2001a)*. The severity of the threat will vary regionally. Extreme high water levels will occur with increasing frequency because of mean sea-level rise. Their frequency may be further increased if storms become more frequent or severe as a result of climate change *(IPCC 2001a)*. The implications for coastal floodplains are still to be agreed upon *(White et al. 1999)*, but four main impacts seem likely: (i) inundate and displace wetlands and lowlands, (ii), erode shorelines, (iii) exacerbate storm flooding and damage, and (iv) increase the salinity of estuaries, and threaten freshwater aquifers *(IPCC 2001c)*.

The small islands of the Pacific are expected to be disproportionately affected, with greatest effects on the economic and social development of many of these countries *(Granger 1997)*. Many of the densely populated atoll islands, such as Tarawa in Kiribati and Funafuti in Tuvalu, have a maximum elevation of no more than three or four metres above mean sea level. Increased sea levels, especially if associated with an increased intensity of storms and tropical cyclones, would result in accelerated coastal erosion, inundation, and loss of land in low-lying islands and coastal areas.

In Australia, estimated fatalities due to storm surges and coastal flooding to date have been low; historically the highest risk region has been the coastal strip from Wollongong to Maryborough *(Coates 1999)*. There is continuing human settlement expansion into coastal catchments around the continent, and rapid coastal growth is predicted for the next four decades *(National Population Council 1992)*. About 25-30% of the coast is subject to increasing development, mostly in the south-east of the country *(State of the Environment Advisory Council 1996)*. Mitigation responses by local governments to coastal flooding have had some success in controlling excess water and promoting productivity and development, but have also produced some severe water quality and ecological problems *(White et al. 1999)*.

7.3.2 Method of analysis

A series of assessments have been conducted *(Hoozemans and Hulsbergen 1995, Nicholls et al. 1999a)* that suggest the impacts of sea-level rise worldwide could be significant in this century, unless there is appropriate adaptive response. The estimates for this current assessment were prepared by Robert J Nicholls, based on the methods reported in *(Nicholls et al. 1999a)*, and further discussed in *(Nicholls 2002)*.

These estimates represent a sub-set of results from a global analysis, which considered the flood impacts of sea-level rise based on a series of scenarios that included (i) global mean sea-level rise, (ii) coastal population change (usually an increase), (iii) subsidence (where appropriate), and (iv) flood defence standards (derived from GDP/capita). The Nicholls method assessed the existing risk of flooding due to storm surges, and how it could increase with sea-level rise. It did not account for any change in frequency of storm surges.

Although global sea-level rise will certainly occur with global climate change *(IPCC 2001c)*, the estimates of the extent of rise vary. The exposure data used in this analysis (i.e., predicted sea-level rise) were taken from predictions made in 1995 *(IPCC 1995):* 19cm for the low scenario, 45cm for the mid, and 80cm for the high. Since Nicholls conducted that analysis, new sea-level rise estimates have been developed *(IPCC 2001c)*. The new projections for mid and high sea-level rises are now higher than those used by Nicholls (increasing from 45 to 48cm, and from 80 to 88cm respectively). The new estimate of the lowest likely increase has reduced, however (from 19 to 9cm). This means that the mid and high predictions in the findings reported here may be slightly underestimated, while those for the low predictions may be slightly overestimated.

The model output was the average annual number of people who experience flooding by storm surge, after including the influence of sea defences and adjusting for population and socio-economic growth. Projections for changes in national populations were taken from World Bank estimates *(Bos et al. 1994)*. In applying the national population increase, it was assumed that coastal populations would increase at twice the rate of the national population *(Nicholls et al. 1999a)*.

Thumerer and others *(Thumerer et al. 2000)* modelled the impacts of sea-level rise along the English east coast, and found flood risk to be a function of the height and condition of sea defences, land elevations, and subsidence rates (isostatic adjustment). The factors used to estimate flood risk in this current analysis were:

1 Maximum area of flood plain after sea-level rise
2 Flood exceedance curve for storm surges
3 Average coastal population density in the base year
4 Occurrence or absence of subsidence

The global model was "validated" against 12 national-scale results *(Nicholls 2002)* – although Australia was not one of these. Validation indicated that the global model results were broadly in line with the pattern and order-of-magnitude of those from the regional- and national-scale models.

Assumptions

Given the high interannual and interdecadal variability of storm occurrence *(Zhang et al. 2000)*, only sea-level rise was modelled, and no other climate changes were considered. Sea-level rise was assumed to be even across the globe, although some regional variation is likely. The modelling of flood impact assumed that the coastal flood plain has a constant slope, and that the population will be distributed uniformly across the coastal zone *(Nicholls et al. 1999b)*. In addition, it was assumed that all areas of a flood unit below the 5m contour would be inundated in a flood event. This is clearly a simplification, as local factors such as topography *(Thumerer et al. 2000)* and human migration out of the flood zone *(Nicholls et al. 1999b)* would also play a role in determining the extent and damage of flooding.

In the absence of available data on flood protection, the standard was estimated to be indirectly associated with a country's GDP, or its "ability to pay" *(Nicholls 2002)*. Thus, wealthy nations (such as Australia and New Zealand) were assumed to enjoy better protection, and low-lying countries were assumed more expensive to protect (per kilometre of shoreline). This estimate assumes that flood defences in Australia and New Zealand will continue to be improved.

The model does not assume anything concerning migration or displacement of people from a region. If this were to occur in large numbers, presumably there would be fewer people exposed to flooding. Estimates are based on the projected population at each time point.

Limitations

Future climate change is predicted to have two major impacts within the coastal zone: (i) an increase in mean sea-level rise (mainly due to the melting of the mountain glaciers and polar ice-caps, and to thermal expansion of the oceans *(IPCC 2001c)*), and (ii) a possible change in the frequency and intensity of storm surges *(Roberts and Kay 1990)*. This analysis only addressed the potential impact of sea-level rise and inundation of low-lying lands. Storm surges are assumed to occur at the current frequency. This is likely to underestimate the future impacts on the coastal zone. Changes in storm surge heights result from alterations in tropical storms and cyclones. There is no consensus yet about whether storm surges will increase in frequency, however the intensity is projected to increase by 0-20% by 2050 *(Jones et al. 1999)*. This prospect is of great concern, given the likely resultant increase in negative impacts.

7.3.3 Findings

Table 17 gives estimates for populations exposed to coastal flooding at the baseline year (1990), and for three points in the future – 2020, 2055, and 2085 - for Australia, New Zealand and a summary total for the Pacific Islands. Table 18 gives estimates for individual Pacific states.

The model estimates that 250 people experience flooding because of storm surges each year in Australia, 95 in New Zealand, and 5141 in the Pacific. Even if sea-level rise were not to increase (now generally considered to be impossible), there would still be a change in the average annual number of people exposed to flooding in the future due to the projected slowing in population growth in the middle of the century, and the progressive upgrade in flood defences due to the assumed increase in living standards. The baseline scenario (no sea-level rise) projects an increase for Australia to 467 people affected in 2020, and 503 in 2055 and 2085. These increases relate to the assumed population increase on the coast. The baseline scenario for the Pacific predicts a decrease in people affected beyond 2020 (from 6075 down to 1209 by 2085) due to an assumed increase in GDP and an improved adaptive capacity for the region as a whole.

The range of scenarios for 2020 and 2050 project that the number of people exposed to flooding in Australia and New Zealand may approximately double, although absolute numbers are still relatively low compared to elsewhere in the region. For the Pacific region as a whole, the number of people who experience flooding by 2055 could increase by a factor of more than 50, to between 63,000 and 92,000 in an average year. The Pacific Islands of Kiribati, Tuvalu, and Papua New Guinea are likely to experience the most extreme increases in people exposed to flooding, relative to the 1991 baseline.

By 2085, the absolute number of people experiencing flooding in Australia was not expected to change from earlier periods. In New Zealand, flood protection was predicted to be insufficient by 2085 under the mid and high sea-level rise scenarios; an estimated 1206 people may be at risk of flooding. Most Pacific Island countries were predicted to have the ability to adapt to the low sea-level rise scenario (of 19cm) by 2085; several, including Papua New Guinea and Tonga, were predicted to be able to reduce the average annual number of people exposed to pre-2020 levels. However, if sea levels rise according to the highest estimates (80cm), most Pacific Islands were predicted to be severely affected by 2085. The figure for the region as a whole under the high scenario was of 170,000 people exposed to flooding annually. Papua New Guinea (58,000), Kiribati (60,900), Micronesia (16,600), and Nauru (10,300) were predicted to be the worst affected.

Table 17 Estimated number of people exposed to coastal flooding at the baseline year (1990), and three points in the future – 2020, 2055, and 2085, for Australia, New Zealand and summarised for the Pacific Islands*

Country	Scenario**	1990	2020	2055	2085
Australia	Baseline	250	470	500	500
	low	-	480	520	530
	mid	-	480	520	540
	high	-	480	530	550
New Zealand	Baseline	100	140	160	170
	low	-	140	170	190
	mid	-	140	170	390
	high	-	150	180	1210
Pacific - Totals	Baseline	5140	6080	1850	1210
	low	-	37650	63210	12470
	mid	-	39710	69040	43390
	high	-	50390	92340	170000

* The modelled projections allow for assumed gains in adaptive capacity due to future gains in national wealth.

** The four alternative emission scenarios used for the sea-level rise analysis are:

1. baseline (1961-1990 observed climate) .
2. low – 19cm rise (rapid greenhouse gas emissions reduction, stabilising at 550ppm CO_2 by year 2170) .
3. medium – 45cm rise (slower greenhouse gas emissions reduction, stabilising at 750ppm CO_2 by year 2210).
4. high – 80cm rise (unmitigated emissions, with a global increase of approx. 1% per year).

Table 18 Estimated number of people exposed to coastal flooding in individual Pacific Islands at the baseline year (1990), and three points in the future – 2020, 2055, and 2085*

Country	Scenario**	1990	2020	2055	2085
Cook Islands	Baseline	8	4	4	5
	low		12	5	6
	mid		12	5	74
	high		15	5	353
Fiji	Baseline	135	41	32	35
	low		109	36	41
	mid		113	36	494
	high		136	38	2356
Kiribati	Baseline	2416	845	754	89
	low		16236	48385	9137
	mid		17235	52907	19345
	high		22432	70995	60973
Marshall Islands	Baseline	131	313	50	55
	low		1182	362	64
	mid		1239	391	771
	high		1532	509	3673
Micronesia	Baseline	38	17	20	24
	low		396	160	284
	mid		421	174	3496
	high		548	227	16681
Nauru	Baseline	2	9	14	16
	low		37	106	177
	mid		39	114	2166
	high		49	149	10333
Niue	Baseline	0	0	0	0
	low		3	1	2
	mid		3	1	27
	high		4	2	131
Palau	Baseline	2	0	1	1
	low		2	1	1
	mid		2	1	11
	high		2	1	51
Papua New Guinea	Baseline	1728	4382	758	921
	low		16208	5403	1056
	mid		16976	5844	12218
	high		20969	7608	58060
Solomon Islands	Baseline	61	34	45	6
	low		115	343	71
	mid		121	371	851
	high		148	484	4050
Tonga	Baseline	146	224	35	38
	low		836	257	46
	mid		876	279	551
	high		1082	363	2627
Tuvalu	Baseline	258	112	127	15
	low		2437	8130	1584
	mid		2587	8890	3376
	high		3372	11929	10684
Vanuatu	Baseline	56	26	3	4
	low		79	24	4
	mid		82	26	9
	high		100	34	29

*The modelled projections allow for assumed gains in adaptive capacity due to future gains in national wealth.

** See note below Table 17.

7.3.4 Discussion

The number of people exposed to coastal flooding in the Pacific region were estimated to be high, even accounting for an adaptive response to sea-level rise. Given the geography of most countries in the region, flood defences were not predicted to be sufficient to protect against the medium and high rises in sea-level projected for as early as 2020. Should population displacement occur in extremely affected countries, resettlement of environmental refugees to other countries may ultimately become necessary.

The continued safety of agricultural production and freshwater resources are areas of concern for several Pacific Island countries. Flow-on effects to human health could result from poverty due to reduced agricultural and aquacultural yields, reduced freshwater supplies, and the social and economic effects of population displacement.

Nicholls *(Nicholls 2002)* emphasises the importance of primary preventive action by the international community – i.e., to reduce global mean sea-level rise by reducing greenhouse gas emissions. Even if this were to occur, the world is "committed" to a certain amount of sea-level rise for at least the next century – and perhaps for the coming millennium *(IPCC 2001a)* – as the result of past emissions. In addition to that, several actions for adapting to future flood impacts were recommended:

1 Upgrade protection against flooding.
2 Control growth in exposure by limiting population growth in coastal floodplains.
3 When protection or accommodation of existing lifestyles becomes untenable, retreat may be the only option available for some populations in future.

The potential to adapt is variable. Australia and New Zealand (with less impacts predicted) are far more able to adapt to the impacts of sea-level rise than many of the states of the Pacific Islands. Adaptation to sea-level rise for human needs may exacerbate impacts elsewhere (i.e., the environment). For example, construction of additional flood defences may place pressure on coastal ecosystems *(Nicholls 2000).* Linking coastal adaptation to coastal management seems sensible in this context.

7.4 Malaria

7.4.1 Reason for consideration

At the global level, malaria is considered the world's most important vector-borne disease: approximately 40% of the world's population is at risk of contracting the disease, and malaria is endemic in 92 countries *(World Health Organization March 2002)*. In Australia, the disease is no longer endemic, with eradication achieved in the 1960s. Only 12 locally acquired cases of malaria have been reported in Australia since 1962, all in Far North Queensland *(Brookes 1997, Walker 1996)*. Most notable was an outbreak of *vivax* malaria at Cape Tribulation in October 2002 (S Ritchie and J Hanna, unpublished data). In this case, a parasitaemic individual who contracted malaria in Madagascar camped at Noah Beach where large numbers of *Anopheles farauti s.s.* mosquitoes were subsequently found, resulting in 10 cases of locally acquired malaria.

Approximately 8368 (imported) malaria cases were recorded between 1991 and 2001 – an average of 750 every year *(Communicable Diseases Network Australia 2002)*. *Plasmodium falciparum* accounted for less than 50% of these notifications. All States report imported cases, although approximately one half occur in the Northern Territory and Queensland. The rate of notifications has steadily increased since the 1960s, reflecting the increase in travel between Australia and endemic regions. The reported rate may underestimate the true number of cases, because of failure to take into account those who are diagnosed and treated abroad, and the prevalence of under-reporting.

The mortality and morbidity of malaria is highly treatment-dependent. In some developing countries, the death rate is as high as 15%. Data were not available on the case-fatality rate in Australia. In Canada, the case-fatality rate for imported *P. falciparum* malaria varies from 0.6% to 4.2% and increases to > 30% for those over 70 years of age *(Canadian Health Department October 1997)*.

Of the four species that infect humans, two of them predominate overwhelmingly: *Plasmodium vivax* and *P. falciparum*. Vivax malaria, with its capacity for over-wintering dormancy, predominates in cooler, temperate zones. *Falciparum* requires warmer conditions and predominates in most tropical and sub-tropical regions. It has a much greater lethality than *vivax* malaria.

Some mosquitoes of the genus *Anopheles* transmit malaria. *An. farauti sensu lato* are the only mosquitoes conclusively shown to have transmitted malaria in Australia (in an outbreak in Cairns in 1942, *Walker 1998b)*, and observations since the 1900s suggest they are the most important Australian vectors *(Bryan et al. 1996b, Cooper et al. 1995, Sweeney et al. 1990)*. Circumstantial evidence supports the assumption that *An. annulipes* was the vector in isolated cases of transmission in the south in early outbreaks (Sydney, Bega, and Melbourne).

The relationship between climate and malaria is well documented (discussed in *Kovats et al. 2001, Martens et al. 1999a, Martens et al. 1995)*. In general, the potential for mosquito-borne diseases is expected to increase as a result of climate change. Warmer conditions are predicted to extend the geographical distribution and seasonal abundance of mosquitoes, and accelerate the within-vector development of pathogens, thereby increasing the efficiency of disease transmission *(Martens et al. 1999a, McMichael et al. 1996a)*. Such predictions assume no change in prevention effectiveness.

Previous research

Only for *falciparum* malaria have the climate relationships been independently modelled at the global level by several research groups *(Martens et al. 1999b, Rogers and Randolph 2000)*. Of these, the last two models have been influential in the recent literature. However, they employ fundamentally different approaches – the former uses a biologically-based model (incorporating a central, literature-derived equation about vectorial capacity and its relationship to meteorological variables), whereas the latter derives an empirical statistical equation from the current global distribution of malaria in terms of temperature and rainfall. The former model *(Martens and others)* thus estimates where the disease *could* be, solely as a function of climate conditions, while the latter model *(Rogers and Randolph)* estimates where the disease *would* be if the current social-technological determinants of disease occurrence applied, unchanged, in a climatically altered future world.

The model of Rogers and Randolph *(2000)* gives global coverage, including Australia. Their estimate of malaria distribution includes the northern parts of the Northern Territory and the Cape York Peninsula. The model did not predict the Queensland coastal strip from Cairns down to Mackay. The published predictions from this particular model, however, are of uncertain value. It has been recognised, since publication, that the central statistical equation in that study was based on incorrectly specified maps of the current malaria distribution (David Le Seur, personal communication, 2002).

Martens and others *(1999b)* used a biological model (called "MIASMA") to estimate the potential transmission of *falciparum* malaria. The model included vector-specific information regarding temperature and rainfall and their relationship with mosquito distribution. The baseline model (Figure 13) estimated that the region around Cairns was climatically suitable for year-round transmission of malaria, and that the region around Darwin and the eastern part of Australia down to just north of Sydney was suitable 7 to 11 months of the year. This model estimates climatic suitability only, and does not account for any environmental modification or vector control, which means that transmission in most of these regions is at present unlikely. The model estimate broadly concurs with published observations of past geographic distribution of the vector, prior to vector control and environmental modifications. The future estimates show a retraction of climate suitability in the south of the country, and an increase in the north-east (Figures 14 & 15).

In Australia, Bryan, Foley and Sutherst *(1996b)* modelled malaria-suitable regions. They conducted a sensitivity analysis: given an assumed increase in temperature of 1.5°C and a 10% increase in rainfall conditions, *An. farauti s.l.* were predicted to extend their distribution a further 800km south in coastal Queensland to Gladstone ($23^{0}50'$S), *(Bryan et al. 1996b)*.

They used an empirical-statistical model (called "CLIMEX"), which used information on the current distribution, relative abundance, and seasonal phenology of the malaria mosquito to determine the model parameters that best describe the mosquito's climatic requirements. The aim was to capture the core features of the species' climatic requirements, not to describe the mosquito population dynamics in detail.

Like the MIASMA model of Martens and others, CLIMEX estimates where malaria *could* occur as a function of climatic conditions. Unlike the MIASMA model, however, it takes the current known distribution of the vector as evidence for the climatic constraints that operate on its breeding and survival. The current distribution obviously also includes the impact of human activities that have, over time, acted to restrict the environments available to the mosquito (such as changes in water supply, vector control practices etc). Therefore, the CLIMEX approach already includes an element of human adaptation. The model does not adjust for any changes in these types of human activities in the future.

Figure 13 Estimate of potential distribution of malaria for baseline climate, assuming no environmental modification or disease control (from Martens *et al.* 1999)

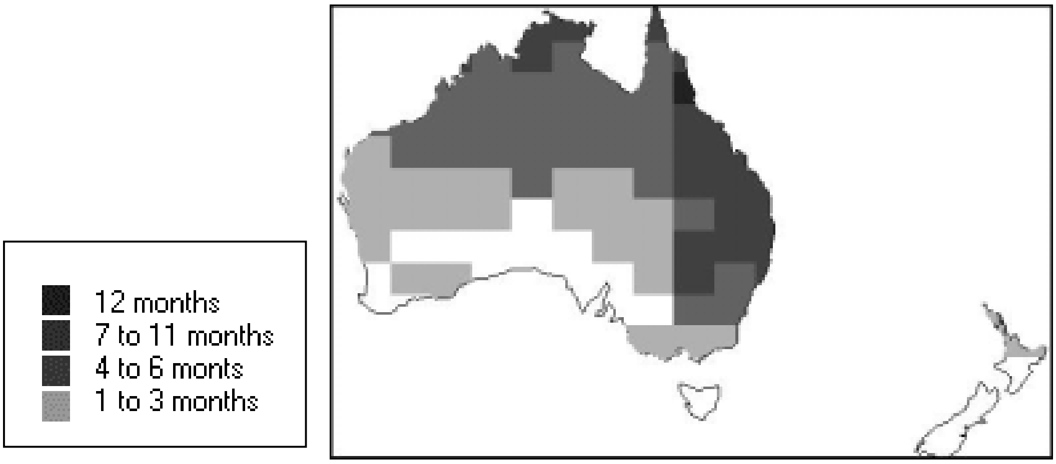


Figure 14 Estimate of potential malaria distribution at 2010-2040 ("mid" GHG scenario), assuming no environmental modification or disease control (from Martens *et al.* 1999)

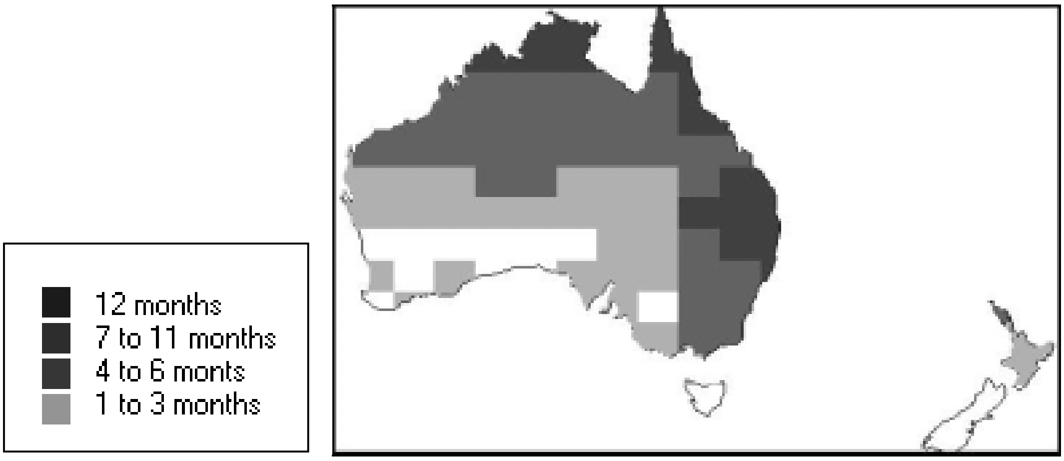
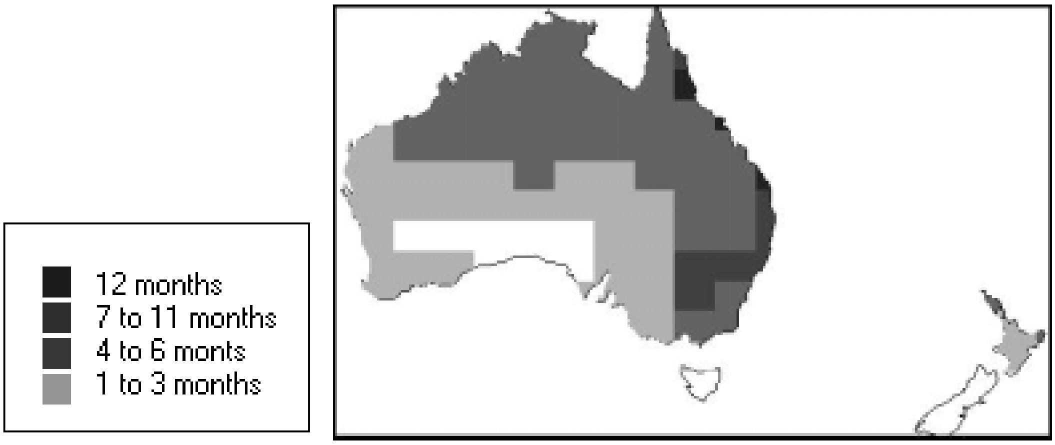


Figure 15 Estimate of potential malaria distribution at 2040-2070 ("mid" GHG scenario), assuming no environmental modification or disease control (from Martens *et al.* 1999)



7.4.2 Method of analysis

This analysis examines the impact of climate change on malaria transmission on the mainland of Australia. It represents a sequel to the analysis by Bryan and others *(Bryan et al. 1996a)*, which predicted the malaria receptive zone in Australia could extend under climate change to include much of the coastal area of Queensland. Since that analysis, further increases in global warning and more extreme changes in rainfall have been projected (IPCCa 2001). There has also been a new record of the primary mosquito vectors *An. farauti s.l.* in Australia *(van den Hurk et al. 1998)*. The new record – at Mackay (21^0 09^0 S) – is approximately 350km south of the previous most southerly record at Townsville, and involves a mosquito population that has been known unofficially for some time. For both reasons, a re-analysis of the future malaria receptive zone is timely.

