FOUNDATION PAPER | ONE

CLIMATE CHANGE

Victoria:
the science, our people
and our state of play

State Government Victoria

Commissioner *for* Environmental Sustainability Victoria

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The warming around Australia is consistent with the global pattern and cannot be explained by natural variability alone.

CSIRO AND THE AUSTRALIAN BUREAU OF METEOROLOGY, STATE OF THE CLIMATE 2012[1]

Victoria's climate is naturally variable and severe weather events such as bushfires and floods have occurred throughout history. Climate change may lead to changes in the distribution, intensity and frequency of events like these. Some recent events …… are consistent with scientific understanding of conditions that may be more likely in a warmer world, compared to natural variability alone. However, it is very difficult to identify the specific causes of individual extreme weather events.

REPORT ON CLIMATE CHANGE AND GREENHOUSE GAS EMISSIONS IN VICTORIA, VICTORIAN GOVERNMENT DEPARTMENT OF SUSTAINABILITY AND ENVIRONMENT MELBOURNE, MARCH 2012[2]

When I testified before the US Senate in the hot summer of 1988, I warned of the kind of future that climate change would bring to us and our planet. I painted a grim picture of the consequences of steadily increasing temperatures, driven by mankind's use of fossil fuels. But I have a confession to make: I was too optimistic.

My projections about increasing global temperature have been proved true. But I failed to fully explore how quickly that average rise would drive an increase in extreme weather.

In a new analysis of the past six decades of global temperatures, my colleagues and I have revealed a stunning increase in the frequency of extremely hot summers, with deeply troubling ramifications for not only our future but also for our present.

This is not a climate model or a prediction but actual observations of weather events and temperatures that have happened. Our analysis shows it is no longer enough to say global warming will increase the likelihood of extreme weather and to repeat the caveat that no individual weather event can be directly linked to climate change. To the contrary, our analysis shows that, for the extreme hot weather of the recent past, there is virtually no explanation other than climate change.

JAMES HANSEN, DIRECTOR NASA GODDARD INSTITUTE FOR SPACE STUDIES, AUGUST 2012[3]

Let us pursue the impending energy revolution even more resolutely so that 100% of our energy can be supplied from renewable sources as soon as possible. At least we would not have made any mistakes if – which I doubt – we discovered in a few decades that CO_2 emissions were not responsible for climate change after all. All that we would then have done is trigger the unavoidable changeover to other energy sources somewhat earlier. And we would leave some of that precious raw material called oil for future generations. Let us tackle this industrial change now – we have nothing to lose.

PROF. PETER HÖPPE HEAD OF GEO RISKS RESEARCH/CORPORATE CLIMATE CENTRE, MUNICH RE, 2011[4]

We need to support each other, collaborate and share, push the boundaries, mainstream the issues, communicate better and make reporting more effective.

COMMUNITY MEMBER, SW VICTORIA, MANY PUBLICS: PARTICIPATION INVENTIVENESS AND CHANGE CFES, APRIL 2012[5]

INTRODUCTION

Rigorous analysis and objective reporting of scientific knowledge which includes people, culture and policy is at the core of my approach to environmental reporting.

The State of the Environment Report 2013 (SOE) will be a synthesis of the work of scientists and practitioners and it will provide and integrate material to reflect a localised, Victorian perspective on environmental trends.

In my reporting framework for the State of the Environment report 2013, *Science, Policy, People*[6] produced in accordance with the section 17 of the *Commissioner for Environmental Sustainability* Act 2003 (the Act),[7] I outlined my intention to deliver a report which would ***inform the Victorian community*** *about the health of the natural environment and* ***influence government*** *to achieve environmental, social, cultural and economic sustainability*.

My framework identified an audience for environmental reporting beyond policy makers and legislators - that of a public with an increasingly sophisticated appreciation of environmental issues. This caused me to re-evaluate traditional forms and processes of environmental reporting. Broadening the audience for the SOE also necessitated a change in reporting timeliness. A new urgency has developed in providing information to people about the science, environmental trends and the policy response.

To address these issues I undertook to release three foundation papers as part of the research and engagement process for the production of the SOE report.

This **Climate Change Foundation Paper** outlines climate change impacts in the Victorian context. This paper is published as other rigorous, highly authoritative and leading commentary from Price Waterhouse Coopers *Low Carbon Economy Index 2012*[i], the United Nations *Policy Implications of Permafrost Warming*[ii], the World Meteorological Organization *2012: Record Arctic Sea Ice Melt, Multiple Extremes and High Temperatures*[iii] and the World Bank report *Turn down the heat*[iv], each recite scrupulous examinations of the science and impacts of climate change and our role in generating it. In the light of this deeply concerning commentary I am reinforced in the view that this paper is both necessary and timely. The material presented in this paper, reflecting the science and our work and consultation over the last two years is an invitation to consider the questions raised. The issues for consideration are complex and responses will evolve over time, and at all levels. The international community is continuing to work through this complexity, as evidenced in the recent United Nations Framework Convention on Climate Change Doha Conference. The pace for some is too slow, however this does not lessen the need or urgency of continued efforts.

The ***Biodiversity and Land Foundation Paper*** will focus on managing land for biodiversity outcomes - threats to biodiversity, incentives for private landholders to manage for biodiversity outcomes, monitoring & reporting.

The ***Water Foundation Paper*** will focus on urban water issues, incorporating integrated water cycle management, water sensitive urban design, stormwater management and innovation.