The CLIMEX model

CLIMEX (developed by Robert Sutherst, CSIRO Entomology) is a climate-matching model that produces indices derived from the responses of a mosquito species – in this case *An. farauti s.l.* – to particular components of climate. A hydrological model was used to calculate a soil moisture index. This was combined with temperature to estimate a weekly population 'growth index' for the species. Extreme values were taken into account in a series of stress indices that estimated the threat to that species posed by prolonged adverse periods of excessively cold, hot, dry or wet conditions. The involvement of humidity was accounted for in the calculation of evaporation for the hydrological model. Finally, the growth and stress indices were combined into an 'ecoclimatic index', scaled from 0-100. This index represents the overall climatic suitability of a given location for the permanent survival and propagation of *An. farauti s.l.*

The analysis also considered the distribution of *Plasmodium vivax* and *P. falciparum,* the two most significant species of malaria parasite. They differ in their pathology, with the former causing less severe symptoms than the latter. In areas of the world with low temperatures, there is evidence that transmission of malaria is hindered by the lack of development of the malaria parasites, rather than by the vectors alone. Various estimates of the species' temperature requirements indicate that *P. vivax* has a developmental threshold temperature of around 14-16°C, lower than the 16-19°C needed for *P. falciparum (Martens et al. 1999b)*.

The values of 15°C and 18°C were used as the temperature thresholds for *P. vivax* and *P. falciparum* respectively for this analysis. As the moisture requirements for transmission are related to the vector, only a temperature model was used for *Plasmodium*. The modelling considered the current distribution of the parasites, and calculated potential distribution with an increase of 3°C.

Climate change scenarios used in this analysis

The CSIRO climate projections used for the other analyses in this report could not be used for the malaria modelling, due to software incompatibilities. Instead, the climate grid from the Climate Research Unit in Norwich UK (50 km^2 resolution) was used. Due to the resolution of the climate grid, there is likely to be some unsatisfactory averaging of coastal plains areas adjacent to the Great Dividing Range. This may affect the accuracy of the estimates to the extent that the results should be interpreted as indicative of the likely patterns of climate suitable for mosquitoes, rather than of being precise local estimates.

A "sensitivity analysis" was conducted to assess the potential changes in the distribution of *An. farauti s.l.* in response to climate change. This method used changes in rainfall, temperature, or both as the scenarios (Table 19). Choice of these parameters was guided by the extremities of temperature and rainfall change predicted by the CSIRO (using the ECHAM4 and CSIROMk2 projections for 2020 and 2050 that were used for the other analyses in this assessment). The modelling considered, for example, how an increase in 1, 2, or 3°C would change distribution of the vector. Change in rainfall represented the percentage increase or decrease from the long-term average total annual rainfall. Change in temperature was the increase in degrees celsius from long-term average annual temperature. The baseline (B) situation was included (i.e., current temperature, current rainfall) so that changes in temperature and rainfall can be compared.

Limitations

The role of host (human) density, a factor in the transmission of malaria, was not included in modelling. Highest risk areas can be inferred from the risk maps to be those where humans are most densely collected.

Some difficulty was experienced in getting a model fit that was internally consistent. The inclusion of the newly identified *An. farauti s.l.* population in Mackay indicated that some areas further south, such as St Lawrence and Gladstone, and all of the offshore islands were able to support populations of the mosquito. This finding supported the view of van den Hurk and others *(1998)* of the need for further research on the distribution of this malaria vector, so as to improve the definition of the Australian malaria-receptive zone. It increases the uncertainty of the accuracy of the projected distributions.

Table 19 Temperature and rainfall parameters used in the sensitivity analysis*

△ Rainfall (%)	**△ Temperature (^oC)**				
	Baseline	+0.5	+1	+2	+3
Baseline	B0	B1	B2	B3	B4
+4	B5	2020(1)	2020(2)	2020(3)	—
-12	B6	2020(4)	2020(5)	2020(6)	—
+20	B7	—	2050(1)	2050(2)	2050(3)
-40	B8	—	2050(4)	2050(5)	2050(6)

* Numbering relates to the numbering on the maps (B0, B1, 2020(2), etc.). For example, the B1 scenario relates to an increase of temperature by 0.5°C, and no change in rainfall. The 2020(5) scenario relates to an increase of 1°C and a 12% decrease in rainfall.

7.4.3 Findings

Current distribution of malaria vector - *An. farauti s.l.* (Figure 16)

The CLIMEX model indicated that current climatic conditions appear highly suitable for *An. farauti s.l.* in the very northern parts of Queensland and the Northern Territory (around Darwin).

Temperature limits to the development of malaria parasites (Figures 17 & 18)

The analysis predicted that the two primary species of malaria - *Plasmodium vivax* and *P. falciparum* – would be able to develop for several months in summer in most parts of Australia (conditional on a suitable vector being present), except in the southern highlands and the mid north-west.

Temperatures favoured *P. falciparum* most in the tropical north and *P. vivax* was slightly favoured in the temperate areas to the south of the continent. Under the most extreme temperature increase of +3°C there was a noticeable southward shift of both species, accompanied by a decline in the suitability of the inland and north-western regions due to excessive heat.

Future distribution of malaria vector

Change in temperature, no change in rainfall

Increasing temperatures (Figure 19) may progressively extend the southern distribution of the malaria-receptive zone from Mackay to the Bundaberg/Fraser Island area, while also making that belt of coast progressively more suitable. It is also predicted that the mosquito may colonise further inland in the southern area.

No change in temperature, change in rainfall

A 4-20% increase in rainfall (Figure 20 B5; Figure 21 B7), without an accompanying increase in temperature, was not predicted to effect distribution substantially from present. The modelling predicted the possibility that the mosquito may colonise further inland, especially in the Northern Territory.

With a 12-40% reduction in rainfall (Figure 20 B6; Figure 21 B8) distribution was predicted to contract towards the coast. A 40% reduction in annual rainfall displaced the mosquito from all but the wet coastal areas around Mackay, Cairns, Cape York and the islands off Darwin.

2020 scenarios

Warmer (0.5 – 2°C) and wetter (+ 4% rainfall) - Figure 22

The malaria receptive zone is predicted to spread down the coast to southern Queensland with increasing temperatures, possibly accompanied by some spread into the coastal hinterland.

Warmer (0.5 – 2°C) and drier (-12% rainfall) - Figure 23

The malaria receptive zone may spread down the coast to southern Queensland with increasing temperatures, but is predicted to be confined to the coastal zone due to the reduced rainfall.

2050 scenarios

Warmer (1.0 – 3°C) and wetter (+ 20% rainfall) - Figure 24

The malaria receptive zone may spread down the coast to southern Queensland with increasing temperatures, and a more significant spread into the coastal hinterland is predicted.

Warmer (1.0 – 3°C) and drier (- 40% rainfall) - Figure 25

The malaria receptive zone may spread down the coast to southern Queensland with increasing temperatures. It is predicted to be strictly confined to the coast and islands, however, given the extreme reduction in projected rainfall.

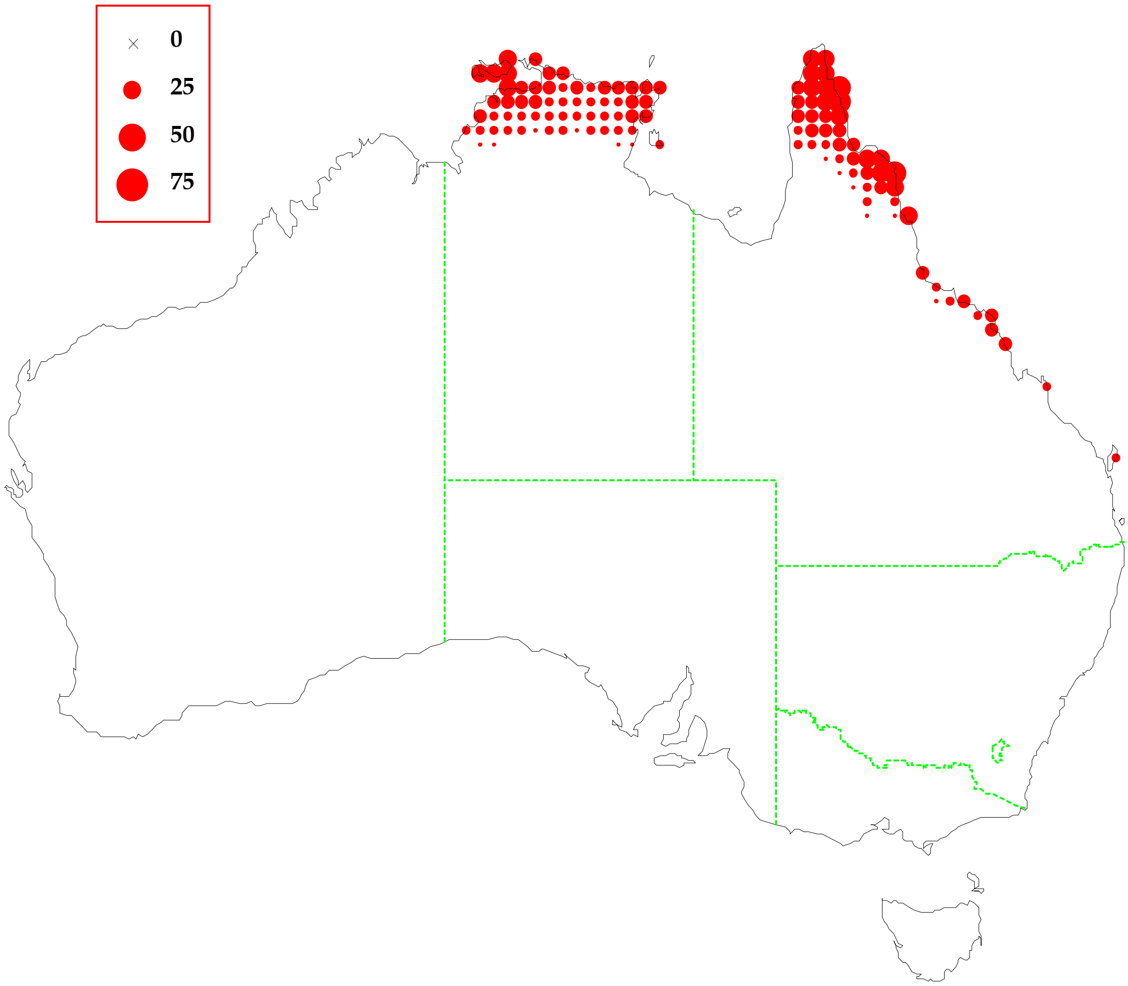
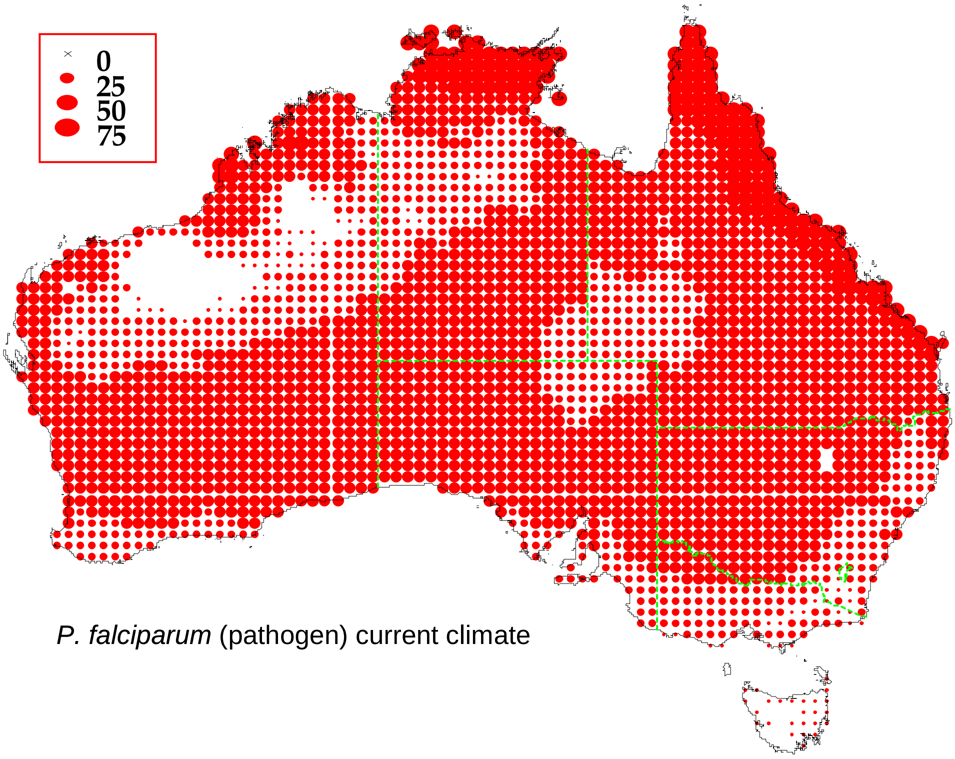
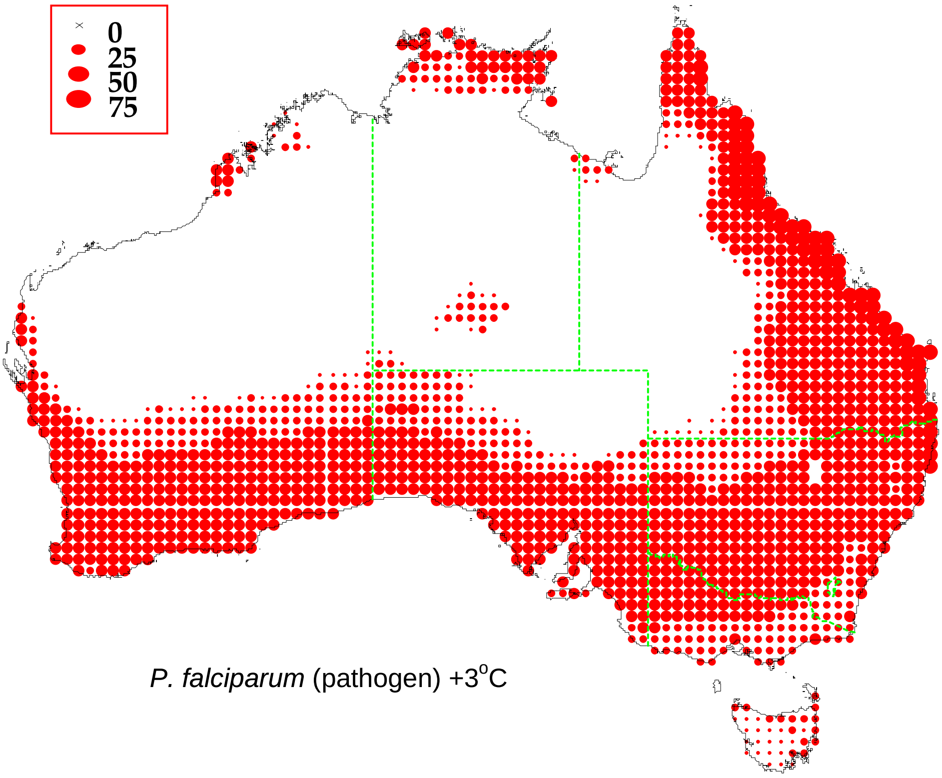


Figure 16 CLIMEX ecoclimatic indices for *An. farauti* distribution under current climate (values indicate climatic suitability – the higher the value, the more suitable is the geographic region for maintenance of the mosquito)



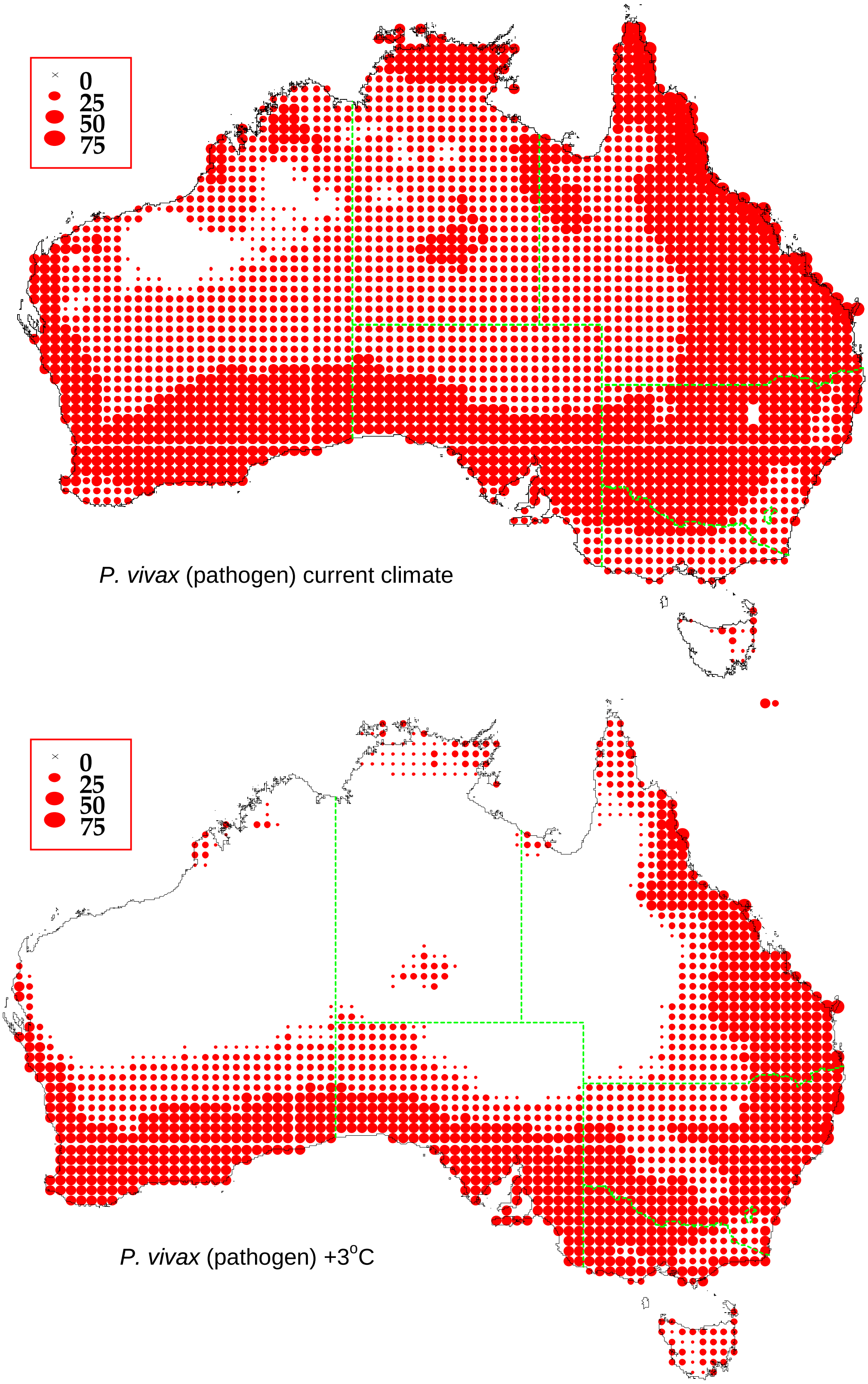
P. falciparum (pathogen) current climate



P. falciparum (pathogen) +3°C

Figure 17 Ecoclimatic index estimates for *P. falciparum* distribution, the malaria pathogen, under current climate conditions (top), and increase of 3°C temperature (bottom)

Note that transmission of malaria requires suitable climate conditions for both the vector and the pathogen to exist.



P. vivax (pathogen) current climate

P. vivax (pathogen) +3^{o}C

Figure 18 Ecoclimatic index estimates for *P. vivax* distribution, the malaria pathogen, under current climate conditions (top), and increase of 3^{o}C temperature (bottom)

<u>Note</u> that transmission of malaria requires suitable climate conditions for both the vector and the pathogen to exist.

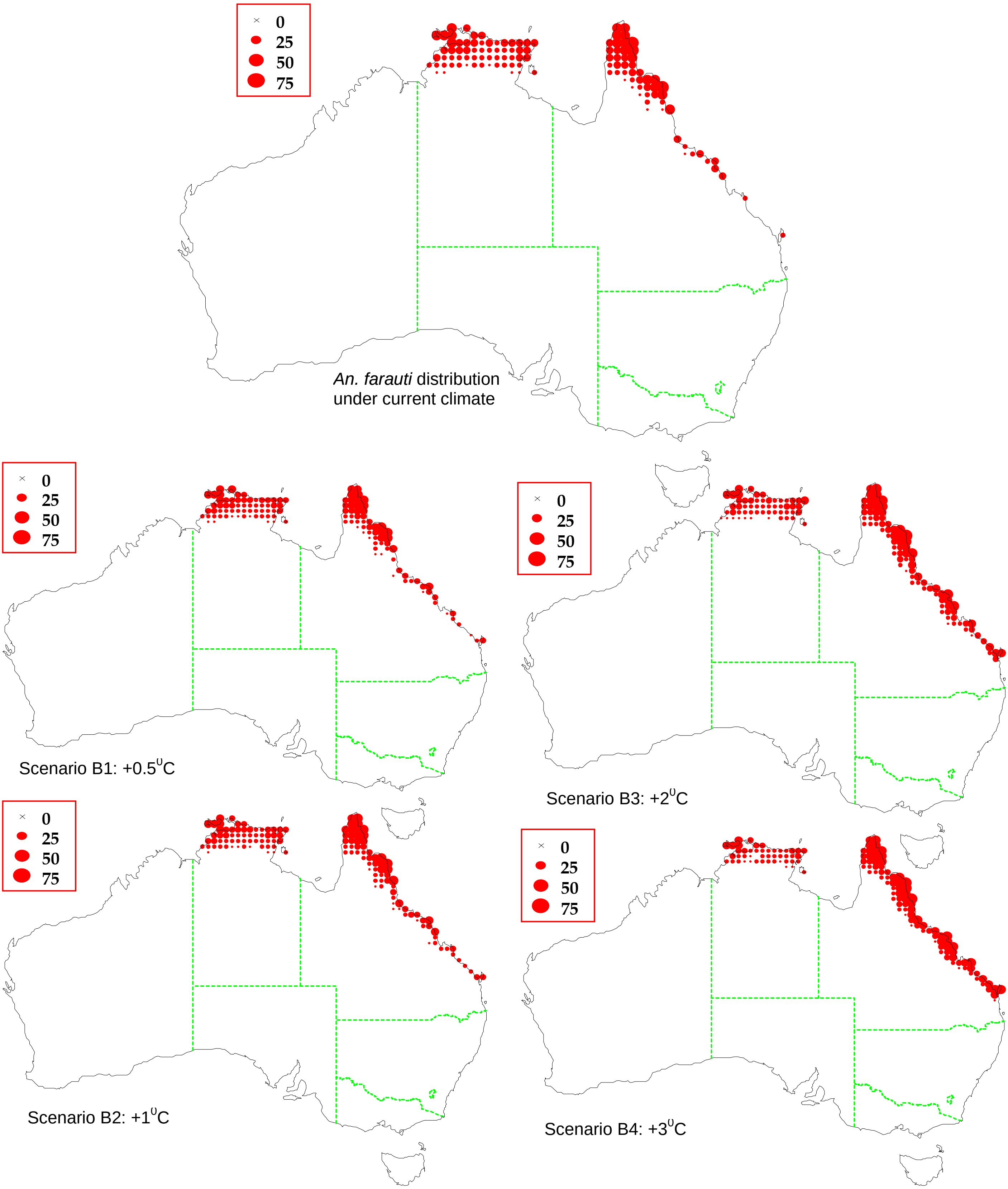


Figure 19 CLIMEX ecoclimatic index values for *An. farauti* distribution with increasing temperatures (precipitation same as baseline)

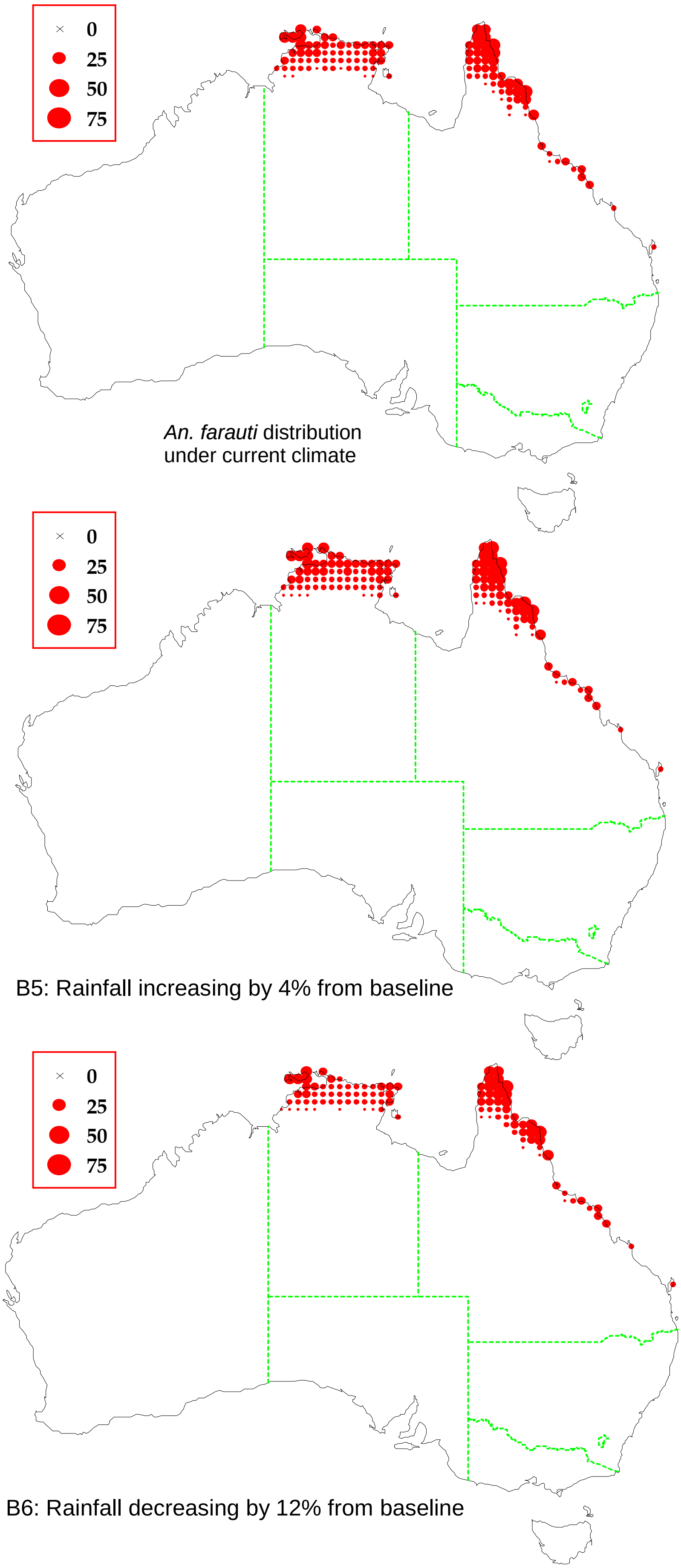
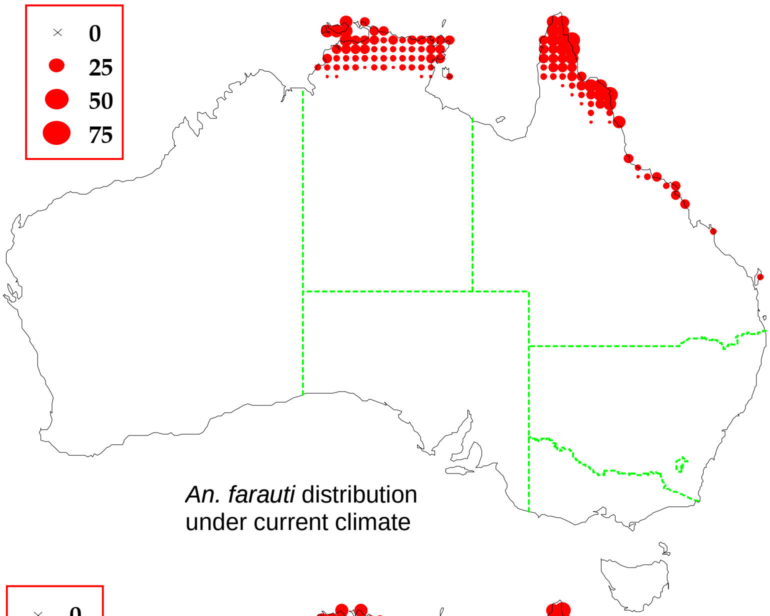
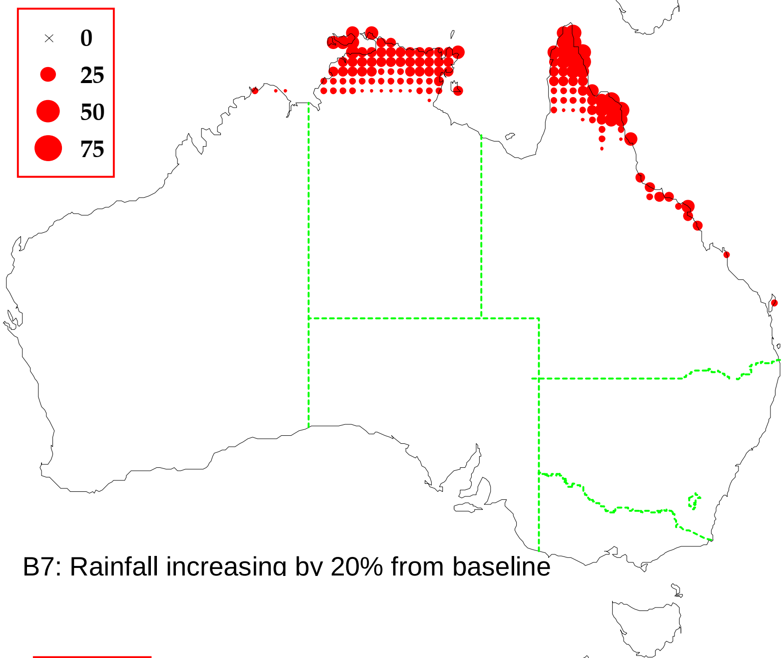


Figure 20 CLIMEX ecoclimatic index values for *An. farauti* distribution, given estimated changes in precipitation patterns for **2020** (temperature same as baseline)





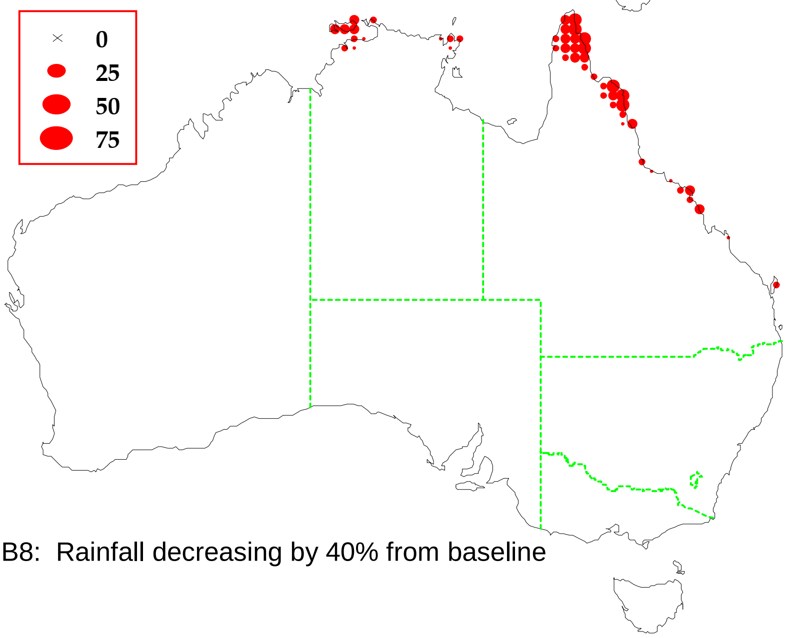


Figure 21 CLIMEX ecoclimatic index values for *An. farauti* distribution, given estimated changes in precipitation patterns for **2050** (temperature same as baseline)

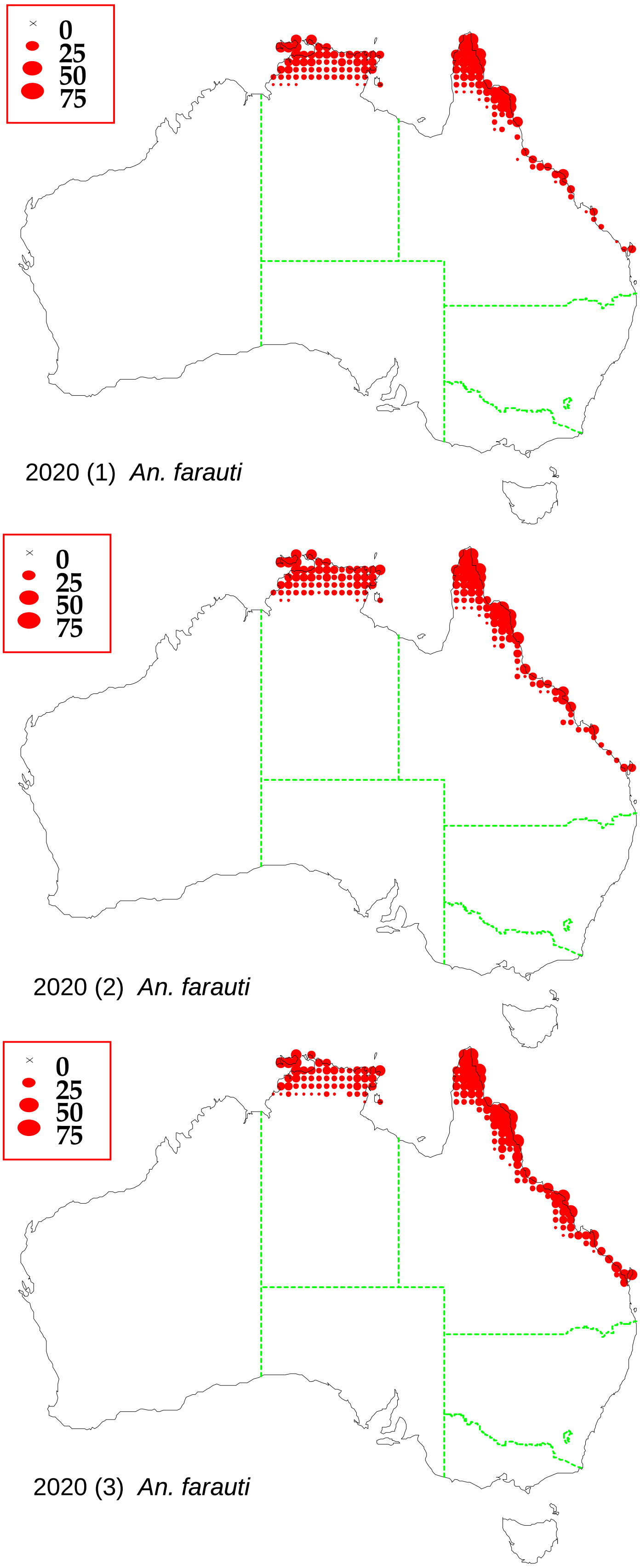


Figure 22 CLIMEX ecoclimatic index values for *An. farauti* for **2020** temperature scenarios with increasing rainfall (+4%)

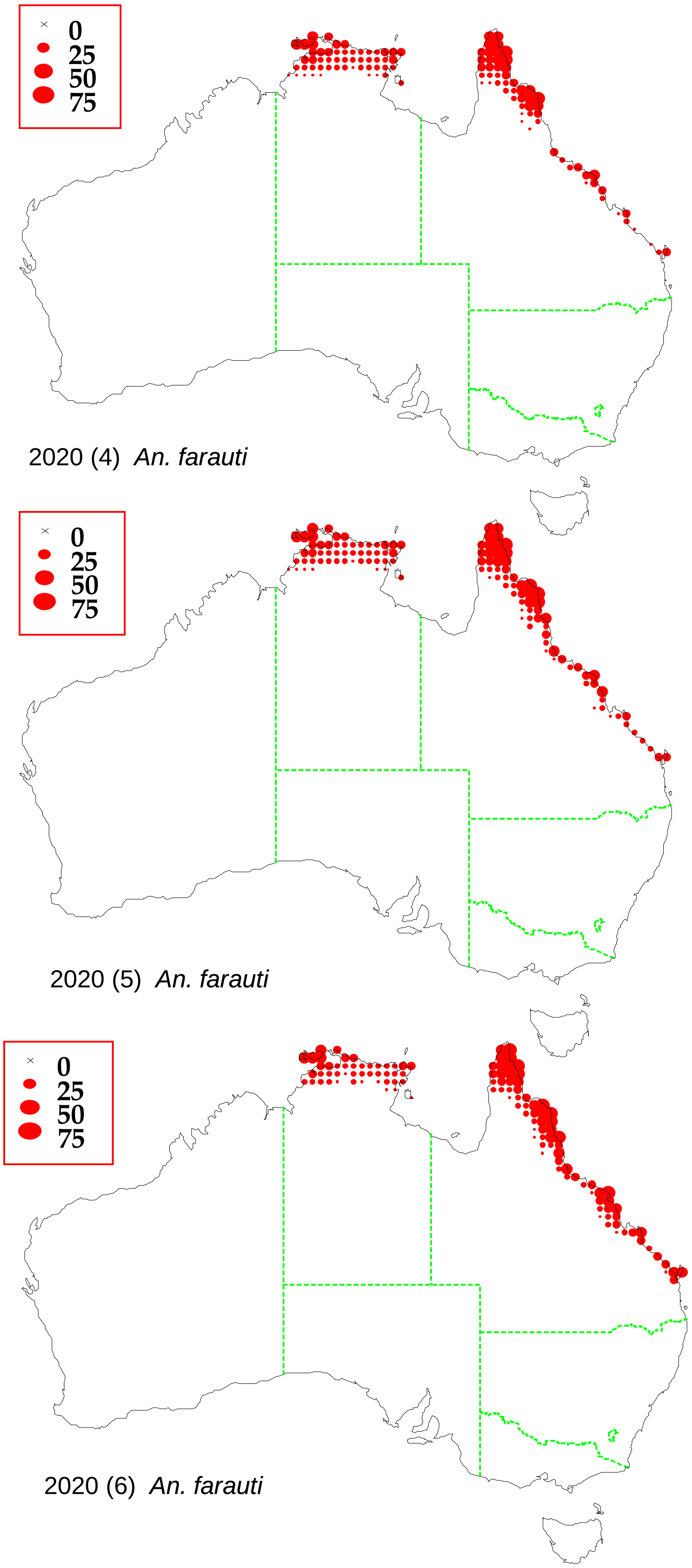


Figure 23 CLIMEX ecoclimatic index values for *An. farauti* for **2020** temperature scenarios with decreasing rainfall (-12%)

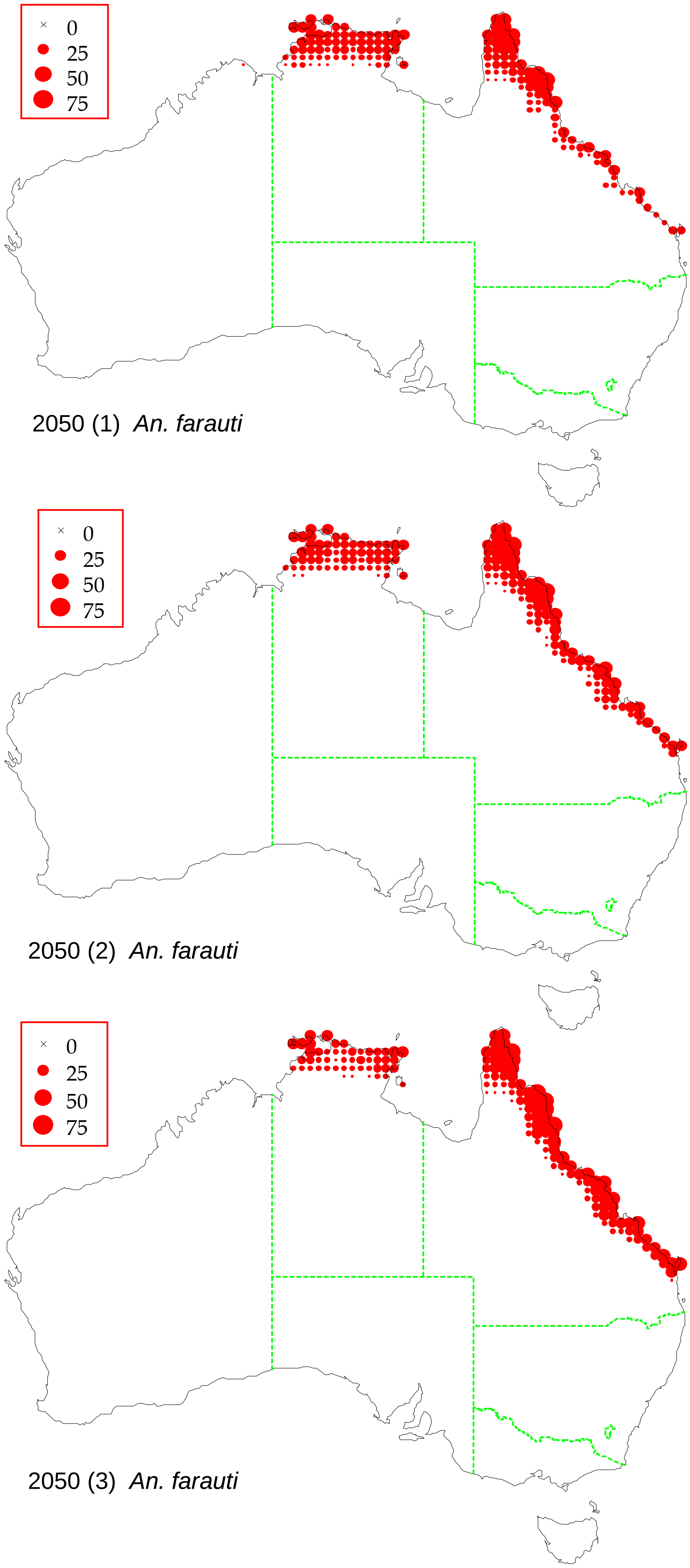


Figure 24 CLIMEX ecoclimatic index values for *An. farauti* for **2050** temperature scenarios with increasing rainfall (+20%)