My framework identified an audience for environmental reporting beyond policy makers and legislators...

i www.pwc.com/en_GX/gx/low-carbon-economy-index/assets/pwc-low-carbon-economy-index-2012.pdf
ii http://www.unep.org/pdf/permafrost.pdf
iii http://www.wmo.int/pages/mediacentre/press_releases/pr_966_en.html
iv http://climatechange.worldbank.org/sites/default/files/Turn_Down_the_heat_Why_a_4_degree_centrigrade_warmer_world_must_be_avoided.pdf

Governments can be greatly assisted in their regulatory and decision making processes by independent authorities who provide insights into community aspirations and instructive, balanced comment on the policy process

Purpose of this paper

There are many areas in government and academia conducting research and analysing environmental trends – working to bring the best possible scientific knowledge to our considerations of policy direction and public debate. Each 'discipline' is seeking to explain biophysical changes and social dynamics through rigorous scientific inquiry and research processes relevant to it. Interdisciplinary, cross sectoral discussion and community involvement is still evolving and gives societal meaning to the new knowledge and facilitates appropriate actions.

The purpose of this **Climate Change Foundation Paper** is to provide an independent and integrated presentation of some of the impacts of climate change in a Victorian setting. It is not intended to replicate the work which has already been undertaken on climate change impacts, bushfires, floods or infrastructure implications but rather to mine those works for insights and present them in a way which may assist the Victorian community – the broader constituency and audience for environmental reporting – to better understand some of the scientific and policy issues we need to consider as we decide on how best to protect and manage our natural resources.

This foundation paper is intended to encourage a lively and productive exchange of ideas and an ongoing discussion about good and best practice in determining responses to the risks which attend our natural environment and the significant economic, social and cultural role the environment has in the lives of Victorians.

Independent statutory roles, such as mine, have a unique function in our system of government. They stand at a distance from government and, depending on their legislative accountabilities, undertake independent investigations or analysis and provide impartial reports. Governments can be greatly assisted in their regulatory and decision making processes by independent authorities who provide insights into community aspirations and instructive, balanced comment on the policy process. I intend for my reporting functions, and the engagement processes of my office, to provide such a contribution to the Victorian Government.

Our situation as told by the science

Australia's pre-eminent climate science scholars and reporters, CSIRO and the Australian Bureau of Meteorology (BoM), have now provided the public with two reports on the State of the Climate (2010 and 2012).[8] They have also provided us with two reports through the South Eastern Australian Climate Initiative (SEACI), which also provides valuable science in the context of climate change and variability in our part of the world.[9] These documents give us cogent and compelling analysis and commentary on climate change in our region.

Some facts

CSIRO/BoM *State of the Climate 2012* (SOC2012) tells us:

- each decade since the 1950s has been warmer than the previous one
- Australian annual-average daily maximum temperatures have increased 0.75°C
- Australian annual-average daily mean temperatures have increased by 0.9°C
- Australian annual-average overnight minimum temperatures have warmed by more than 1.1°C since 1910.

2010 and 2011 were Australia's coolest years recorded since 2001 due to two consecutive La Ñina events which drive temperatures down but, even subject to this phenomenon, 2011 was the warmest La Ñina year on record and still warmer than all but one year in the 20th century.

SOC2012 also reports that global average mean sea level rose faster between 1993 and 2011 than during the whole 20th century. Australia is an island continent and our climate is influenced by systems over the Indian, Southern and Pacific oceans. Sea surface temperatures around Australia have increased faster than the global average and in 2010 recorded temperatures were the highest on record increasing by 0.8°C since 1910.

Australia is an island continent and our climate is influenced by systems over the Indian, Southern and Pacific oceans. Sea surface temperatures around Australia have increased faster than the global average and in 2010 recorded temperatures were the highest on record increasing by 0.8°C since 1910.

Some projections

SOC2012 states that climate models suggest:

- Australian average temperatures are projected to rise by 1.0 to 5.0°C by 2070 when compared with the climate of recent decades – this means an increase in the number of hot days and warm nights and a decline in cool days and cool nights
- an increase in the number of droughts is expected in southern Australia but it is also likely that there will be an increase in intense rainfall events in many areas
- it is likely that there will be fewer tropical cyclones in the Australian region, on average, but the proportion of intense cyclones is expected to increase.

No regrets

The *Australia State of the Environment 2011,*[10] report attested to real concerns about the changing climate and its impacts on the environment, the economy, and on us. The authors commented:

> *Climate change is now widely understood as a prime risk to both our environment and our society.*

This is a no-regrets strategy – what do we have to lose by being cautious in our consumption, production and waste?

In the Australia State of the Environment 2011 report we also read that our 'highly developed economy places us in a good position to reduce our emissions and undertake climate change adaptation'. An example of action we might take to reduce emissions is presented in the *Low Carbon Growth Plans* produced by ClimateWorks Australia.[11] These plans suggest that we can still take meaningful action to arrest emissions, but also note that the issue is pressing and that this is the critical decade in which to effect serious, sustained change.

Other commentary from multiple reputable and prestigious observers - Global Climate Leadership Review 2012,[12] Organisation for Economic Co-operation and Development (OECD)[13] - argues that it makes good fiscal, social and environmental sense to intelligently and purposefully address climate change risks.

This is a no-regrets strategy – what do we have to lose by being cautious in our consumption, production and waste? What do we have to lose if, as a community, we start to consider how to adapt to changing climate conditions?