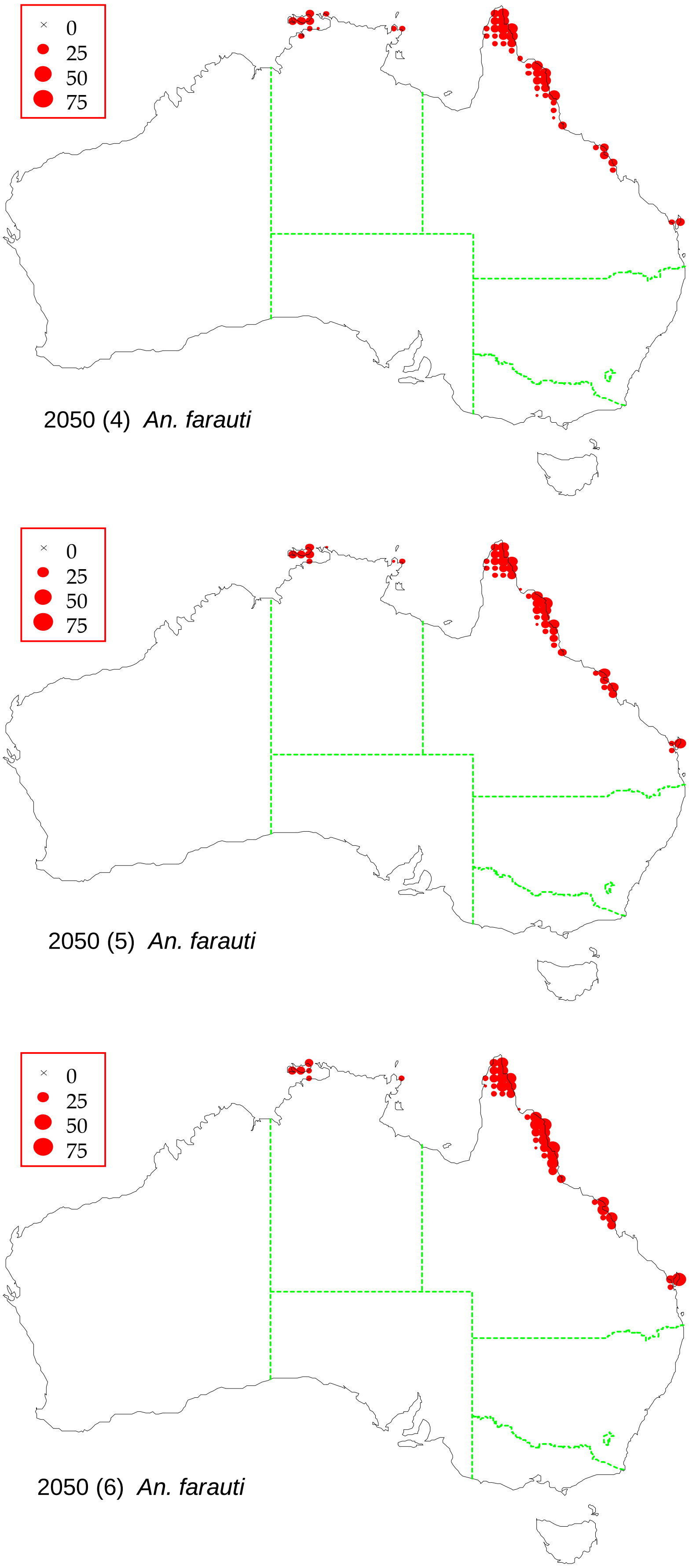


Figure 25 CLIMEX ecoclimatic index values for *An. farauti* for **2050** temperature scenarios with decreasing rainfall (-40%)

7.4.4 Discussion

This analysis considered where malaria transmission *could* occur, in terms of climatic conditions. The climatic limits to the malaria receptive zone in Australia are assumed to correspond with the climatic requirements of the only competent vector of malaria in Australia, namely *An. farauti s.l.*. The model results indicate that there is a hypothetical risk of the malaria receptive zone expanding southwards under climate change, to include regional towns like Rockhampton, Gladstone and Bundaberg, if human adaptive measures (such as an increase in epidemiological surveillance and vector control) do not occur in these regions.

Walker listed three elements necessary for the re-introduction of malaria in Australia:

(i) suitable anopheline vectors in sufficient numbers to maintain transmission,
(ii) suitable climate for vector and parasite, and
(iii) infected individuals *(Walker 1998a)*.

The risks from malaria under climate change are limited, and relate mostly to an extension of the malaria receptive-zone, with the potential for transmission within that zone if a number of other risk factors change. This conclusion is based on (i) continuation of an effective public health response to the threat of malaria, and (ii) an ongoing ability to quickly identify and treat malaria cases. Public health and local government infrastructure and practices to date have ensured that transmission in the current malaria-receptive zone (Figure 16) do not occur *(Bryan et al. 1996a)*. Although the probability of the re-introduction of malaria into Australia is very low, there is a need for continued surveillance and a rapid response to any introduced cases *(Walker 1998a)*. Surveillance would be necessary to ensure that malaria does not recur in the international tourist spots of coastal north Queensland *(Walker 1998b)*, particularly as the total population density and the number of infected travellers is expected to increase. The outbreak of *vivax* malaria at Cape Tribulation in 2002 highlights the threat that ecotourism in an area of high malaria receptivity can play.

The ability to treat malaria (thus reducing the period of parasitaemia and the probability of transmission) is not certain in the longerterm, given the rate at which the parasites are developing resistance to available drugs, and the apparent limited effectiveness of new prophylactic drugs. This was illustrated by the recent high incidence of malaria amongst Australian defence forces in East Timor, where primaquine-tolerant parasites existed and doxycycline failed to prevent some infections *(Kitchener et al. 2000)*. With the potential for greatly increased rates of migration of infected people into Australia from neighbouring islands in the tropical Pacific that are stressed by climate change, the pressure on the public health system from imported malaria is likely to increase. This may be less than the threat to Australians travelling in the region with increasing prevalence of drug resistance.

The overall conclusion is that in the foreseeable future malaria is not a direct threat to Australia, either under the current climate or under climate change, as long as a high priority is placed on prevention via the maintenance and extension of public health and local government infrastructure.

7.5 Dengue Fever

7.5.1 Reason for consideration

Transmission of dengue viruses is influenced by climate, among many other factors *(Gubler 1997)*. The development, dynamics, abundance and geographic distribution of the vectors and virus are related to ambient temperature, moisture, and humidity, and hence are expected to be affected by climate change *(Martens 1998c)*. The north and central areas of Queensland are considered potentially receptive to the establishment of dengue, but the evidence suggests that the virus is not endemic in Australia at present *(Mackenzie et al. 1996a)*. *Aedes aegypti* is the only dengue vector that is currently present in mainland Australia (Queensland only). Since the 1940s cases have been confined to Queensland, and principally to the northern and eastern parts of that state *(Mackenzie et al. 1996a)*.

Ae. albopictus is another dengue vector common in SE Asia and Papua New Guinea, but not yet established in Australia (although incursions have been detected by quarantine authorities on a number of occasions in recent years). It has a higher cold tolerance than *Ae. aegypti*, and has recently colonised areas of northern Italy and North America *(Centre for Disease Control and Prevention USA 2002, Knudsen et al. 1996)*. It would potentially be able to colonise most populated regions of Australia. *Ae. albopictus* is a peri-domestic dweller, and can colonise urban as well as rural areas with low human populations. Thus, it provides the potential to link suburban and rural areas, and tropical and temperate areas, and to extend the potential zone of dengue transmission.

Social factors are also important in determining the ability of *Ae. aegypti* to establish in a region, given that receptacles holding freshwater are the favoured breeding sites. *Ae. aegypti* was more widely distributed throughout Australia in the past. Outbreaks of dengue have been recorded since as early as 1879 (in Townsville), and the mosquito was common in Brisbane and extended into Sydney pre WWII *(Lee et al. 1989)*. Dengue has also been reported in Western Australia (from Carnarvon, Broome and Wyndham), and in the Northern Territory (Darwin). Key factors in the emergence and then later disappearance of the vector from these regions have been the increasing urbanisation of society, including the conversion from rainwater tanks to a reticulated supply, the use of refrigerators instead of water-cooled safes, diesel- rather than steam-powered trains, and the use of domestic insecticides *(Gubler 1998, Mackenzie et al. 1996b, Reiter 1996).*

Since the commencement of national reporting in 1991, 2595 cases of dengue have been recorded, approximately 250 cases per year *(Communicable Diseases Network Australia 2002)*. Imported cases are regularly diagnosed in all capital cities of Australia. In addition, local transmission following the importation of virus has caused several outbreaks in recent years: in Charters Towers in 1993 (26% of the non-immune population were infected) *(McBride et al. 1998)*, in Cairns and the Torres Strait in 1996 (201 cases), and in the Cairns region in 1998 (500 cases, Hanna *et al.* 2001).

There are four serotypes of the dengue virus. Dengue haemorrhagic fever and dengue shock syndrome are life-threatening complications that are thought to result from a second dengue infection, with a virus different in serotype to that which caused the primary infection *(Halstead et al. 1970)*. The large numbers of tourists that travel between Australia and countries in Asia and the Pacific, where dengue is endemic, has greatly increased the risk of introduction of the virus *(McBride 1999, Mackenzie et al. 2002)*.

The potential for epidemics of dengue haemorrhagic fever or dengue shock syndrome in North Queensland has increased in recent years, following widespread infection of several populations with dengue type 2.

7.5.2 Method of analysis

Several models have been developed to describe the relationship between dengue and temperature over time *(Jetten and Focks 1997, Patz et al. 1998)*. However, this analysis used an empirical model *(Hales et al. 2002)* to estimate the population living in a region climatically suitable for dengue transmission. Hales and others investigated the relationship between multiple climate parameters and global distribution of dengue, and produced a model which has been quantitatively validated against the reported distribution. Using logistic regression analysis, they modelled the presence or absence of the global distribution of dengue (for the period 1975-1996) based on long-term average vapour pressure (from the baseline climate period of 1961-1990). The output of this model was a number between 0 and 100%, representing the estimated probability that one or more epidemics of dengue fever would have been recorded under baseline climate conditions. Regions were defined as "at risk" of dengue where the model indicated a greater than 50% probability of transmission. The accuracy of the model was assessed by comparing the results with the recorded distribution of dengue fever, and the geographical limits of dengue distribution were modelled with 89% accuracy.

The statistical relationships from this analysis were applied to the alternative climate scenarios for the years 2020 and 2050 for Australia. The alternative scenarios have been described in Section 6.2. In brief, they comprise three projected emission scenarios (high, mid, and low) and two global climate models (CSIROMk2 and ECHAM4). Regions were defined as "at risk" of dengue where the model indicated a greater than 50% probability of transmission. The results were converted from ASCII format into a geographic information system program format. A map of the Australian Statistical Local Areas was overlaid onto each of the dengue distribution scenarios, and the future population at risk was calculated (the mid-level SLA population projections were used – see Section 6.2 for methods). Regional gridded climate data were not available to prepare estimates of future risk at the same resolution for the Pacific Island countries or New Zealand. For these countries, national scale estimates were based on the HADCM2 global circulation model *(Cullen 1993)*.

7.5.3 Findings

The results presented for Australia are the number of people estimated to be living in a region climatically suitable for dengue transmission, under the different climate scenarios. Note that the model does not account for the possibility of adaptive strategies, which would in all likelihood reduce the risk of transmission substantially. Projected population change is accounted for in the future estimates. The results for Australia are also presented in map format, with major towns highlighted. Validation for the methods used to derive these results have been published by Hales and others *(Hales* et al. *2002)*.

Baseline estimates (Figure 26, Table 21)

The model estimates for the current potential dengue risk region, based on climatic risk factors only, included the major towns of Broome, Darwin, and Katherine. A narrow section of the coastline south of Townsville and north of Mackay was also defined as "at risk". Table 21 gives the population estimates of the number of people living in those regions: now, at 2020 and 2050.

The model slightly underestimated the current region where dengue transmission has been reported. Epidemic dengue transmission has been reported from towns not included in the current zone – such as Cairns, Charters Towers and Townsville. However, the model did estimate that these towns were on the very edge of climate suitability. The grid cell covering Cairns, for example, had a probability of 0.46, and the cell for Townsville had a probability of 0.48 (the criterion for suitability was 0.5). Owing to the cities in north Queensland being excluded from risk by the model, the figure of 0.17 million currently living in a dengue risk region is an underestimate.

Table 21 Australian populations estimated to be living in a region suitable for *Ae. aegypti*

Baseline (million)	Scenarios		2020 (million)	2050 (million)
0.17	Mid			
		CSIROMk2	0.33	0.77
		ECHAM4	0.34	1.16
	High			
		CSIROMk2	0.51	1.24
		ECHAM4	0.49	1.61
	Low			
		CSIROMk2	0.30	0.78
		ECHAM4	0.29	0.75

2020 Scenarios (Figures 27 & 28, Table 21)
Mid emission scenario

- There was minimal change in the dengue receptive zone, with a slight increase in geographic spread south of Townsville along the coast. With projected population increases, 325-337,000 people were estimated to be at risk.

High emission scenario

- The dengue receptive zone spread further south down the coast from Townsville, but not as far south as Mackay. 490-510,000 people were estimated to be living in the risk zone.

Low emission scenario

- Minimal change to the baseline distribution.

2050 Scenarios (Figures 29 & 30, Table 21)
Mid emission scenario

- A spread into the hinterland of Townsville and Mackay was indicated, with the dengue receptive zone reaching as far south as Rockhampton. With projected population increases, 770-1,160,000 people were estimated to be at risk.

High emission scenario

- With higher humidity, there is a substantial incursion inland from the coastal region between Cairns and Rockhampton. The southerly spread was estimated to reach down to Maryborough and Gympie in the east, and to Carnarvon in the west. 1,240-1,610,000 people were estimated to be living in the risk zone.

Low emission scenario

- The dengue receptive zone remained confined to the coast in the northeast, extending down to Mackay. 750-780,000 people were estimated to be living in the risk zone.

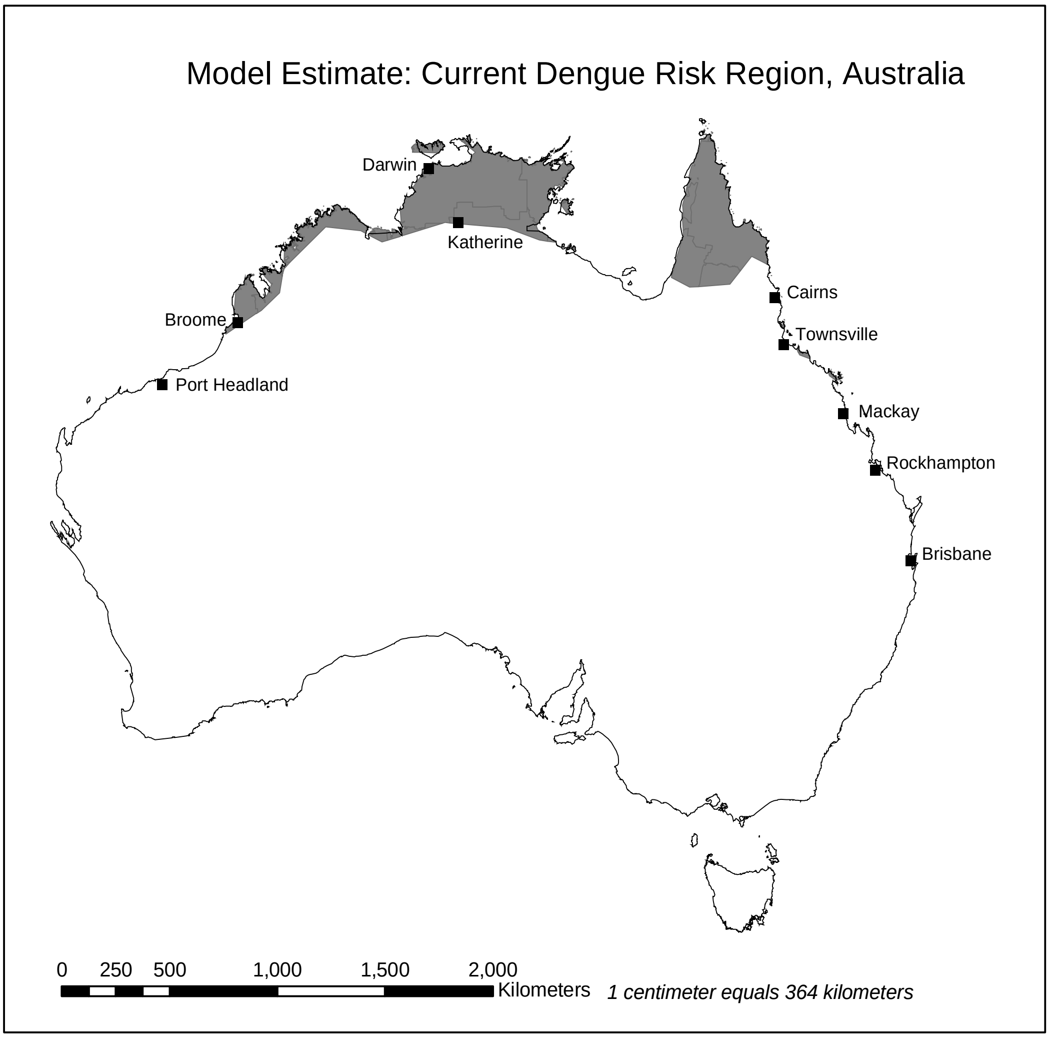


Figure 26 Model estimate of the current geographic region suitable for *Ae. aegypti* (based on baseline [1961 to 1990] vapour pressure estimates)

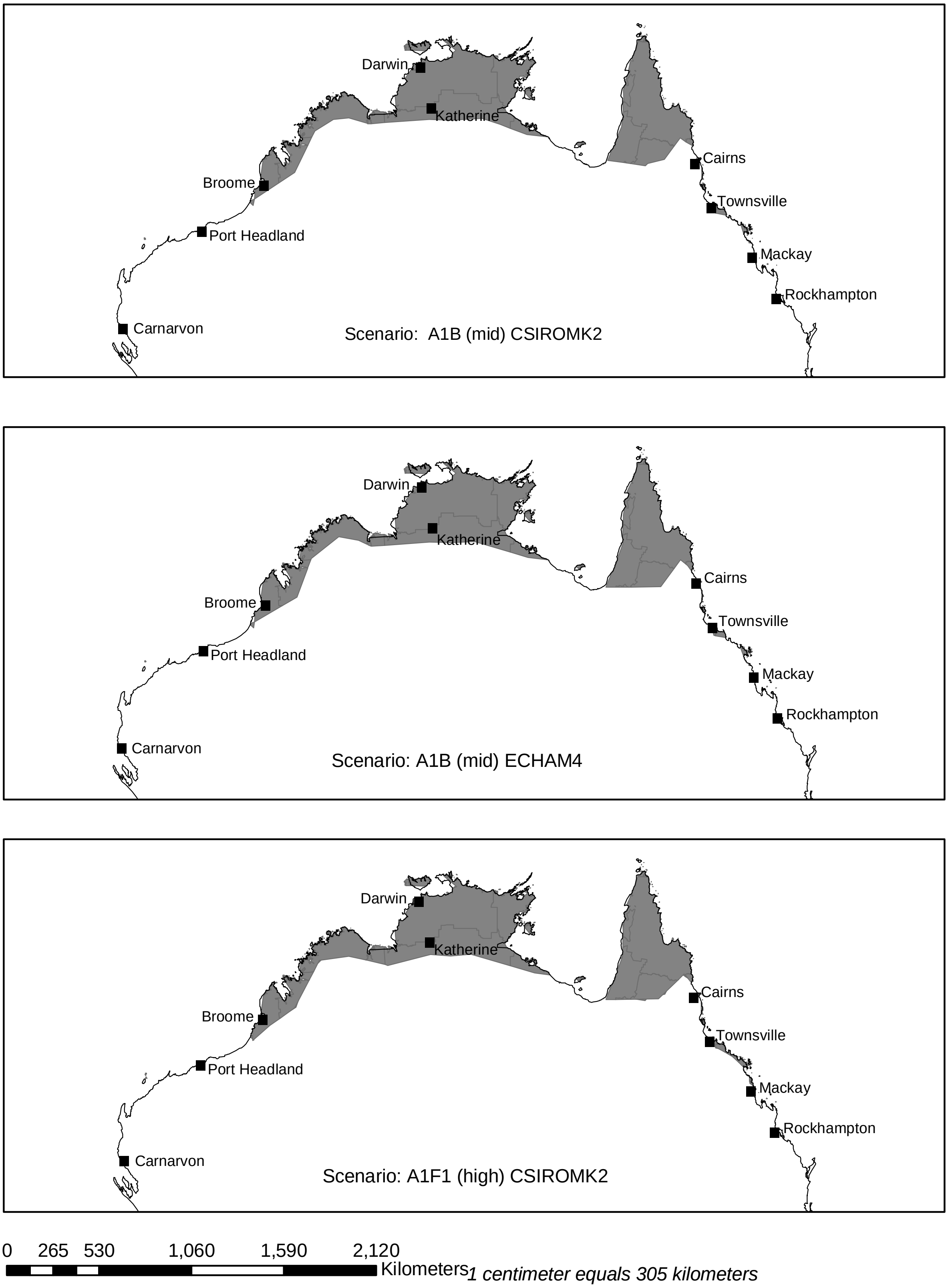


Figure 27 Estimated geographic region suitable for *Ae. aegypti*, under alternative climate scenarios for **2020**

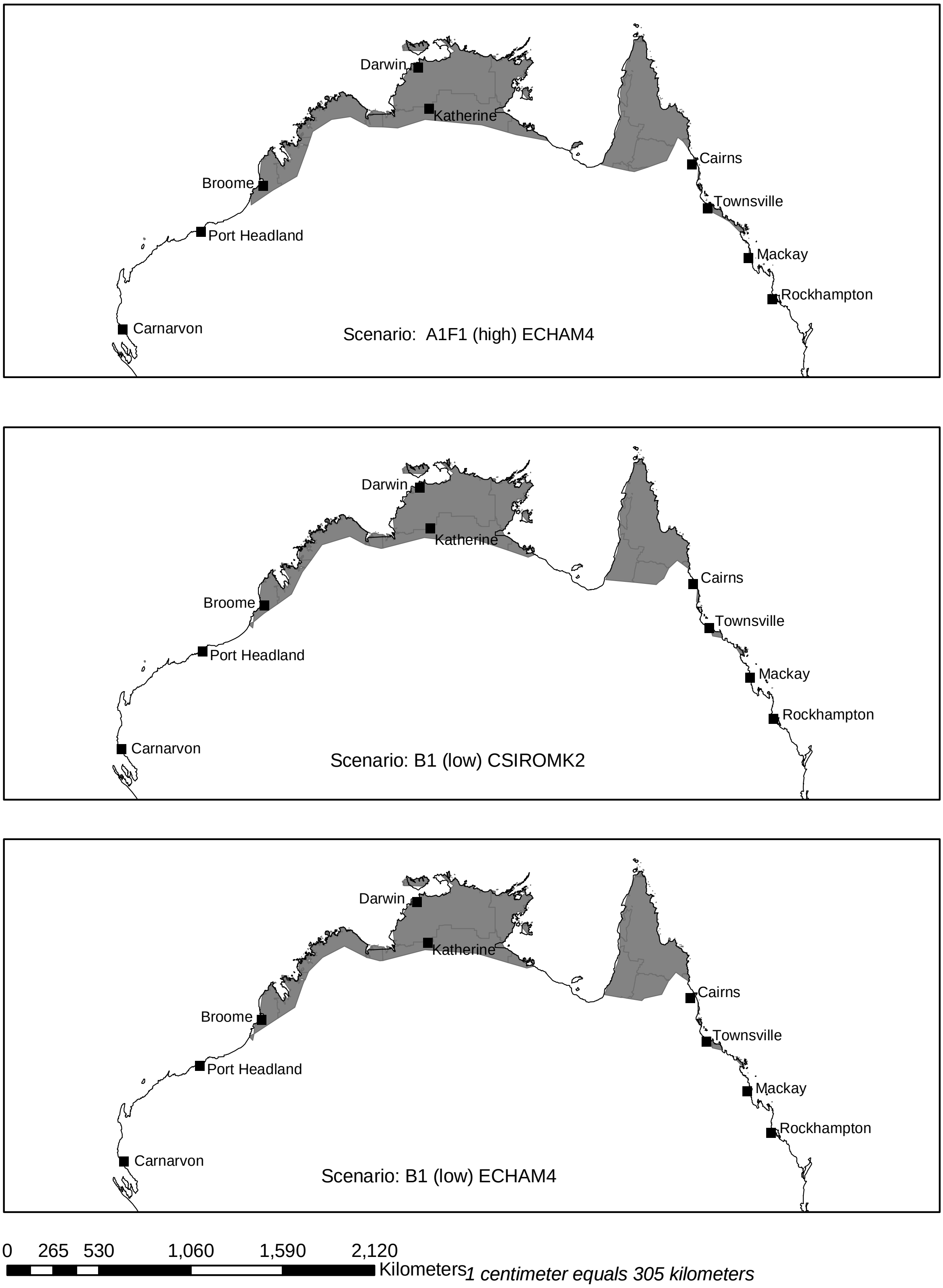


Figure 28 Estimated geographic region suitable for *Ae. aegypti*, under alternative climate scenarios for **2020**

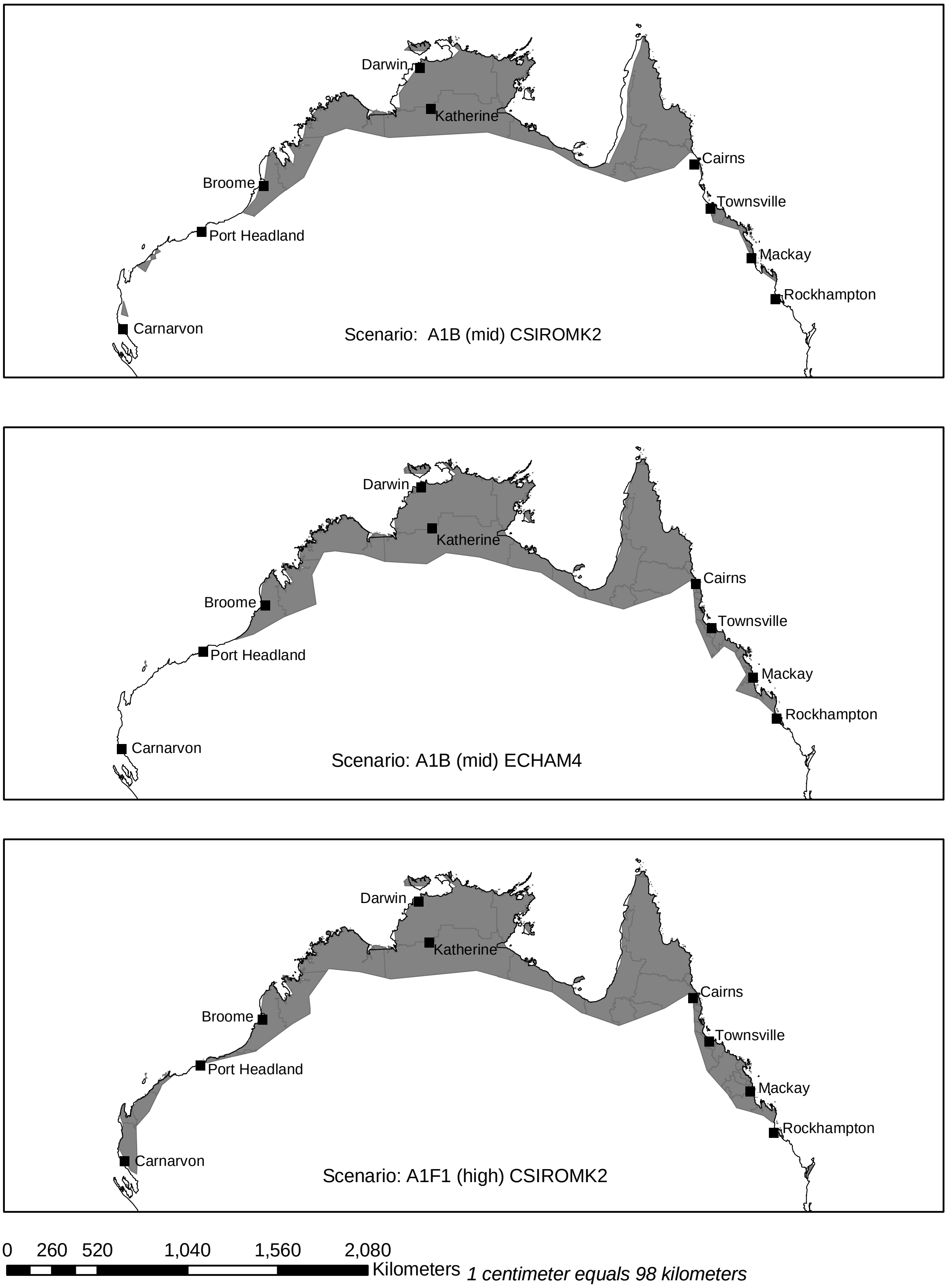


Figure 29 Estimated geographic region suitable for *Ae. aegypti*, under alternative climate scenarios for **2050**

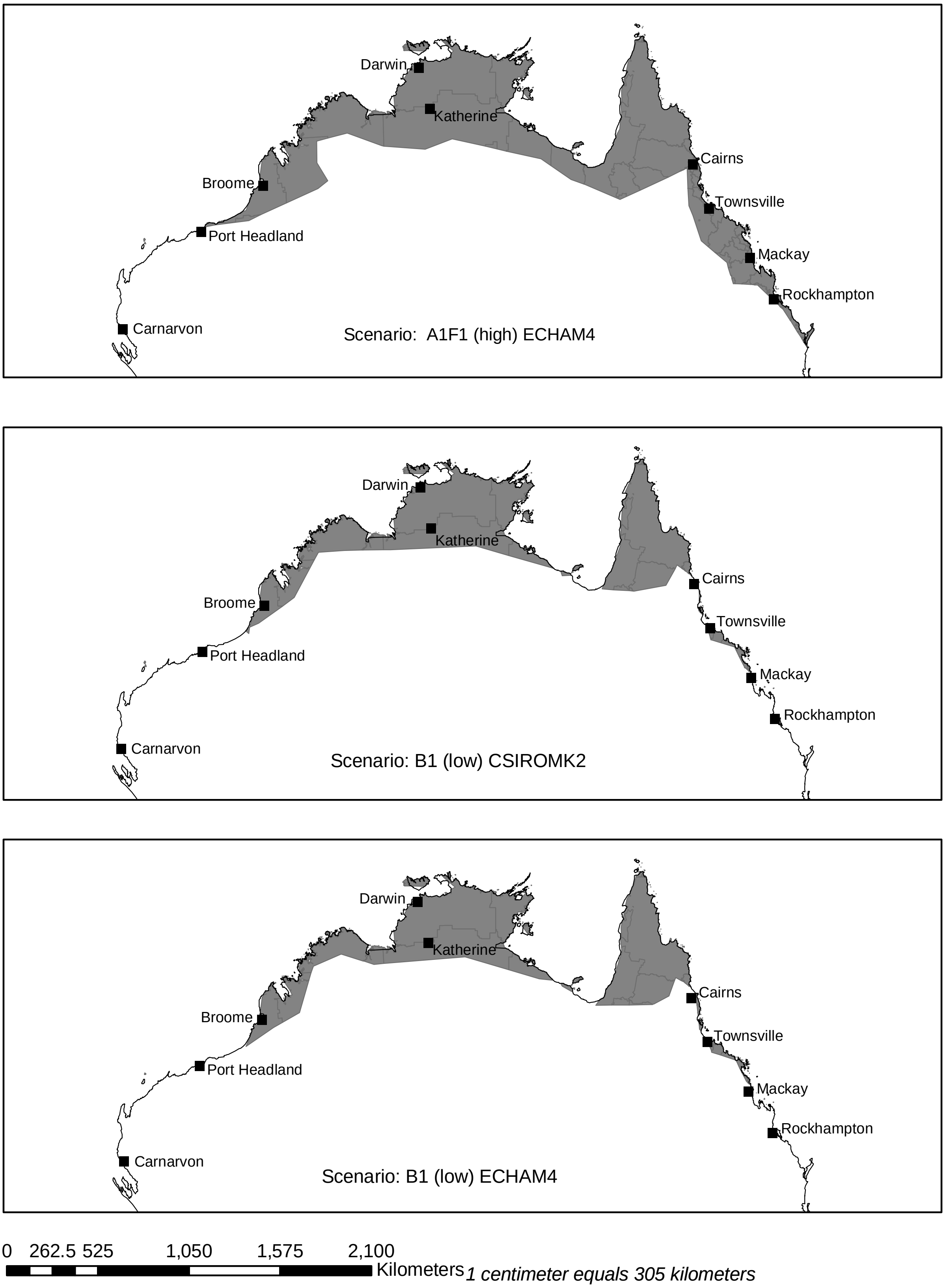


Figure 30 Estimated geographic region suitable for *Ae. aegypti*, under alternative climate scenarios for **2050**

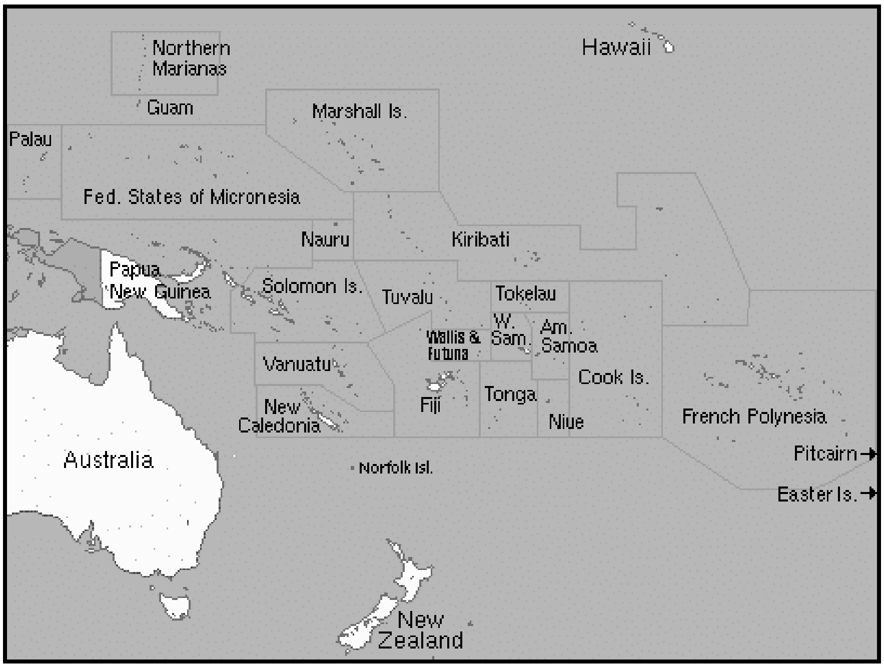


Figure 31 Map of the Pacific Islands countries

Table 22 gives probability estimates for the suitability of maintenance of the dengue vector for New Zealand and the Pacific Islands. New Zealand climate was not predicted to become suitable for maintenance of the dengue mosquito in the next 50 years. All Pacific regions are currently suitable for dengue transmission, and most of these countries were predicted to become more suitable in future.

Table 22 Estimates of the suitability of climatic conditions for the maintenance of *Ae. aegypti* in the baseline period, 2020, and 2050 (values greater than 0.5 indicate that climate is, or will be, suitable for dengue transmission)

COUNTRY	1961-1990	2020	2050
New Zealand	< 0.5	< 0.5	< 0.5
Cook Islands	0.84	0.89	0.90
Fiji	0.71	0.80	0.85
French Polynesia	0.76	0.83	0.87
Guam	0.95	0.97	0.98
Hawaii	0.59	0.70	0.77
Kiribati	0.92	0.96	0.97
Marshall Islands	0.93	0.96	0.98
Micronesia	0.94	0.97	0.98
Nauru	0.93	0.96	0.98
New Caledonia	0.52	0.62	0.69
Northern Mariana Islands	0.94	0.96	0.98
Papua New Guinea	0.68	0.75	0.79
Samoa	0.92	0.95	0.97
Solomon Islands	0.88	0.93	0.95
Tonga	0.89	0.93	0.94
Tuvalu	0.88	0.93	0.96
Vanuatu	0.75	0.84	0.88

7.5.4 Discussion

There are four main issues relating to the possible climate change-related public health impacts of dengue in Australia:

1 Will *Ae. aegypti* spread further south and west, so that the dengue-transmission zone encompasses more of the high-density populations on the eastern or even western seaboard?
2 What would be the annual cost – both in human cases and public health response – to an expanded climatically suitable zone for dengue transmission?
3 What would be the potential for an increase in the "transmission season" (the number of months where conditions are suitable)?
4 What would be the consequences if the exotic dengue vector, *Ae. albopictus*, became established in Australia?

Climate change is likely to increase the area of land with a climate suitable for *Ae. aegypti*, the main dengue vector in Australia. *Ae. aegypti*, given predicted vapour pressure constraints, may expand its range to include the towns southwest as far as Carnarvon, and southeast as far as Rockhampton, Bundaberg, Maryborough and Gympie. If no other contributing factors were to change, a larger number of Australians living in northern parts of Australia would be at risk of dengue infection – between 300-500,000 in 2020, and 750,000-1,600,000 in 2050.

These results predict that the risk of dengue transmission, based on climate factors alone, would increase (i.e., a greater geographic area was predicted to become suitable for transmission). However, this increase in risk need not necessarily translate into an increase of dengue cases, provided there is (i) a continuation and expansion of the public health response to dengue, and (ii) a continuation of quarantine efforts to ensure that the secondary dengue vector, *Ae. albopictus,* does not become established in the country.

Although both dengue and malaria are diseases with a human host and a mosquito vector, a number of factors combine to make dengue a greater public health threat than malaria. First, there is more potential for dengue outbreaks to spread rapidly within populations. Effective, fast-acting treatments are available for malaria that kill the parasite, and malarious people remain infectious for a much shorter period. No treatments are available that reduce the period of viraemia with dengue. Second, the dengue mosquito is a morning/evening biter that prefers to breed in the urban environment and to feed on humans. Prevention requires constant attention to clearing or treating domestic containers that hold water, such as buckets, potplant bases and tyres, and infrastructure such as sump pits and telecommunication pits, and to applying mosquito repellents during outbreaks. In addition, an appropriate design of potplant holders, rainwater tanks, sumps and telecommunication pits should be considered to make them less suitable as mosquito breeding sites. The malaria mosquito does not breed in urban environments and is a night biter, and bed nets provide a simple form of protection. For these several reasons, the risk of exposure is higher with the dengue vector.

The future capacity to reduce dengue transmission, and to minimise the risk of epidemics of dengue haemorrhagic fever and dengue shock syndrome, relates to the effectiveness of dengue prevention. In regions of Australia where climate conditions are currently suitable for dengue transmission, annual low case numbers are dependent on the vigilance of public health and local government authorities. In other words, the extent to which the public health burden of dengue remains relatively low would depend on the continued adequate financing of public health controls.

In the absence of a formal quantification of the current cost of dengue prevention in affected regions, an estimate of annual dengue-related expenditure for the Tropical Public Health Unit, Queensland Health, is presented (see box below). This unit, in conjunction with the local government authority, is responsible for annual dengue surveillance, monitoring, vector control, and preventive education in the North Queensland region.

RECURRENT DENGUE PREVENTION COSTS

Case Study: *Tropical Public Health Unit Network (TPHUN), Queensland Health, North Queensland*

The TPHUN covers the geographic region in the north from the Torres Strait through to Mackay in the south. The Unit has offices in Cairns, Townsville, Mackay and Mt Isa. The medical entomology group of the TPHUN spends an estimated $300,000 per year on dengue management. This money employs a team of three 'dengue action response team' (DART) workers who work full-time on dengue, two medical entomologists and a vector control officer (the latter three spend approximately 70% of their time on dengue). These staff are principally focused on disease surveillance (through tracking imported cases) and vector control (household spraying and backyard clean-up). In addition to wages, other major costs are for vehicle hire, building rental, travel, and pesticide use.

The TPHUN spends approximately $25-30,000 a year on health promotion, most of which is directed towards TV advertising. Additional dengue response costs not included in this analysis are: hospital costs relating to management of individual cases; laboratory testing; quarantine; and Australian military personnel prevention costs (relating to activities in the Townsville area). Together, the local councils (Cairns, Townsville, Thuringowa and Mackay) spend an additional $50-75,000 on dengue management in a typical year. During a dengue response, 4-8 Council staff would be diverted specifically to respond to the dengue risk. In summary, the Far North region spends a minimum of $350-400,000 per annum on dengue management (Ritchie, personal communication, 2002).

Present costs in the North Queensland region are in the order of $300-400,000 per annum (excluding individual hospital and GP costs, pathology, and quarantine surveillance) for a population of several hundred thousand people at risk of dengue transmission. This estimate also does not value the economic cost borne by individuals infected with dengue (such as number of days off work, visits to the doctor, treatment etc). By 2050 it was predicted that some 750,000 to 1,600,000 people may be living in a dengue transmission zone. Such an increase suggests that a concomitant increase in dengue management expenditure of 3-5 fold may be needed to maintain the current low level of dengue transmission, and that many other public health and local government areas may need to become involved in dengue risk management. The cost estimate assumes that there would not be any increases in risk management efficiency as the population at risk increases. This is probably reasonable, as the populations are disparate, and management programs would probably need to be established in additional regions. It also assumes the same rate of introduction of dengue into the region as at present.

Given the ability of *Ae. albopictus* to rapidly colonise vast geographic regions *(Mackenzie et al. 1996a)*, the possibility of its introduction into Australia provides a significant public health threat. Several interceptions of *Ae. albopictus* at Australian ports have been made by the Australian Quarantine and Inspection Service (AQIS), but all have been successfully erradicated (Ritchie et al. 2001). Continued surveillance programs, such as the port vector surveys conducted by AQIS, would be needed to ensure that the regular larval importations that are detected in northern Australian ports *(Mackenzie et al. 1996a)* do not lead to the permanent establishment of the vector.

Future Research

Climate is one of the fundamental drivers of vector and pathogen distribution and survival, and hence of epidemics of vector-borne diseases. The effect of climate becomes enhanced if adaptive measures falter or cannot be extended to the whole population. The potential future increase in the limits of dengue, although unlikely to lead to a large increase in cases, suggests the need to retain the high standard of public health services in currently affected regions, and to expand them into future affected regions (i.e., along the borders of the current distribution). Future populations are likely to become exposed to more than one dengue serotype, particularly with the risk of more imported cases resulting from aircraft travel. Hence, the need to improve risk communication is also likely to increase. Targeted prevention education, and evaluation of the effectiveness of prevention campaigns, would appear to be future research priorities.

It is important to note that this analysis did not provide any information about future changes in transmission season. The number of months where conditions are suitable for dengue transmission may extend, thus potentially increasing the frequency and severity of epidemics in a currently affected region. Both these factors warrant further investigation.