Outline of the paper

In this foundation paper I have set myself the task of examining some of the hazards and vulnerabilities associated with climate change for our state and how we might consider addressing them. Victoria's greenhouse gas emissions profile is presented, however, this foundation paper does not interrogate mitigation. Rather, it should be viewed as having a focus on adaptation, noting that the concepts are not mutually exclusive and in the future will increasingly merge.

We commence in **Chapter One** with a discussion of climate science and its application to Victoria. To do this we work from the Intergovernmental Panel on Climate Change (IPCC) scenarios and CSIRO climate modelling to map outcomes. Climate change impacts, potential future climates for Victoria and possible scenarios are also presented.

In **Chapter Two** we examine some of the direct and indirect impacts of climate change on biodiversity and primary production.[14] We consider the issues associated with Victorian climate change and the pivotal role of citizen scientists in recording what is happening. We also look at the movement of species associated with climate change, impacts on marine and coasts, phenology, carbon storage.

The key messages from this chapter of the paper are that a changing climate will have a deleterious impact upon our natural environment, and in impacting 'ecosystem services' there will be a commensurate impact upon us as well.

In **Chapter Three**, which we have called the 'Susceptibility of the Built Environment', we look at some of the impacts, both direct and indirect, and the cascading outcomes on infrastructure should we continue with a business as usual mindset. The 'cascading' impacts are the issues of grave importance in this chapter and the conclusions we form attest to the need to consider our actions now. We also consider strategies for adapting our infrastructure to a changing climate - for example demand management is used to explain a "soft" strategic approach.

Having examined some of our vulnerabilities to climate change we also investigate the hazards - drought and floods, bushfires and heatwaves in the remaining chapters.

Chapter Four provides a discussion of the impacts of flood and drought with a focus on regional Victoria (water regulation and supply issues will be addressed in the SoE).

In **Chapter Five** we discuss responding to the risk of increased likelihood of bushfire, fire ecology, human health impacts, reducing exposure, the need for accurate and current information, fire mapping and communicating fire risk (fire management responses and fire regimes will be addressed in the SoE).

Chapter Six presents the impacts of heatwaves on people and biodiversity and discusses some of the innovations in reducing exposure, predominantly in urban landscapes.

The vulnerabilities and hazards I have elected to present in this foundation paper are the result of my consideration of scientific knowledge and research and my extensive community and technical consultation process.

Every chapter of this foundation paper develops significant contemporary ideas for consideration. The paper does not purport to present all ideas or solutions. New ones are being continually developed. What is important is that our responses to the impacts of climate change be integrated into what we build for ourselves and envisage for future generations.

Finally, I would like to thank all of the departments, agencies, scholars, technical specialists and community members who have met with me, and my office, as we developed this foundation paper. I would also like to acknowledge Professor Dave Griggs of the Monash Sustainability Institute for his insightful comments. And, in particular I would like to acknowledge Harvey Stern and Robert Dahni from the Bureau of Meteorology and Leanne Webb, Penny Whetton, Craig Heady and John Clarke from CSIRO for their work in the development of the future climate classes for Victoria presented in Chapter One of this foundation paper.

Professor Kate Auty PhD, MEnvSc, Dip Int Env Law (UNITAR), BA(Hons)LLB, GAICD

Commissioner for Environmental Sustainability

The 'cascading' impacts are the issues of grave importance in this chapter and the conclusions we form attest to the need to consider our actions now.

CHAPTER **ONE** - VICTORIA AND THE SCIENCE OF CLIMATE CHANGE

Policy settings, advances in innovation and technology and social responses will all influence our future climate.

In this chapter we consider climate change science and examine a number of potential impacts in Victoria through the prism of the IPCC emission scenarios - alternative images of how the future climate might unfold, influenced by how much we, as a global community, are willing to change our dependence on fossil fuels. Policy settings, advances in innovation and technology and social responses will all influence our future climate.

As part of our research process we asked CSIRO to provide us with Victorian climate change data from 23 global climate models.[15] BoM then determined how these will reflect future climate classes in the state. This work has not been previously undertaken and the results are presented in section 1.5 of this chapter.

The chapter concludes with a discussion of CSIRO's climate analogues. This work demonstrates a potential future climate scenario for Victorian towns and cities. It poses the critical question - should we look at those analogous regions now in order to review and potentially adopt different agricultural and human settlement practices?

1.1 What is climate change?

Global climate change is a complex issue and our scientific understanding of it is increasing all of the time as research continues.

The United Nations Framework Convention on Climate Change 1994, provides the following definition:

> *"Climate change" means a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.*[16]

The IPCC provides the following explanation of the contributions of human activity on climate change in comparison to natural processes.