7.6 Diarrhoeal Disease

7.6.1 Reason for consideration

In general, the incidence of diarrhoea increases as the weather warms (the "seasonal effect"). Higher temperatures promote proliferation of bacteria such as *Escherichia coli* in contaminated foods *(Black 1995)*. Spore maturation of *Cyclospora cayetanensis* quickens as temperatures warm *(Smith et al. 1997)*. In Peru and Australia the incidence of cases of food-borne disease has been found to significantly increase in the summer months *(Lester 1997, Madico et al. 1997)*. High temperatures linked to El Niño were associated with marked increases in diarrhoea and dehydration in Lima, Peru *(Salazar-Lindo et al. 1997)*. A study in the UK *(Bentham and Langford 2001)* found the monthly incidence of food poisoning to be associated with temperature (especially in the previous month). Using data on the relationship between reported and actual numbers of cases of food poisoning, it was estimated that annually there might be an additional 179,000 cases of food poisoning by the year 2050 as a result of climate change *(Bentham and Langford 2001)*, assuming no adaptive measures were taken. Some diarrhoeal diseases are more prevalent in winter than summer. Globally, rotavirus is reported to be more common in the cooler months, although seasonal peaks of infection can vary broadly from autumn to spring, depending on the climate zone *(Cook et al. 1990)*. In most countries, food-borne disease is increasing due to changes in behaviour, food consumption, and commerce.

Droughts add to pressures on drinking water supplies, jeopardising both the quantity of flows and their quality. Following the complete failure of the wet season in Fiji in 1997-98, an inverse relationship was noted between the number of cases of diarrhoea and water availability *(Singh et al. 2001)*.

Excessive rainfall events, in certain watersheds, can transport faecal contaminants (human and animal) into waterways and drinking water supplies. People can also be exposed through recreational activities such as swimming *(Rose et al. 2001)*. Research in the United States has shown an association between intense rainfall events and outbreaks of campylobacteriosis *(Rose et al. 2001)*. One explanation for this finding is that heavy run-off may cause animal wastes to be washed into reservoirs in sufficient quantities to overwhelm treatment processes.

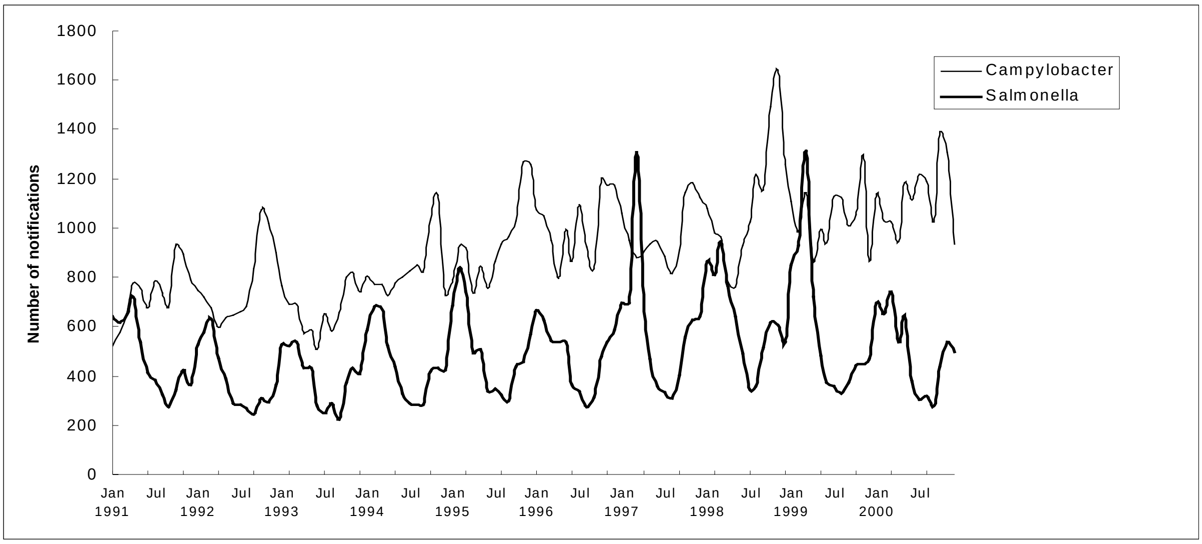
Similar studies have not been carried out in Australia, although a study of the Canberra water catchment region identified numbers of potential "pathogen hotspots" for the occurrence, survival and transport of pathogens *(Hanigan 2002)*. The number of hotspots would be critically impacted by frequent high-intensity rainfall events. The high density of farm animals in many parts of the country, and the fact that many communities rely on surface water sources, means that some Australian and New Zealand water supplies may also be at risk of contamination from this source following extreme rainfall events.

Coastal waters in Australia are sometimes contaminated with untreated sewage. Temperature changes also affect coastal water quality, with warmer sea surface temperatures favouring pathogen survival and proliferation *(IPCC 2001b)*. Extreme rainfall events may potentially increase nutrient levels in freshwater and seawater. It is possible that these combined effects may favour the production of harmful marine algal biotoxins (resulting in fish and shellfish poisoning) although these relationships require further elucidation (for a discussion see *IPCC 2001b)*.

Current Impacts in Australia

The most important pathogenic agents of diarrhoeal diseases in developed countries have been classified as: bacterial (*Campylobacter, Salmonella, E. coli,* and *Shigella*), viral (C*alicivirus, Rotavirus*), and parasitic (*Cryptosporidium, Giardia*) *(Tauxe and Cohen 1995)*. Gastrointestinal infections due to these organisms are transmitted from person-to-person (faecal-oral route, or respiratory), animal-to-person, or are food-borne or water-borne. Food-borne transmission is estimated to account for 35% of all diarrhoeal cases in the United States *(Mead et al. 1999)*. In Australia, an estimated 2-4 million cases of food-borne infectious disease occur annually *(ANZFA 1999)*.

Hall, D'Souza and Kirk *(Hall et al. in press)* reviewed the seasonality of food-borne disease notifications in Australia. They reported an upward trend in *Campylobacter* notifications between 1991 and 2000, while *Salmonella* numbers increased at first then stabilised in recent years (Figure 32). Notifications of *Salmonella* infections increased in summer, peaking in March.



Source *(Hall et al. In Press)*

Figure 32 Total number of notifications in Australia for *Campylobacter* and *Salmonella* by month, 1991-2000

For *Campylobacter*, notifications increased in spring, peaking in November. Much food-borne disease in the community is not reported to the notifiable system, since this depends on the affected person visiting a doctor, submitting a stool specimen, and obtaining a positive laboratory result that is notifiable *(Hall et al. in press)*. Thus, these figures are undoubtedly a large underestimate of the true incidence.

Prior to the 1970s, deaths due to diarrhoeal diseases showed a north-south gradient in Australia *(Gentilli 1979)*, erased principally due to improvements in medical care. Crude rates of salmonellosis notifications appear to show an increase with decreasing latitude and increasing average yearly temperatures along the eastern seaboard *(Hall et al. in press)*, although there is no strong evidence of this yet. This gradient in salmonellosis rates may be partly explained by other environmental factors, although it suggests a strong climatic influence.

Improvements in food practices and water sanitation in the last century have resulted in the control of some of the most deadly infections in the developed world *(Tauxe and Cohen 1995)*. In developing countries, economic status and educational level have been found to affect diarrhoeal incidence through behavioural factors (i.e., poor hygiene). Other factors such as sewage disposal, inadequate food storage and preparation, child feeding patterns, and lack of potable water also contribute to the high incidence of diarrhoea (reviewed in *Black 1995)*.

Housing and environmental infrastructure for people living in remote Aboriginal communities in Australia is often inadequate *(Bailie 2002)*. Ewald and Hall conducted a review of housing and health in a remote Central Australian Aboriginal community *(Ewald and Hall 2001)*. They noted that while many studies have documented poor environmental conditions and poor health amongst Aborigines, few have systematically demonstrated a causal association between the two. Nonetheless, the quantity of anecdotal evidence is persuasive, and numerous ethical and methodological issues stand in the way of traditional epidemiological studies being conducted in these communities. A recent study of 155 communities in Western Australia found that over 30% had water supply or sanitation problems, and 30% had waste disposal difficulties and a problem with pests *(Gracey 1997)*. Rates of salmonellosis are much higher in the Northern Territory and northern Western Australia, where remote Aboriginal populations comprise a significantly higher proportion of the total state population compared to the southern States of Australia *(Roche 2001)*.

7.6.2 Method of analysis

In their assessment of the global burden of disease due to climate change, McMichael, Campbell-Lendrum and others *(2002)* noted several uncertainties in estimating the magnitude of effect of climate change on diarrhoeal incidence:

- The sites from which these relationships are defined cover only a small part of the spectrum of global climate variation. Different relationships may apply at higher, or particularly lower, temperatures.
- The relative importance of different pathogens and modes of transmission (e.g. via water, food, insects or human-human contact) varies between locations, and is heavily influenced by level of sanitation *(Black 1995)*. This will cause geographical variation in the relative importance of various pathogens, which are known to vary in their response to climate (e.g. *Cook et al. 1990)*.

- While several studies describe climate effects on particular diarrhoeal pathogens (e.g. *Eberhard et al. 1999, Konno et al. 1983, Purohit et al. 1998)*, these cannot be directly used to estimate effects on diarrhoeal disease without information on (i) their relative contribution to overall disease incidence, and (ii) equivalent data on climate-sensitivity and relative prevalence for all other diarrhoea pathogens.
- Despite convincing evidence on the effect of extreme rainfall on water-borne outbreaks of diarrhoea *(Curriero et al. 2001)*, this cannot easily be generalised without information on the relative contribution of such outbreaks to overall diarrhoea incidence.
- Rainfall effects on overall diarrhoea (where observed) are non-linear, and cannot easily be extrapolated to other regions.

This analysis likewise takes the approach of McMichael and others, and conservatively restricts analysis to the effect of increasing temperatures on the incidence of all-cause diarrhoea, making no prediction of the effect of changing rainfall patterns.

Dose-response relationship

A quantitative analysis of the relationship between climate and the incidence of diarrhoea has not been conducted in developed countries. Due to the comparative wealth of developed versus developing countries, their access to sanitation infrastructure, education, and higher standards of housing, it was not appropriate to generalise the results from the Peruvian or Fijian studies to the broad Australian population. Living conditions and access to services in many remote Aboriginal communities of Australia are extremely poor, however, and it is reasonable to compare their facilities and capacity to adapt with that of people living in developing nations. Consequently, this analysis examined the impact of increasing temperatures on the incidence of severe all-cause diarrhoeal disease for Aboriginal people living in central Australia.

Checkley and others *(Checkley et al. 2000)* used time series models to analyse the impact of ambient temperature and relative humidity on daily hospital admissions of diarrhoea in children under 10 years in Lima, Peru. The daily number of admissions for diarrhoea was linearly related to ambient temperature and relative humidity. For every 1°C increase in ambient temperature there was an associated 8% (CI 7-9%) increase in the number of admissions. Relative humidity was highly correlated with ambient temperature, and had no significant independent association with hospital admissions. Further, temperature was seasonally related to diarrhoeal increases. An increase of 1°C in the cooler months had a greater effect on admissions (12% more cases) than the same increase in the summer months (4% more cases). The mean ambient temperature in Lima during the study period ranged from 16-19°C in winter (May to November), and from 20-26°C in summer (December to April) *(Checkley et al. 2000)*. Rainfall is extremely low in the city (on average 10mm per year). In central Australia, the temperatures are slightly more extreme, although the pattern is similar: mean temperature ranges from 13-20°C in winter (May to September), and from 22-29°C in summer (October to April). The region is classified as arid, with an average annual rainfall of 300mm.

Singh and others studied the relationship between diarrhoeal incidence and temperature and rainfall in Fiji over a twenty year period *(Singh et al. 2001)*. There were positive associations between diarrhoea and temperature and extreme rainfall. The reported incidence was of a 3% (CI 1.2-5%) increase in cases for each 1°C increase in temperature in the previous month (i.e., temperature had a lagged effect). Incidence also increased with extremely high rainfalls (presumably due to water contamination from flooding) and low rainfall (due to interrupted water supply, and resultant poor hygiene). This study lacked a clinical or laboratory definition of diarrhoea, and had no information on the age distribution of cases.

For the purpose of this analysis, it was assumed that diarrhoea among Aboriginal people living in the central Australian region was likely to respond to increases in temperature in the same manner as has occurred in populations in Lima, Peru, and in Fiji. The mid-point estimate of the two studies was used to provide the dose-response relationship. That is, a 5% increase in risk of severe diarrhoea was assumed for each 1°C increase in predicted future temperatures. Relative risks were calculated by multiplying the projected increase in temperature by the dose-response value. The resulting increase in relative risk was multiplied with the baseline annual diarrhoeal admission estimate to provide an estimate of the possible future numbers of admissions.

Data

The Northern Territory Department of Health and Community Services provided records of all diarrhoeal admissions to the Alice Springs hospital for children under 10 years of age from December 1996 to June 2002 (5.5 years). In addition to date of admission, the age, sex, and Aboriginal status of the child were recorded.

A diagnostic description for each case provided some information about the causative agent. It was assumed that diarrhoea responded to temperature in a similar manner for both sexes and all ages. The Alice Springs hospital receives patients from a large catchment area, ranging from as far north as Tennant Creek, west into the Gibson Desert, south to the northern parts of South Australia, and east to communities on the edge of the Simpson Desert. The Northern Territory's Alice Springs Health Region boundary was used to approximate this region. Summary annual temperature and rainfall averages were estimated for the region, using data supplied by the CSIRO in OzClim, for future time points and alternative scenarios (see Section 6.2).

An incidence rate could not be estimated for this region due to the lack of an available denominator population. In addition to the unknown true extent of the Alice Springs hospital catchment area, estimating population numbers for remote Aboriginal settlements is extremely difficult due to the constant movement of people between settlements (Gillian Hall, personal communication, 2002). This analysis provides an estimate of the current extent of severe diarrhoeal disease among Aboriginal people in central Australia, and of the likely increase in diarrhoeal admission numbers. It does not account for changes in population size or distribution in future, changes in infrastructure (such as improvements to housing and water supply), changes in diarrhoeal interventions, etc.

7.6.3 Findings

3824 diarrhoea episodes in children aged less than 10 years were recorded at the Alice Springs hospital between December 1997 and June 2002. Of these, 90% (3434) recorded an Aboriginal status. Cases were evenly distributed by sex, with only slightly more boys (52%) than girls. The majority of admissions were children aged less than two years old (79%). Only 3% of admissions were children aged five and over (see Figure 33).

On average, there were 624 (range 504-675) episodes of diarrhoea recorded among Aboriginal children at the Alice Springs hospital each year. There appeared to be a seasonal pattern to admissions, with a peak between the months of March and May (Figure 34), and lowest numbers between July and September in most years (Figure 35 is a time-series of monthly admissions over the period). Long-term mean temperatures for the region typically peak in the months of December to February (28°C), and are lowest from June to August (13°C).

Given assumptions relating to future climate projections, the mean annual temperatures for the region are projected to increase by 2020 by 0.5-1.0°C, and by 2050 by 1.0-3.5°C. This was predicted to translate to an increase of 3-5% in diarrhoeal admissions by 2020, and of 5-18% by 2050, relative to the baseline. Thus, expected cases were predicted to increase to some 640-660 by 2020, and to some 660-730 by 2050.

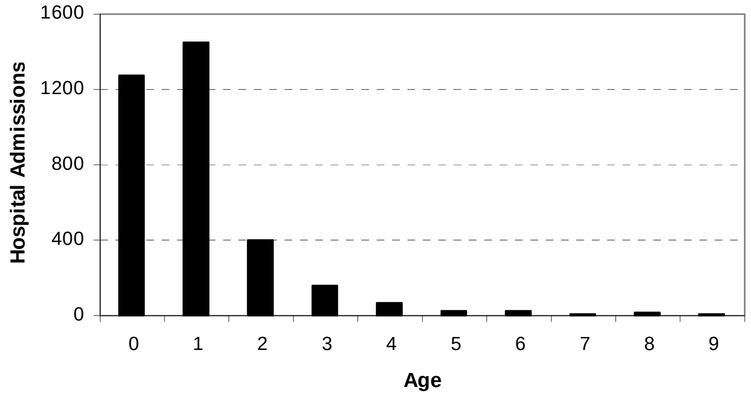


Figure 33 Age distribution of Aboriginal diarrhoeal admissions (children aged < 10 years) to Alice Springs hospital, December 1996 to June 2002

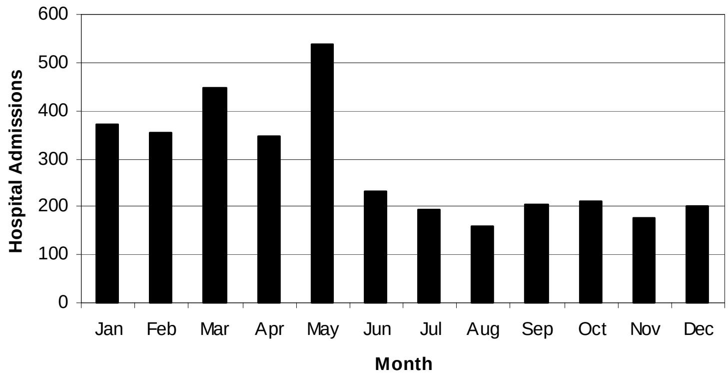


Figure 34 Monthly numbers of Aboriginal diarrhoeal admissions (children aged < 10 years) to Alice Springs hospital, December 1996 to June 2002

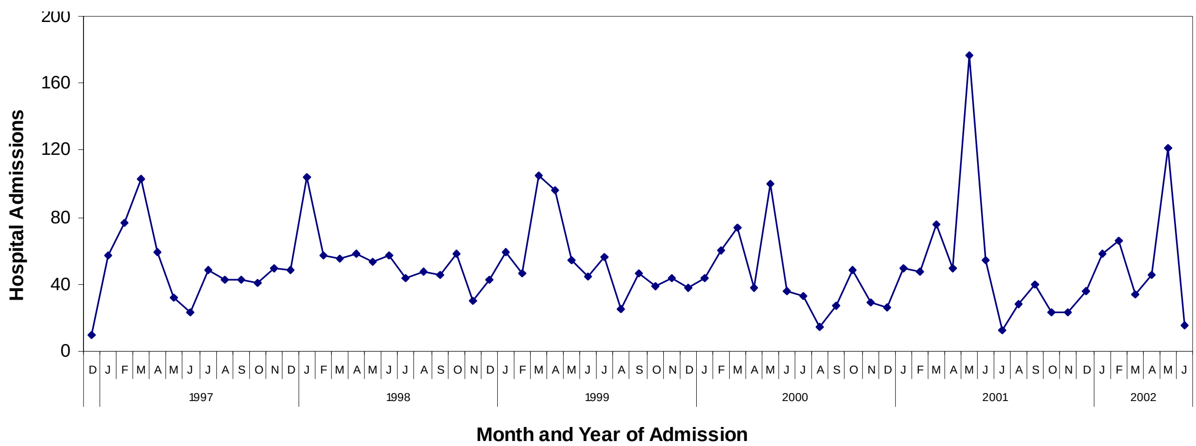


Figure 35 Monthly time-series between December 1996 and June 2002 of Aboriginal diarrhoeal admissions (children aged < 10 years) to Alice Springs hospital

Table 23 Estimates of the relative risk and number of expected cases of diarrhoea hospital admissions in Aboriginal people (for alternative climate scenarios, relative to baseline climate)*

Scenario		Temp. increase °C	Relative risk	Expected cases*
Baseline		–	–	624
2020				
Mid	*CSIROMk2*	0.6	1.03	643
	ECHAM4	0.8	1.04	649
High	*CSIROMk2*	0.8	1.04	649
	ECHAM4	1.0	1.05	655
Low	*CSIROMk2*	0.5	1.03	640
	ECHAM4	0.6	1.03	643
2050				
Mid	*CSIROMk2*	1.9	1.10	683
	ECHAM4	2.4	1.12	699
High	*CSIROMk2*	2.8	1.14	711
	ECHAM4	3.5	1.18	733
Low	*CSIROMk2*	1.0	1.05	655
	ECHAM4	1.3	1.07	665

* These estimates assume baseline population size and age distribution, and no change in other diarrhoea risk factors (such as interventions to prevent diarrhoea).

7.6.4 Discussion

The seasonal pattern of diarrhoeal hospital admissions in children less than 10 years of age in Alice Springs is similar to that observed in Lima, Peru. Peak admissions occurred with a 1-2 month lag following peak summer temperatures, and admission numbers dropped sharply as average monthly temperatures dropped in winter. The predicted increase in admissions was relatively insignificant by 2020. By 2050, however, an annual increase in admissions of 11% (5-18%) was predicted. These admissions represent the most severe diarrhoeal cases among Aboriginal children in the central Australian region (i.e., those serious enough to result in hospital admission). The impact of rising temperatures on the transmission pathway leading to less severe diarrhoea (i.e., not requiring hospitalisation) is not clear, although it is biologically plausible to assume a similar order of magnitude increase in the number of cases.

This analysis estimates Aboriginal diarrhoeal admissions in central Australia in the future, based on the current incidence of admissions. This is likely to be conservative, as natural growth appears to be higher for Aboriginal Australians than it does for the total Australian population (Australian Bureau of Statistics media release, 30 March 1998). In addition, growth patterns vary regionally, and the fertility rate for Aborigines in Central Australia is likely to be higher than for elsewhere. The baseline incidence (independent of climate change) would vary over time, and could be expected to decrease with economic development and improvements to sanitation and hygiene.

Climate is only one of the many environmental and social factors that have been related to the incidence of diarrhoeal disease. Water quality depends not only on weather events, but also on the management of water resources, and the disposal of sewage into fresh and seawater bodies. As coastal populations increase, so does the level of sewage produced. Recent conflict over sewage disposal into seawater off Sydney's beaches, for example, highlights the potential health risks associated with increasing urbanisation in Australian cities.

Although this analysis has focused on remote Aboriginal issues, other communities in Australia may also be at greater risk of diarrhoeal disease as temperatures rise. Successful adaptation to these conditions would require the continued upgrading of sewerage systems and safe food storage infrastructures. However, food contamination typically occurs early in the production process, rather than just before consumption, and increasing trends in food importation mean that improved surveillance and preventive measures would also be needed *(Tauxe 1997)*.

8. OTHER HEALTH IMPACTS

8.1 Ross River virus disease

Ross River virus (RRv) is an arbovirus that is widely distributed throughout Australia. It has also been reported in many Pacific island countries including Papua New Guinea, the Solomon Islands, American Samoa, Fiji, New Caledonia and the Cook Islands *(Aaskov et al. 1981, Rosen et al. 1981, Scrimgeour et al. 1987)*. The virus can cause epidemic polyarthritis, which consists of arthritic symptoms that persist for several months and can be severe and debilitating. In some people the disease has been reported to linger for years *(Westley-Wise et al. 1996)*. The disease is a significant public health issue in Australia, with 51761 notifications from 1991 to 2002 (an average of some 4500 cases per year). There is no treatment for the disease and, in the absence of a vaccine, prevention remains the sole public health strategy.

The epidemiology of Ross River virus disease varies across Australia *(Russell 1994)* reflecting the multiple vector and host species implicated in transmission, and the impact of diverse climatic and environmental conditions on their biological processes. The primary enzootic cycle is between reservoir vertebrate hosts (typically marsupials) and the mosquito vector. Given low immunity in the host population and suitable climatic conditions, massive virus amplification occurs, resulting in a spillover of infection into human populations. Unlike some other vector-borne diseases, numerous mosquito species are believed to be capable of transmitting the virus, and many different hosts have been suggested. In tropical and sub-tropical regions temperature and rainfall levels enable adult vectors to remain active all year *(Kay and Aaskov 1989)*, a continuous transmission cycle results, and the disease is endemic. In colder, temperate regions, mosquitoes are active only during the warmer months (Nov-Apr) *(Dhileepan 1996)*, and viral activity is typically epidemic.

Several studies have identified a relationship between single climate variables and breeding and survival of the RRv vector mosquitoes *(Dhileepan 1996, Lindsay et al. 1989)*. The complex ecology of RRv has meant that, to date at least, analyses of the climate-disease relationship are confined to the local or regional level. Woodruff and others *(Woodruff et al. 2002)* modelled the association between climate variables and epidemics of RRv disease in the Murray region, and found a strong relationship between heavy rainfall and outbreaks of disease. They concluded that early warning of weather conditions conducive to outbreaks of RRv disease was possible at the regional level with a high degree of accuracy. Rainfall, temperature and tides have been associated with monthly case incidence in Queensland *(Tong et al. 2002)*, and El Niño-Southern Oscillation has showed some promise as a predictor of RRv disease epidemics in south-eastern States *(Maelzer et al. 1999)*.

8.1.1 Possible impact of climate change

More frequent extreme rainfall events are predicted in future (even in regions where average annual rainfall may decrease by up to 5%). In relation to RRv disease, Russell has speculated that *Ochlerotatus* (previously included in the *Aedes* genus) populations in dry areas may be adversely affected by decreased winter rainfall, possibly delaying or precluding virus activity *(Russell 1998)*. Conversely, the predicted increase in summer rainfall may increase the availability of mosquito habitat that, combined with higher average temperatures, may lead to higher humidity, a lengthened season of abundance and greater transmission levels *(Russell 1998)*. Rising temperatures on their own, without an accompanying increase in rainfall in a region, are unlikely to lead to an increase of RRv disease in most parts of Australia.

In New Zealand, a key issue for the health sector is how to prevent the establishment of exotic disease-carrying mosquitoes. *Oc. camptorhynchus*, a competent mosquito vector for Ross River virus, became established in Napier in 1998 and an eradication program commenced in 1999.

In summary, rising temperatures and changing rainfall patterns are likely to have significant impacts on the epideniology of RRv disease. These impacts would vary by geographical area. In view of the dynamics of transmission for this disease, more research is required at the regional level into the ecology of the virus, its hosts and vectors, and the impact of human activities (such as environmental modification, vector control and preventive education) on reducing the risk of infection *(Tong et al. 2002)*. Modelling of the relationship between climatic factors and disease outbreaks will help in the prediction of future potential consequences of climate change.

8.2 Increased exposure to solar ultraviolet radiation

Stratospheric ozone destruction is essentially a separate process to greenhouse gas accumulation. However, greenhouse gas warming of the troposphere appears to be linked to cooling of the stratosphere *(IPCC 2001b)*. The link with climate change, appreciated only recently, is that lower temperatures in the stratosphere may accelerate the destruction of ozone by chlorofluorocarbons (CFCs). Although emissions of ozone-depleting chemicals such as CFCs have fallen significantly because of international agreements, global climate change may delay recovery of the stratospheric ozone. High levels of ultraviolet radiation will continue to pass through to Earth's surface for longer than would occur without climate change.

The effects of solar ultraviolet radiation on skin cancer, skin ageing, and cataracts of the eye are important public health issue in Australia and New Zealand, which have the highest skin cancer rates in the world *(Marks et al. 1989)*. These high rates cannot be attributed to relatively recent phenomena such as ozone depletion or climate change because of the relatively long incubation time of serious skin cancer forms such as melanoma. Much of the risk is likely to be due to a predominantly pale-skinned population living in an environment with relatively low air pollution, plentiful sunlight and an outdoors-oriented lifestyle *(Armstrong 1994)*. In a warmer world, patterns of exposure to solar radiation can be expected to change (such as an increase in swimming and other outdoor activities). These behaviours do signal a high degree of vulnerability to prolonged elevated levels of UV radiation *(McKenzie and Elwood 1990)*. The present levels of UV radiation have been increasing for the past 20 years *(McKenzie et al. 1999)*, and it is expected that the incidence of melanomas and other skin cancers will increase as a result of increasing UVR *(Longstreth et al. 1998)*. Preliminary evidence also suggests that higher environmental temperatures enhance UV carcinogenesis; if this were true, the effect of rising temperatures on skin cancer incidence may soon be greater than that of ozone depletion *(Leun and Gruijl 2002)*.

8.3 Respiratory diseases

Asthma is a major health concern in Australia, with a prevalence that is one of the highest in the world *(AIHW 2000)*. Asthma became a National Priority Health Area in Australia in 1999. Studies of the prevalence of asthma in New Zealand have shown an association with average temperature *(Hales et al. 1998)*. Predicted changes to the Australian climate will certainly influence the life cycle of a range of plants and animals that have been linked to asthma occurrence *(Curson 1993)*.

However, although there is a demonstrated relationship between many allergen-producing organisms such as plants, mould, house mites and cockroaches, and climatic factors such as humidity, rainfall, temperature and sunshine *(Beggs 2000)*, the mechanism for the relationship between climate and asthma is contradictory and not well understood *(Koren 1997)*.

Because of the multicausal nature of asthma initiation, it is not clear how climate change would affect this disease. Further research into general allergies and asthma, including their seasonal and geographic distribution, is required.

8.4 Tropical cyclones and major bushfires

8.4.1 Cyclones

Current areas vulnerable to cyclones in Australia are the east and north coasts of Queensland, the coast of the Northern Territory, and the north-west coast of Western Australia (Figure 36). Vulnerability decreases quite strongly moving southwards of these regions, with the exception of the cyclone alley region near Onslow, Western Australia *(Walsh et al. 2001)*. In the future, the main public health challenge in terms of tropical cyclone risk would probably be the fast population growth in the tropical regions of Australia, particularly the east coast of Queensland. This would strongly increase the people and infrastructure that are vulnerable to tropical cyclones (Walsh, personal communication, 2002).

Current knowledge of the effect of climate change on tropical cyclones in the Australasian region *(Walsh et al. 2001)* can be summarised as follows:

1 No increase in the regions of cyclone formation is suggested.

2 Possible changes in cyclone numbers is uncertain at this time – tropical cyclone numbers off the coast of Queensland (the main vulnerable area) are closely tied to whether the climate is in an El Niño or La Niña state (i.e., they are more prevalent with a La Niña, or "wet" event). However, the effect of climate change on El Niño cycles is yet unclear.

3 There appears to be no substantial evidence that tropical cyclones will travel further south than at present, although the possibility cannot be excluded.

4 Increases in the maximum intensities of storms are likely, possibly in the range of a 5-10% increases in wind speeds.

8.4.2 Bushfires

Approximately 80% of Australia's population live along the coastal strip from Brisbane to Adelaide, in one of the most fire-prone regions of the globe *(Cunningham 1984)*. This region has mild wet winters, long hot summers, and highly flammable fire-adapted vegetation (Coates 1999).

Bushfires have claimed more lives in recent years than any other natural hazard in Australia (Coates 1996). The total number of people killed by bushfires in Australia during the years 1960 to 2001 was estimated at 224 (Table 24). Slightly more than 50% of these bushfire-related deaths were in Victoria, which has been the case since at least 1827 (Natural Hazards Research Centre). The frequency and intensity of bushfires appears to have increased in recent years, while the risk of death has not. This is largely due, it seems, to improved evacuation techniques, public education, and communication *(Coates 1996)*.

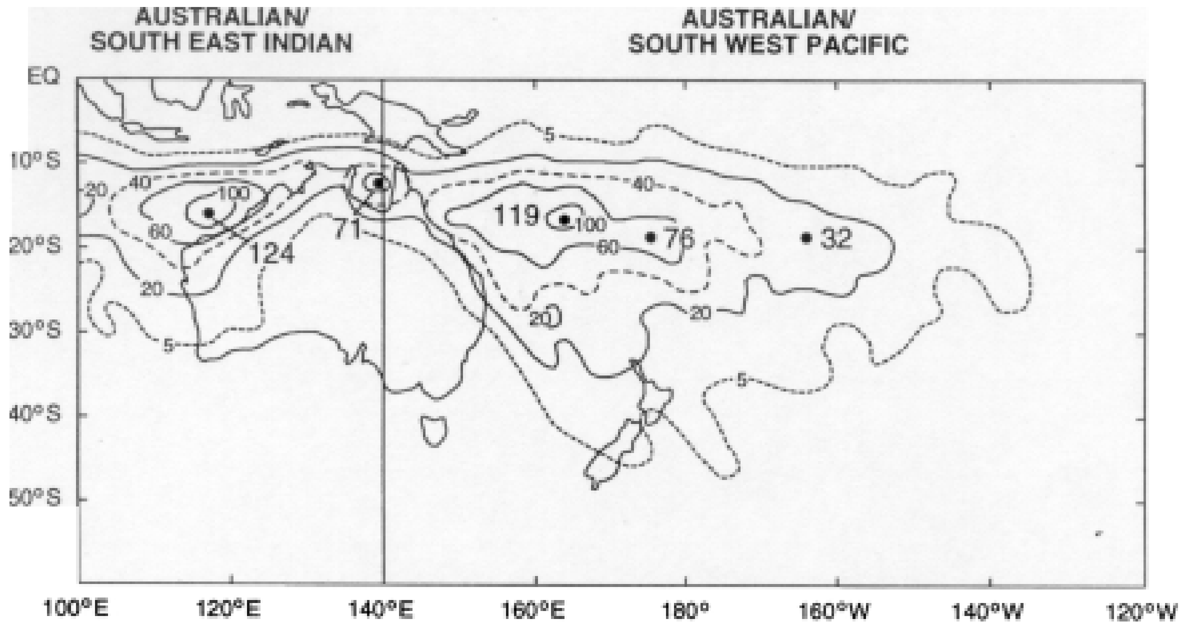


Figure 36 Frequency of tropical cyclones per 100 years, passing within 75 nautical miles (139 km) from a given point in the Australia/South Indian Ocean region (from (McBride 1993), after (Neumann 1993).

Table 24 Estimated deaths, injuries and costs associated with bushfires in Australia, 1960-2001

State	Total Deaths	Total injuries	Total costs ($m)
VIC	116	2025	1120
SA	62	1390	580
TAS	28	900	400
NSW	18	190	275
ACT	0	0	100
WA	0	0	0
QLD	0	0	0
NT	0	0	0
National	**224**	**4505**	**2475**

Source: EM-DAT database *(OFDA/CRED 2002)* and the Emergency Management Australia database *(Emergency Management Australia 2002)*. See Section 7.2 for a discussion of the methods used to derive these figures.

Williams and others *(2000)* assessed potential changes in fire danger using simulated weather data from the CSIRO9 climate model for present (circa 1990) and enhanced greenhouse conditions (circa 2050). The authors assessed changes in the Forest Fire Danger Index (FFDI) due to climate change at eight sites: Katanning (Western Australia), Normanton (northern Queensland), Miles (southeast Queensland), Alice Springs (Northern Territory), Hobart (Tasmania), Mildura and Sale (Victoria). The frequency of the "very high" FFDI category at Sale, Victoria, was predicted to double by around the year 2050. Since that analysis, CSIRO has developed the Mark 2 and Mark 3 versions of the climate model, considered to be better than the CSIRO9 *(Hennessy personal communication, 2002)*. However, output from these models (and overseas models) has not been used in an updated fire impact assessment.

The expansion of urban settlements into bushland settings on the fringe of cities may constitute future populations at risk. An updated assessment of the impact of climate change on fire danger is needed for Australia.

9. PACIFIC ISLAND HEALTH ISSUES

In terms of public health in general – and the planning and provision of health services in particular – it is important to consider the possible implications of climate change and sea-level rise on Pacific Island countries. These have been identified as being among the countries most vulnerable to climate change,[1] and it is anticipated that they will experience some of the earliest and most severe consequences over the next two centuries *(Burns 2002, IPCC 2001a)*.

The Pacific Islands consist of nearly 30,000 islands, of which about 1,000 are inhabited by Polynesian, Melanesian and Micronesian peoples (Figure 37 and Table 25). Excepting Fiji and Papua New Guinea, the rest of the Pacific Islands fall within the United Nations definition of "small island states": that is less than 10,000 square kilometres in size, and inhabited by less than 500,000 people *(Pernetta 1988)*.

Sea-level rise – the most significant climate-related projection for small islands *(IPCC 2001c)* – and extreme weather events, such as tropical cyclones, floods and droughts, have wide reaching and multiple adverse societal, environmental and economic effects (summarised in Table 26).

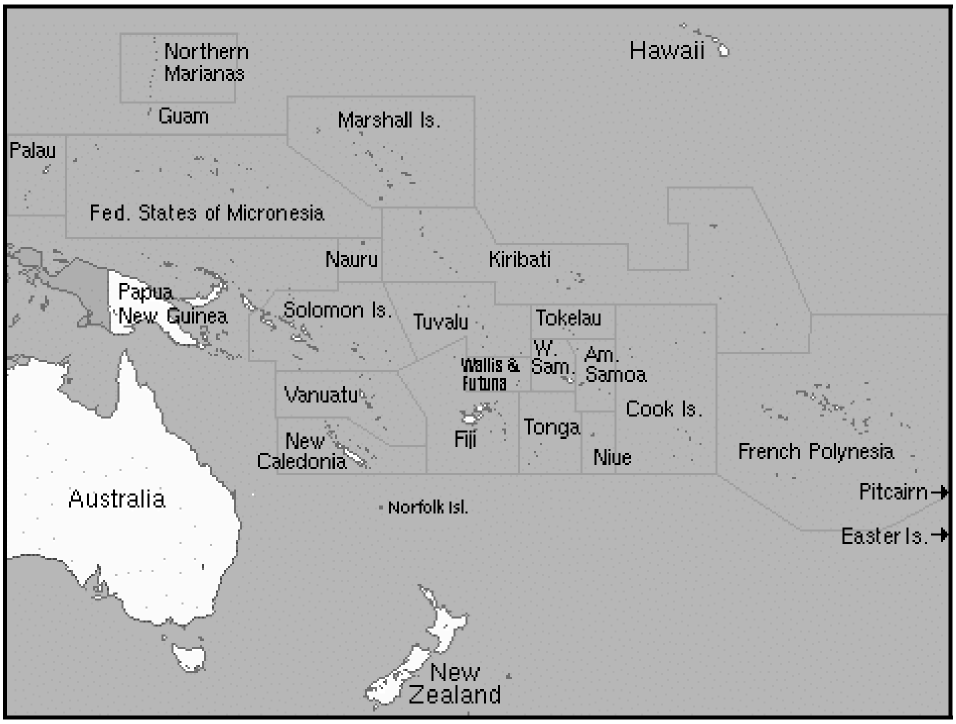


Figure 37 Map of the Pacific Islands countries

[1] An assessment of the level of vulnerability of the Pacific Islands needs to consider economic and socio-cultural characteristics, as well as constraining factors such as geographic size, elevation, limited resources, proneness to natural hazards, dependence on external markets and population growth rates (Alm et al. 1993; SPREP 1996).

Table 25 Basic demographic and political profile of the Pacific Island states

Country	Political Status	Population (1996)	Land Area (km^2)	Population Density
American Samoa	Territory of the United States	58,900	200	234
Cook Islands	Self-governing, in free association with New Zealand	19,900	237	79
Easter Island	Overseas territory of Chile	2,500	166	15
Micronesia	Independent Nation	109,200	701	149
Fiji	Independent Nation	800,500	18,272	39
French Polynesia	Overseas territory of France	220,000	3,521	54
Guam	Territory of the United States	153,700	541	246
Kiribati	Independent Nation	78,400	811	89
Marshall Islands	Independent Nation	57,400	181	240
Nauru	Independent Nation	11,200	21	472
New Caledonia	Overseas territory of France	196,800	19,103	9
Niue	Self-governing, in free association with New Zealand	2,300	259	9
Northern Mariana Islands	Commonwealth in political union with the United States	62,700	471	92
Palau (Belau)	Independent Nation	17,700	488	31
Papua New Guinea	Independent Nation	4,141,800	462,243	8
Pitcairn	Overseas territory of the United Kingdom	47	5	11
Samoa	Independent Nation	165,100	2,935	55
Solomon Islands	Independent Nation	395,200	28,530	10
Tokelau	Territory of New Zealand	1,500	10	158
Tonga	Independent Nation	90,000	747	127
Tuvalu	Independent Nation	9,600	26	348
Vanuatu	Independent Nation	173,900	12,190	12
Wallis & Futuna	Overseas territory of France	14,800	255	54

Source: (1) Pacific Islands Populations Data Sheet 1996, Noumea, Population Demography Programme, South Pacific Commission, http://library.kcc.hawaii.edu/psiweb/pacific/pac_isl/pac_isl8.html. Site visited July 2002. (2) US Central Intelligence Agency, *The World Factbook 2000*, http://www.odci.gov/cia/publications/factbook. Site visited July 2002.

9.1 Human health issues

Climate change effects such as heat waves, cyclones, droughts, floods, storm surges, and landslides present threats to population health from directly related injuries, illnesses and mortality. The Pacific Islands are particularly vulnerable to extreme events, a function of their specific hazards (earthquakes, volcanic eruptions, cyclones, tsunamis and landslides), and location of infrastructure and productive activities in areas that are disaster prone *(Kreimer 2001)*. Even very small changes in mean sea-level would have severely negative effects on atolls and low islands *(IPCC 2001c)*, and the densely populated islands of Kiribati, Tuvalu, and the Marshall Islands are at obvious risk. So too are many islands of higher elevations, as the largest concentration of populations and key infrastructure in the Pacific region generally occur no more than one mile from the coast *(Pernetta 1988)*.

Table 26 Anticipated adverse effects of climate change in Pacific Island countries

Sector	Key Impacts
Coastal zone	• Accelerated coastal erosion rates • Inundation of low-lying areas and atoll islands • Coral bleaching and degradation • Possible loss of areas of mangrove ecosystems
Water resources	• Increased severity and frequency of flood events • Increased severity and frequency of droughts • Salinisation of atoll and other coastal groundwater resources
Agriculture	• Decreased crop yields due to droughts and increased severity of extreme events • Salinisation of soils
Human health	• Direct effects of extreme events such as cyclones • Increased heat stress and discomfort • Increased risk of vector-borne disease (such as malaria and dengue fever) and diarrhoeal diseases • Indirect effects on health and nutrition arising from socioeconomic impacts of extreme events such as droughts and cyclones

9.2 Indirect impacts on human health

9.2.1 Increase in some diseases

Heavy rainfall and flooding is expected to support an increase in the incidence of water-borne diseases, and increasing temperature, humidity and rainfall may increase the incidence of vector-borne diseases, such as dengue, malaria and yellow fever *(IPCC 2001b)*. There is a strong link between the incidence of ENSO events and dengue fever outbreaks in the South Pacific island states *(Hales et al. 1996).* The 1997/98 epidemic in Fiji affected 24,000 people and killed 13, at a cost of US$3-6 million *(World Bank 2000)*. Drought and water shortages can lead to diarrhoea *(Singh et al. 2001)*, eye and skin diseases, poor nutrition and general low level of health. This is more pronounced in poorer areas, for example in urban squatter settlements, where access to facilities such as adequate shelter, water supply and sanitation are reduced.

9.2.2 Impact on water resources

Perhaps the most critical near- and long-term threat to Pacific Island health and welfare is the possible impact of climate change on freshwater quality and quantity *(Burns 2002, Meehl 1996)*. Rapid population increases (attributed to advances in health care) are already placing strain on the limited freshwater resources *(Burns 2002)*. On very small islands, groundwater lenses may shrink or even disappear with a 45cm (mid-estimate) increase in sea levels *(Roy and Connell 1991)*. Rainfall is expected to increase substantially in some regions and decrease in others. Water supplies to drier regions of main islands and smaller outer islands, particularly atolls, are seriously threatened by drought periods expected to be enhanced by climate change. If the region moves to a more El Niño-like state (not yet clear), this would bring increased droughts. Over the summer of 1982-83 a severe drought in the Southern Cook Islands associated with an El Niño event made it difficult for inland villages to obtain an adequate water supply in Rarotonga *(McCormack 2001)*. In 1998, 40 atolls of Micronesia ran out of water during an El Niño event *(Tutangata 2000)*. In addition to water supply for local populations, reduced water resources threatens tourism.

9.2.3 Coastal damage

Woodroffe and McLean *(1992)* suggest that 12.5% of Kiribati's total land area would be vulnerable with a 1 metre rise in sea-level. Notwithstanding the obvious impact of major land loss which is predicted to necessitate the relocation of communities or entire island populations (with severe impact on the psychological and cultural well-being of populations), other adverse impacts of sea-level rise include: loss of land for agriculture and forestry; coastal erosion; saline intrusion; loss of marine food sources and tourist attractions; loss of infrastructure (such as roads, bridges, buildings); and the consequent social and economic costs associated with these *(Maul 1993)*.