> *Human activities contribute to climate change by causing changes in Earth's atmosphere in the amounts of greenhouse gases, aerosols (small particles), and cloudiness. The largest known contribution comes from the burning of fossil fuels, which releases carbon dioxide gas to the atmosphere. Greenhouse gases and aerosols affect climate by altering incoming solar radiation and outgoing infrared (thermal) radiation that are part of Earth's energy balance. Changing the atmospheric abundance or properties of these gases and particles can lead to a warming or cooling of the climate system. Since the start of the industrial era (about 1750), the overall effect of human activities on climate has been a warming influence. The human impact on climate during this era greatly exceeds that due to known changes in natural processes, such as solar changes and volcanic eruptions.*[17] *(Figure 1).*

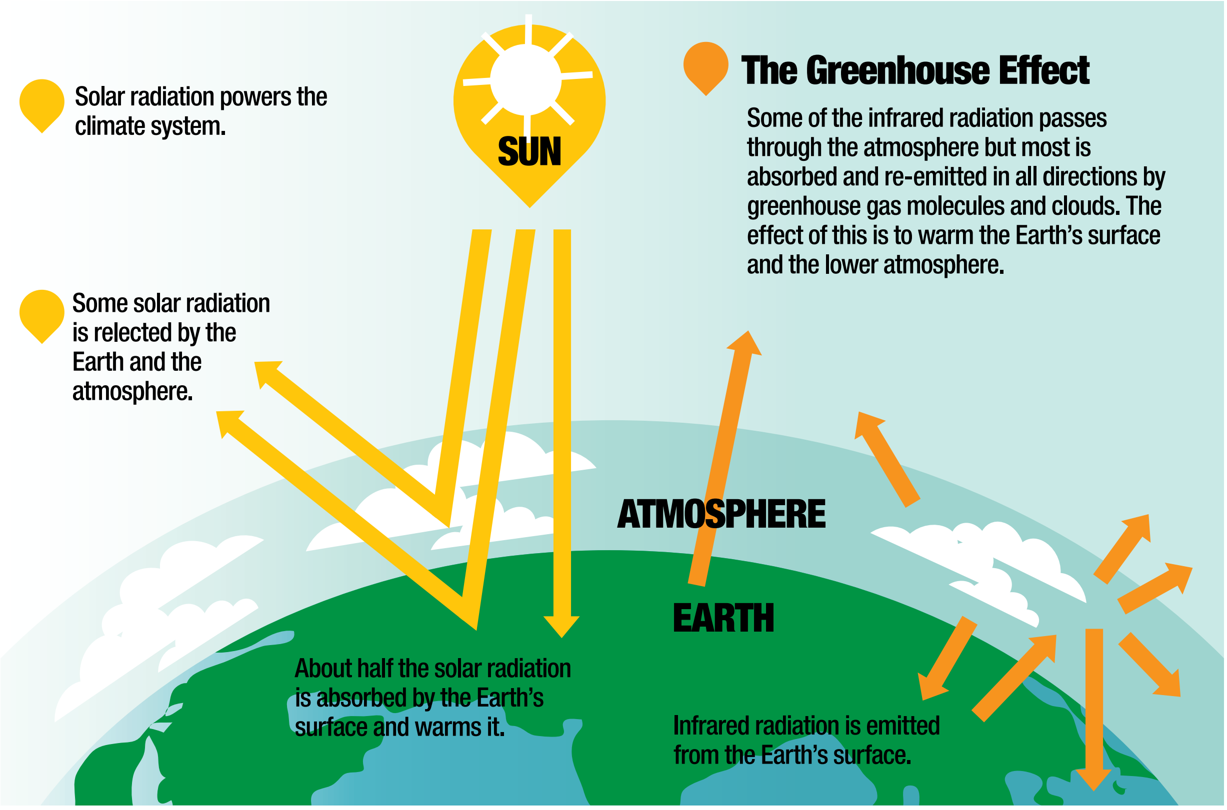


Figure 1:
IPCC's diagrammatic representation of the greenhouse effect.
IPCC FAQ 1.3. An idealised model of the natural greenhouse effect. Modified by CfES.[18]

Solid scientific evidence supports the position that climate change is caused by emissions of greenhouse gases. Although there is a great deal of natural variability in global temperatures there are clear fingerprints of human-induced climate change. These are seen in phenomena that would not occur if rising temperatures were not tied to human activity and were purely natural.

It is difficult to directly attribute a single "climate/weather event" to climate change but extreme weather events are increasing. The exceptional will become common – rainfall records will be broken more regularly, droughts and bushfires will be more frequent and intense. However, as further research is undertaken and data sets are expanded it is foreseeable that scientists will more readily be able to attribute single climate events to climate change.[19]

Estimating the magnitude of temperature increase over time is highly dependent on scenarios of human emissions creation (see below). In its last report, the IPCC estimated that mean global temperature increases this century were likely to be in the range 1.8-4.0°C, depending on emissions scenarios. In Australia, CSIRO estimates that the range of temperature increase is between 1-5°C.[20]

Commonly we hear the suggestion that limiting global warming to two degrees will allow us to avoid the worst impacts of climate change. There is growing evidence however that this is not the limit for acceptable climate change, rather it is the threshold between dangerous and "extremely dangerous" climate change.[21] Because warming above this threshold is within the bounds of possibility, we must be prepared to consider more severe impacts from warming.

> " … [I]f carbon dioxide emissions suddenly stopped, global temperatures would stop growing but would not drop significantly for at least 1000 years. It would take centuries to remove the carbon dioxide that has already accumulated in the atmosphere, and allow for the slow release of heat that is already stored in the oceans".[22]