9.2.4 Damage to coral reefs and mangroves

Coral reefs and mangroves act as protection zones for coasts and are important habitats for marine life, and thus subsistence and commercial fisheries. Mangroves are a source of raw materials (for fuel wood and construction) and medicinal plants. High levels of sedimentation due to flooding can adversely affect both environments. The increased seawater temperature associated with El Niño events (which are expected to increase with global warming) has resulted in coral bleaching and coral mortality *(Brown 1997, Glynn 1993, Goreau 1992, Wilkinson and Buddemeier 1994)*. Coral death threatens marine biodiversity, reduces fish supplies for local communities, and diminishes the attraction of reefs for tourism. For Aitutaki, an island in the southern group of the Cook Islands, tourism is the primary industry, and the reputation of its lagoon is the primary tourism attraction. El Niño-induced coral bleaching in Aitutaki's lagoon was considered the major factor in the loss of corals during the last fifteen years *(McCormack 2001)*. Estimates for losses in fisheries and tourism values as the result of climate change impact on coral reefs in Viti Levu (Fiji) is between US$5-14 million by 2050 *(World Bank 2000)*.

9.2.5 Reduction of agriculture and forestry

Pacific Island states such as Fiji and the Solomon Islands rely on forests for both subsistence and commercial purposes. Many island populations rely heavily on a small number of staple crops for domestic consumption such as taro, yams, coconuts and bananas, and a similarly small number of export crops, such as sugar and rice.

Agricultural productivity is negatively influenced by cyclones (which cause crop and tree damage), floods (which wash out and rot crops, and waterlog soils), and droughts (which reduce or stop crop growth). Forests are threatened by soil erosion and landslides caused by flooding, wind damage from cyclones and the risk of fires associated with periods of low rainfall. Damage to crops and trees poses threats to population food, fuel and timber supply and economic welfare from export.

A further significant threat to domestic and export food supplies is seawater intrusion to soils and reduction of the freshwater lens (due to increasing sea-level rise and freshwater demand). Taro, a swamp-grown staple crop harvested throughout the Pacific Islands, is at particular risk of seawater intrusion and damage *(Wilkinson and Buddemeier 1994)*. For example, Kiribati's production of the staple crop *pulaka* (giant taro) is expected to be severely reduced due to changes in freshwater quality *(East-West Center 2001)*. Reduction in the food supply has obvious ramifications for the physical health of these populations, but it would also have broader repercussions given the central role of *pulaka* in Tuvaluan society *(SPREP 1996)*.

9.3 Economic costs

Vulnerability relates to poverty *(Kreimer 2001)*, and the resources a population has available to respond to change. The island nations of the Pacific already face significant development challenges because of their economic vulnerability. Their economies are small and remote from markets, often have a limited natural resources base, rely heavily on costly imports and are highly vulnerable to natural disasters. They tend to be characterised by large public sectors and poorly developed private and informal sectors *(Commonwealth Department of Foreign Affairs and Trade 2002)*. A large proportion of the infrastructure in these countries is inadequate and in need of repair. Health and education systems are not keeping up with the demands of technological advances and growing populations. There is a shortage of skilled personnel to fill key positions in government and the private sector. Beyond the physical costs of death and injury, the economic losses (both short-term damage and long-term replacement of infrastructure) divert government resources from longer-term development objectives, and consume a substantial share of multinational lending resources and foreign aid *(Kreimer 2001)*. In turn, this can lead to an increase in regional poverty.

The World Bank has conducted an economic analysis of climate change impacts in the Pacific. In the absence of adaptation, a "high island" such as Viti Levu (Fiji) is predicted to experience average annual economic losses (in 1998 dollars) of US$23-52 million by 2050, equivalent to 2-4% of Fiji's GDP. A "low" group of islands, such as the Tarawa atoll in Kiribati, could face average annual damages of US$8-16 million by 2050, or 17-34% of a current GDP of US$47 million *(World Bank 2000)*. These costs would be considerably higher in years of extreme weather events such as cyclones, droughts and large storm surges.

9.4 Discussion

Agriculture, aquaculture, and tourism are vital activities on which Pacific Island communities' livelihoods depend. Population health and well-being is contingent on maintaining a viable and sustainable environment to support these activities. Although uncertainties remain, it is now highly likely that climate change will negatively affect many facets of Pacific Island people's lives *(World Bank 2000)*. Population health is indirectly threatened by increases in diseases, notably vector-borne diseases. Climate change may exacerbate poverty, by reducing coastal settlement areas and affecting the crops and fisheries on which many communities depend *(World Bank 2000)*.

Both Australia and New Zealand have a long history of involvement in the Pacific Island region and consequently have developed significant political and, in some cases, constitutional links and responsibilities. Australian support for reform in the health sector includes assistance in developing health information systems and providing capacity building and training in Fiji, Samoa, Solomon Islands, Tonga and Vanuatu *(Commonwealth Department of Foreign Affairs and Trade 2002)*. At a regional level, funds are provided through AusAID to promote strategies to address non-communicable lifestyle diseases and the control of emerging health problems such as HIV/AIDS. Australia currently provides assistance for sea level and climate monitoring in the Pacific, to enable governments and communities to appreciate the links between sea level, climate variability and their adaptation requirements.

It is anticipated that the impacts of climate change and sea-level rise, both direct and cumulative, would in many cases exceed the adaptive ability of natural systems and communities in Pacific Island countries. Population displacement from the Pacific may lead to a relatively rapid influx of new settlers to Australia and New Zealand. Considering this, our aid commitments, and the extensive cultural, community, and familial ties with the region, it is likely that Australia would play a role in providing for environmental refugees from Pacific Island countries or increasing our assistance to those countries.

The question of who will fund adaptation measures has been raised by many sectors. It seems clear that the international community will need to be involved in supporting Pacific Island countries to implement "no regrets" adaptation measures *(World Bank 2000)*.

10. ADAPTATION POTENTIAL AND VULNERABILITY

Climate change differs from many other environmental health problems because of its gradual onset, widespread as well as localised effects, and the fact that the most important effects will probably be indirect. These factors inevitably affect perceptions of the problem. In particular, there is a danger that the problem will not be recognised until it is too late to respond effectively, or a substantial cost has already been incurred.

The long causal chain between climate variation and most human health outcomes underlines the critical role of adaptation. It is noteworthy that, particularly in the work of the IPCC's Third Assessment Report (2001b), there has been a substantial growth in the attention being paid to the question of adaptation. While mitigation of greenhouse gas emissions remains the primary need worldwide, it has become clear that the planet is committed to significant climatic change already. Greater emphasis is therefore being given to research evaluating the possibilities for planned and autonomous adaptations, and how impacts might be modulated by differing scenarios of independent non-climate change (e.g. in demography, urban design, technologies, information flows, trade and economic development). The impact on health of mitigation strategies has not been dealt with in this report. However, there could be appreciable health benefits in the short term from many mitigation strategies. Transport policies to cut emissions from vehicles could potentially lead, for example, to lower levels of particulate and gaseous air pollution and increased physical activity.

Climate change may bring conditions that are more favourable for disease and other adverse health impacts, but that does not necessarily mean that such impacts will occur, as long as there is the capacity to adapt to changing circumstances. Nevertheless, many individuals and communities are likely to lack the resources required for adequate response (under assumptions of reasonable economic growth, technology change, etc in the future). For example, not all Australians can afford to heatproof their houses as protection against increasing heatwaves. Even if this option was affordable for most, it may not be sustainable as a global strategy. The environmental costs of providing air-conditioning for the whole population of continental Asia, for example, would be overwhelming.

It would be short sighted to imagine that adaptation provides a complete answer to the problems of climate change. Nevertheless, adaptation must be part of the response. Studies of adaptation to climate change are still relatively few in Australia and New Zealand. Climate change pressures provide further reason for developing and sustaining effective quarantine and other biosecurity measures, which are already a high priority to protect Australia's future well-being, even in the absence of climate change.

11. FUTURE RESEARCH AND PUBLIC HEALTH RESPONSE

As indicated at the beginning of this report, several health outcomes demonstrate an association with climate, but modelling has not yet been able to describe this complexity. Research into the potential health consequences of the following aspects or impacts of climate change would provide valuable information for future public health planning:

- Air pollution and aeroallergen levels
- The rate of recovery of stratospheric depletion, affecting exposure to UV radiation
- Changes in the distribution and transmission of vector borne-diseases (particularly Ross River virus disease, Murray Valley encephalitis, and Japanese encephalitis)
- Indirect effects on food production acting through plant pests, diseases, drought, and excess rainfall.

Further research into the effects of climate variability and change on water supplies and consequent human health effects seems warranted. Areas of importance include:

- analysis of the relationship between heavy rainfall and biological contamination of water supplies,
- the influence of climate variability and extremes on notified illnesses, and
- quantification of the burden of water-related illnesses (including conditions such as gastroenteritis and skin infections) in parts of the country susceptible to water stress.

Climatic effects on water supplies, and on transmission of water-borne diseases, are likely to be greatest where reticulated supply systems are poorly developed (or absent altogether), and communities do not have resources to import water or pay for private treatment facilities.

For food-borne diseases, further preventive measures are likely to be based on a concerted effort to implement and sustain Hazard Analysis Critical Control Point (HACCP) safety processes *(Hall et al. in press)*. This is now an international standard procedure for the management of food-borne hazards *(FAO 1995)*. With the modern tendency to undertake complex processing and widespread distribution of foods, and given the likely effect of climate change to exacerbate the effects of poorly controlled points in the food production process, HACCP procedures will need to be even more stringently applied *(FAO 1995)*.

The 1991 NHMRC report, *Health Implications of Long Term Climate Change*, suggested a substantial number of public health responses to climate change. It is noteworthy that a number of the recommendations have been implemented, such as the establishment of:

- the Communicable Diseases Network, to coordinate surveillance and provide baseline data, and
- a coordinating body charged with the responsibility of integrating government initiatives in this area (the National Public Health Partnership).

Others, such as the establishment of targets and research priorities for climate-related diseases, and research into the social implications (including occupational health and safety) and hazard mitigation relating to climate change, have yet to be fully implemented.

An updated assessment of the impact of climate change on fire danger is needed for Australia.

The future risk of vector-borne disease increases (both in terms of total numbers, and regions at risk) need not necessarily translate into an increase of cases, as long as there is a maintenance and extension of the public health response (involving the increase of epidemiological surveillance and vector control into potentially affected areas). A continuation of quarantine efforts is also needed to ensure that exotic disease vectors (such as *Ae. albopictus*) do not become established in the country.

12. APPENDIX A

Population projections for major cities of Australia, by age group*

	1999			2020			2050		
CITY	<65	65+	total	<65	65+	total	<65	65+	total
Adelaide	934 303	158 066	1 092 369	915 253	255 147	1 170 400	769 643	337 757	1 107 400
Brisbane	1 428 449	172 951	1 601 400	1 833 544	354 456	2 188 000	2 178 338	669 163	2 847 501
Canberra	284 068	24 905	308 973	298 800	57 800	356 600	285 200	86 600	371 800
Darwin	84 688	3 364	88 052	117 787	9 413	127 200	169 100	20 900	190 000
Hobart	168 372	26 017	194 389	147 157	40 543	187 700	100 048	4 7952	148 000
Melbourne	3 001 619	412 275	3 413 894	3 315 713	742 687	4 058 400	3 220 436	1 173 065	4 393 500
Perth	1 213 954	147 721	1 361 675	1 487 029	311 071	1 798 100	1 666 575	555 525	2 222 100
Sydney	3 558 460	473 484	4 031 944	4 159 168	839 832	4 999 000	4 422 621	1 419 679	5 842 300
Cairns	105 492	8 286	113 778	159 625	19 362	178 987	216 357	41 047	257 404
Townsville	75 405	9 142	84 547	80 798	12 693	93 491	77 301	17 741	95 042

* These figures were used for calculating the deaths attributable to heat (Section 7.1).

13. Glossary

Aeroallergens
Allergens present in the air such as pollen and spores.[1]

Alternative emission scenarios
Alternative emission scenarios are predicted models of future climate, based on different emission projections. These are used to provide an assessment of the level of risk to human health brought about by changing climate.

Anthropogenic
Resulting from or produced by human beings.

Arbovirus
Any of various viruses transmitted by infected arthropods (such as mosquitoes), including dengue, Ross River, West Nile, yellow fever, Japanese encephalitis, Murray Valley encephalitis etc.

Atoll islands
A low-lying coral island enclosing a lagoon.

Baseline
The baseline (or reference) is a point against which change is measured. In this report the term baseline refers to observable, present day conditions.[1]

Biodiversity
Biodiversity refers to the numbers and abundance of genetic diversity, species and ecosystem communities in a particular area.[1]

Climate change
The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as "a change of climate which is attributed directly or indirectly human activity that alters the composition of the atmosphere and which is in addition to natural climate variability observed over comparable time periods." [1]

Climate scenarios
A plausible and often simplified representation of future climate, based on a consistent set of climatological relationships that has been constructed to investigate the potential consequences of human induced climate change. Climate projections serve as the raw material for constructing climate change scenarios, which also incorporate information about the observed climate.[1]

Crude rate
A crude rate is a summary measure presented for the entire population. It does not provide information on particular categories within the population (such as age or sex), nor does it adjust for differences in the structure of the population, to allow for comparison between populations.

Dengue receptive zone
Dengue fever is caused by several of the four dengue arboviruses that are transmitted by *Aedes* mosquitoes, principally *Aedes aegypti*. Dengue viruses are endemic in most countries in the tropics. The "dengue receptive zone" refers to an area that may, in the future as the result of climate change, become climatically suitable for the establishment of dengue. This would only occur if other factors (such as public health measures, individual human adaptation, changes in local environments) did not prevent this happening.

Dose-response relationship
The relationship of the observed outcome (response) in a population to varying levels of an environmental exposure. This relationship may be linear, logarithmic, etc.

Ecoclimatic index
The ecoclimatic index is a measure that represents the overall favourableness of a given geographical location for the permanent survival and propagation of mosquito populations. It comprises a stress index (that estimates the threat to a species from prolonged excessive cold, hot, dry, or wet conditions), a soil moisture index, and a growth index (based on temperature). The ecoclimatic index forms part of the CLIMEX modelling software, developed by the CSIRO.

El Niño-Southern Oscillation:
The El Niño is used to describe a warming of the water in the eastern Pacific Ocean, off the coastline of Peru. This oceanic event is associated with a fluctuation of the inter-tropical surface pressure pattern and circulation of the Indian and Pacific Oceans, called the *Southern Oscillation.* The coupled atmosphere-ocean phenomenon is collectively referred to as the El Niño-Southern Oscillation (ENSO). El Niño events impact on the wind, sea surface temperature, and precipitation patterns in the tropical Pacific. It also has climatic effects throughout the Pacific region and in many other parts of the world (referred to as teleconnections). The opposite of an El Niño event is called a La Niña.[2]

Emissions
See "alternative emission scenarios".

Environmental health
The WHO (1993) defined environmental health as comprising "those aspects of human health, including quality of life, that are determined by physical, chemical, biological, social, and psychosocial factors in the environment. It also refers to the theory and practice of assessing, correcting, controlling, and preventing those factors in the environment that can potentially affect adversely the health of present and future generations." [3]

Enzootic cycle
A zoonosis is an infection that affects animals and has the potential to spread to humans. An 'enzootic cycle' refers to the natural cycle of an infectious agent (such as a virus) that circulates continuously within the host animal and vector populations.

Exposure
Proximity or contact with an agent in the environment.

Flash flooding
Flooding that occurs rapidly, generally within six hours of rain beginning to fall heavily. Urban areas are more prone to flash flooding because water runoff from the built environment can be too large for the storm water system to cope with.

Food-borne infections
Consuming contaminated foods or beverages causes food-borne infections. Many different disease-causing pathogens can contaminate foods. In addition, poisonous chemicals or other harmful substances can cause food-borne diseases if they are present in food.

Greenhouse gas emissions
Greenhouse gases are those gases in the atmosphere that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface. Greenhouse gases in the Earth's atmosphere are: water vapour, carbon dioxide, methane, nitrous oxide, ozone, carbon monoxide, non-methane volatile organic compounds, sulphur oxides, and fluorocarbons. Greenhouse gas emissions can be discharged naturally, or are emitted because of human activities such as burning fossil fuels. [2]

Global warming
Is the effect caused by an increase of the concentration of greenhouse gases in the atmosphere, which changes the Earth's radiation balance and results in higher surface temperatures. [2]

Heat-island effect
A heat-island is an area within an urban area that is characterised by ambient temperatures higher than those of the surrounding area because of absorption of solar energy by materials like asphalt, buildings etc. [2]

Heat-attributable deaths
At high temperatures the numbers of deaths in a given population increases. The threshold or point at which deaths due to temperatures increase is not uniform. Regional climatic conditions, mortality rates, and other confounding factors must be assessed to determine the impact that temperature has on mortality in a given area. The number of heat-attributable deaths is likely to increase with temperature increases caused by global climate change.

Incidence
Incidence refers to the number of new cases arising in a given period in a specified population.[1]

La Niña
See El Niño Southern Oscillation.

Linear Regression Analysis
Regression analysis involves finding the best mathematical model to describe y (the outcome variable) as a function of the x's (explanatory variables). The most common form is a linear model.

Malaria Receptive Zone
Malaria is an infectious tropical disease caused by protozoa of the genus *Plasmodium*, transmitted to humans by the bite of an infective *Anopheles* mosquito. Malaria produces high fever attacks and systemic disorders and kills approximately 2 million people every year. The "malaria receptive zone" refers to an area that may, in the future as the result of climate change, become climatically suitable for the establishment of malaria. This would only occur if other factors (such as public health measures, individual human adaptation, changes in local environments) did not prevent this happening.

Ozone
Ozone is a form of oxygen, and is a gaseous atmospheric constituent. In the troposphere (the lower atmosphere), it is created both naturally and by photochemical reactions between gases emitted by human activities. In high concentrations, ozone in the tropospheric layer can be harmful to a wide range of organisms. It also acts as a greenhouse gas. In the stratosphere (the upper atmosphere), ozone is created by the interaction of solar ultraviolet radiation and oxygen. Stratospheric ozone plays a key role in the stratospheric radiative balance. Depletion of stratospheric ozone also leads to increased ground level ultraviolet radiation. [2]

Pathogen
A pathogen is any virus, microorganism or other substance that causes disease – an infecting agent.

Peri-urban dweller
Literally, it means living around the edges or periphery of a city.

Poisson regression analysis
A Poisson distribution is used to describe the occurrence of rare events. Also, see Linear Regression.

Risk factor
An aspect of personal behaviour or lifestyle, and environmental exposure, or an inborn or inherited characteristic, that, based on epidemiologic evidence, is known to be associated with health-related condition(s) considered important to prevent.[4]

Relative risk
The relative risk indicates the likelihood of developing the disease in the exposed group, relative to the non-exposed group. In the context of this report, the incidence of disease in the exposed group (people living in 2020 or 2050 in a world where climate change has occurred) is divided by the incidence in the non-exposed group (i.e., ~2002).

Scenario-based
A scenario is a plausible and generally simplified version of how the future may develop and is founded upon coherent and internally significant assumptions about key relationships and driving forces. This report takes a 'scenario-based' approach. That is, the health impacts attributed to climate change are based upon projected climate change scenarios. [2]

Sea-level rise
Long term changes in the mean level of the ocean. In this report the term is used to refer to the impact global climate change is predicted to have on the level of the sea, due to thermal expansion or eustatic change (e.g. from the melting of the world's ice caps).[2]

Seasonal effect
A seasonal effect is one in which particular health impacts are temporally clustered by the seasons of the year. The increased mortality rate during wintertime is one such seasonal effect.

Storm surges
Storm surges are caused by the combination of strong onshore winds, low atmospheric pressure and high tides and can result in exceptionally high water levels that can inundate coastal areas. Around the world, storm surges present a major natural hazard in many vulnerable coastal and island regions.

SRES storylines
The SRES scenarios are emission scenarios used as a basis for climate projections. The 'storylines' are a narrative description of a scenario, that highlight different assumptions about demographic, societal, economic, and technical changes likely to influence the rate of climate change.

Threshold
A threshold is the point above which the effect of an exposure occurs.

U-shaped relationship
Cases increase at the lowest and highest extremes of the x-axis range. In relation to heat, greatest deaths are recorded as temperatures are very low as well as very high. No relationship between temperature and deaths is recorded for temperatures in between these extremes.

Ultraviolet radiation
Ultraviolet radiation is non-visible light emitted by the sun. The human eye responds to light with wavelengths from about 790 nm (red) to 430 nm (violet). Light of shorter wavelengths than the human eye 'sees' is called *ultraviolet* (beyond violet) light.

Vector-borne diseases
Diseases caused by pathogens that are transmitted via a vector such as a mosquito, snail, fly etc. Malaria and dengue fever are examples of two types of vector-borne diseases.

Viraemia
Presence of a virus in the blood.

Water-borne diseases
Water-borne diseases are any illnesses caused by drinking or ingesting contaminated water. The contamination can be by bacteria (*Salmonella* and *Leptospirosis*), viruses, or by small parasites (*Cryptosporidium* and *Giardia*).

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14. Acronyms and Abbreviations

ABS	Australian Bureau of Statistics
ACT	Australian Capital Territory
AIHW	Australian Institute of Health and Welfare
AQIS	Australian Quarantine and Inspection Service
CFCs	Chlorofluorocarbons
CSIRO	Commonwealth Scientific and Industrial Research Organisation
ENSO	El Niño–Southern Oscillation
FAO	Food and Agriculture Organization
GCMs	General circulation models
GHG	Greenhouse gases
HACCP	Hazard analysis critical control point
IPCC	Intergovernmental Panel on Climate Change
NHMRC	National Health and Medical Research Council
NSW	New South Wales
NT	Northern Territory
QLD	Queensland
RRv	Ross River virus
SA	South Australia
SD	Statistical division
SLAs	Statistical local areas
SRES	Special Report on Emissions Scenarios
TAS	Tasmania
TPHUN	Tropical Public Health Unit Network
UV	Ultraviolet radiation
VIC	Victoria
WA	Western Australia

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