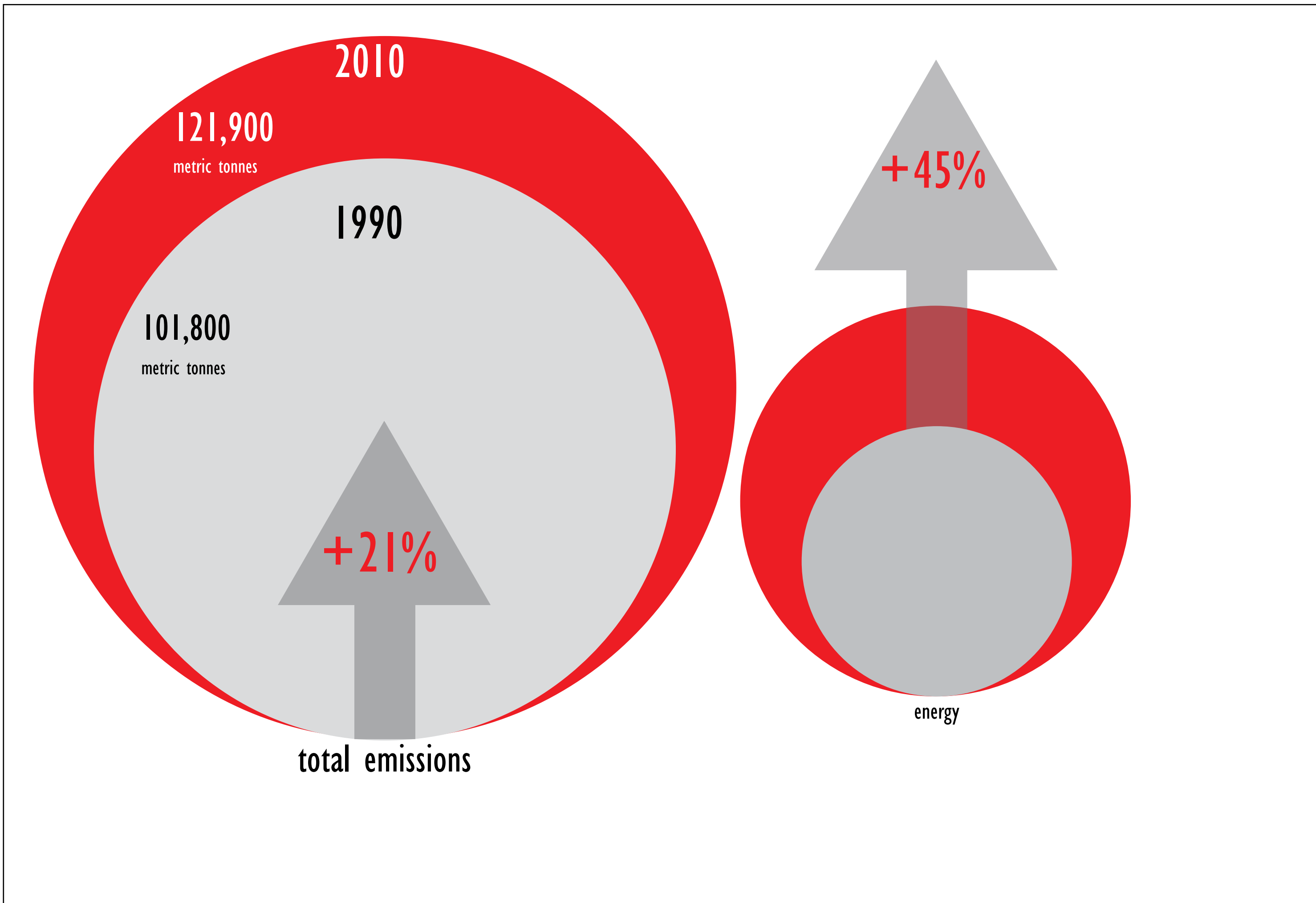
1.2 Greenhouse gas emissions are increasing

Greenhouse gas emissions, hence concentrations in the atmosphere, have increased at a greater rate from 2009 -10 than the average for previous decades. With only current policies in place the OECD estimates that "global greenhouse gas (GHG) emissions [are] projected to increase by 50%, primarily due to a 70% growth in energy-related CO_2 emissions."[23]

Not only is the trend in greenhouse gas concentrations upward, but the International Energy Agency tells us that, globally, we suffered the largest annual rise in carbon emissions ever in 2010 (Figure 2).[24]

The OECD states that current global mitigation pledges are not enough and "more ambitious action is needed" if we are to avoid the worst impacts of climate change. The ambitious actions recommended by the OECD include stringent targets for GHG reductions, setting a price for carbon, removing subsidies for fossil fuels and supporting development of clean energy technologies.[25]

Figure 2: Trends in greenhouse gas emissions since 1990 (shown as CO_2 equivalent) for Victoria by sector, taken from National Greenhouse Accounts (2009/10). Source Australian Department of Climate Change and Energy Efficiency, CfES developed infographic.

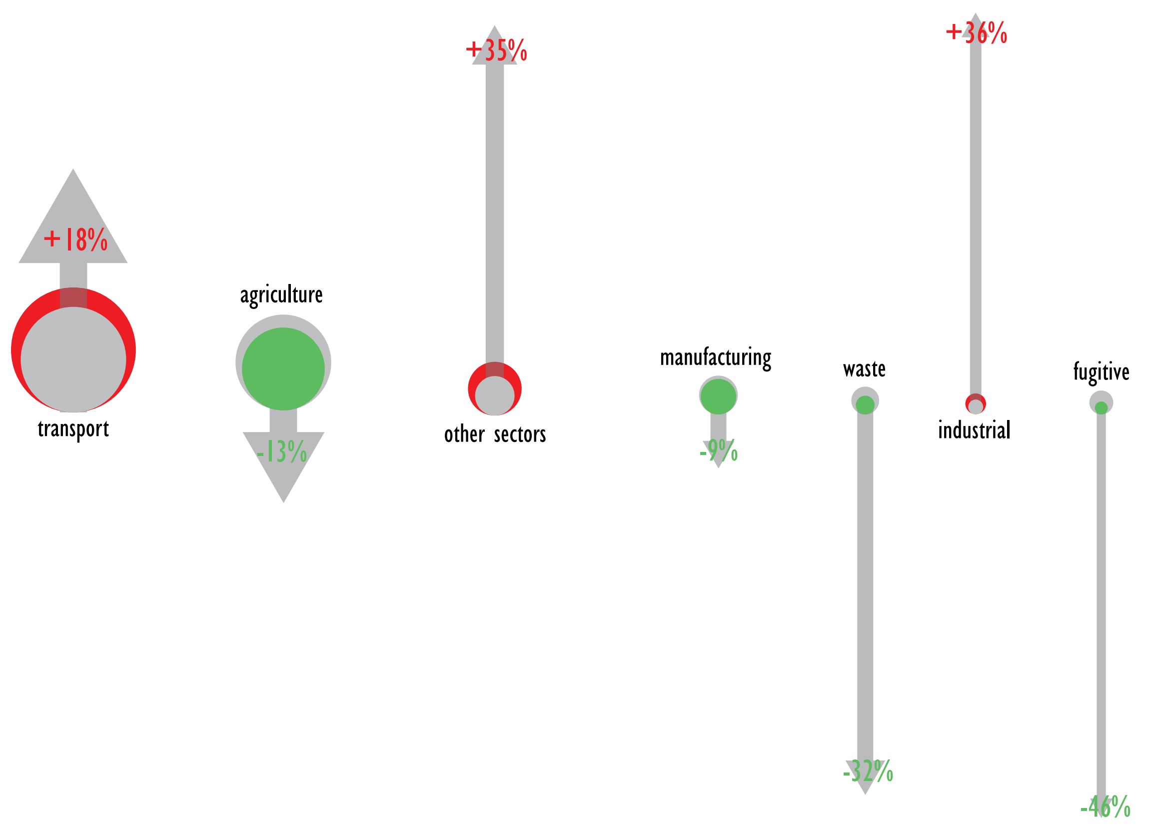


Carbon dioxide from industry, transport and energy generation has the greatest effect on global warming but other gases such as methane and nitrous oxide – anthropogenic sources of which are primarily land-management and agriculture – also make significant contributions.

Each greenhouse gas has a different warming effect on the atmosphere. The combined effect of all greenhouse gases is expressed as the amount of warming that would be caused by an equivalent amount of CO_2 - this is called CO_2e. For example, 1 tonne of methane (CH_4) is expressed as 21 tonnes of CO_2e because over the span of 100 years CH_4 will trap 21 times more heat than carbon dioxide (CO_2) while nitrous oxide (N_2O) will trap 310 times more.[26] This means that small amounts of some gasses have a potent effect on our climate.

Victoria's emissions profile

In Victoria, emissions - reported most recently in the Australia's National Greenhouse Accounts [27] – have shown an increase since 1990 (Figure 2). Although there has been an overall increase in the period, CO_2e emissions have been largely stable since 2000 as increases from the energy and transport sectors have been approximately balanced by reduction in agricultural emissions. This is due, in part, to the fall in livestock numbers associated with the long drought.



IPCC future emissions scenarios

In an effort to promote effective planning for climate change impacts, the IPCC presents several 21st century global economic growth and development scenarios that reflect a range of possible global greenhouse gas emission levels.[28]

These scenarios are:

A1FI: Rapid economic growth and globalisation, where energy is derived from fossil fuels

A1B: Rapid economic growth and globalisation, where energy is derived from a balanced mix of renewable and fossil fuels

A1T: Rapid economic growth and globalisation, where energy is derived from non-fossil sources

A2: Rapid Economic growth and regional development

B1: Economic growth with a more environmental focus, reflecting reductions in resource use and increases in energy efficiency

B2: Sustainable development with a regional focus.

In this foundation paper, to explore climate change possibilities for Victoria, (see section 1.5) we have focussed on three of these scenarios or alternative images. The first two scenarios we use are those where rapid economic growth takes place and (a) we remain committed to the continued and unabated use of fossil fuels (A1FI) and (b) we mix our fuels (A1B). The third scenario we explore is the one where economic growth occurs with a more environmental focus and we reduce our resource use and increase our energy efficiencies. (B1).

Importantly, it needs to be noted that our global emissions are currently tracking closest to A1FI, the first and most resource intense scenario (Figure 3). This business-as-usual path represents a worst-case scenario for climate change outcomes.

However, this does not necessarily mean this is the most likely outcome because concerted global efforts to change the energy mix and consumption patterns may well alter future emissions and their impacts. In other words the global community can still arrest the emissions trajectory.

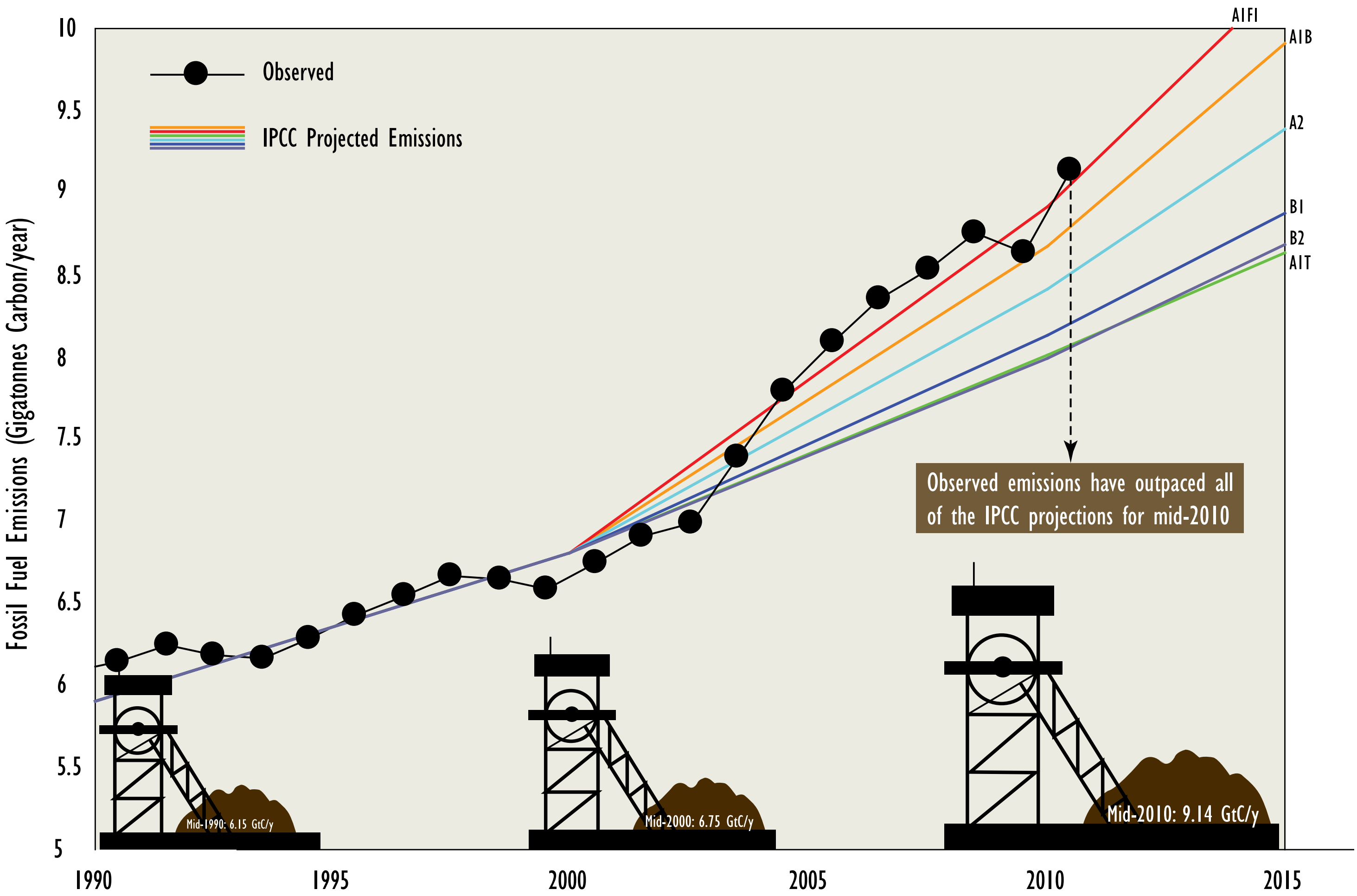


Figure 3:
Global CO_2 emissions from fossil fuels compared to IPCC projections.[29]
(Black dots show the annual increases in CO_2 emissions caused by burning fossil fuels. Coloured lines are the emissions expected by each IPCC scenario from 2000 onwards. Observed emissions are currently tracking at the fossil-fuel-intensive A1FI scenario. The dip in observed emissions in 2009 was caused by the Global Financial Crisis and the resulting drop in industrial activity, rather than by emissions mitigation actions.) Source CSIRO, CfES developed infographic.

1.3 Climate change risks

Rising temperatures

At present, the best CSIRO projections for Victoria suggest a 1.37°C rise by 2050 under a mixed fossil and renewable fuels scenario A1B, The range is suggested as extending from 0.91°C to 1.93°C (Figure 4).[30]

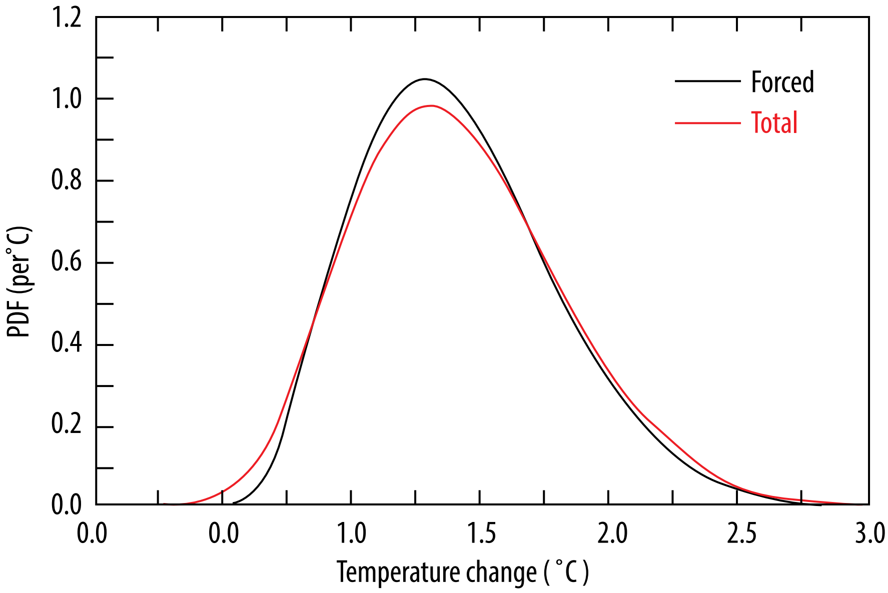


Figure 4: Projected temperature change in central Victoria for 2050 under a mixed fossil and renewable fuels scenario (A1B), represented by Probability Density Functions (PDF) for "Forced" (greenhouse warming alone) change, and for "Total" (greenhouse warming and natural decadal variations) change. Source CSIRO.

As the plotted values increase on the Y axis, the corresponding temperature change on the X axis is more likely. The "Forced" curve shows the expected effect of greenhouse gas warming alone while the "Total" curve includes both greenhouse warming and natural variation in climate. The inclusion of natural variation leads to a slight increase in the uncertainty of outcomes. Figure 5 shows, based on IPCC data, how rising global temperatures are likely to affect us and our environment in Australia.

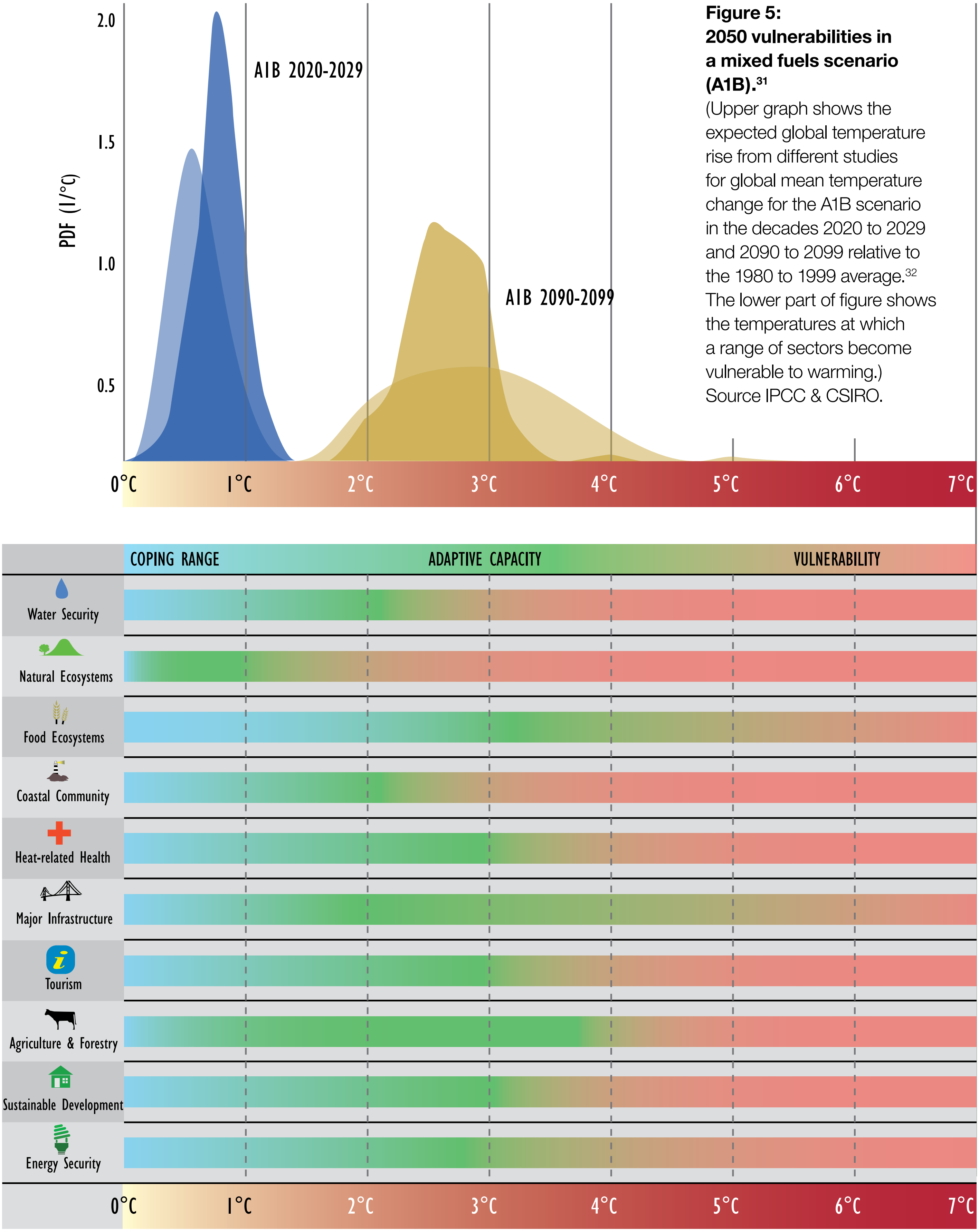


Figure 5: 2050 vulnerabilities in a mixed fuels scenario (A1B).[31]
(Upper graph shows the expected global temperature rise from different studies for global mean temperature change for the A1B scenario in the decades 2020 to 2029 and 2090 to 2099 relative to the 1980 to 1999 average.[32] The lower part of figure shows the temperatures at which a range of sectors become vulnerable to warming.) Source IPCC & CSIRO.

Changes to ocean circulation patterns mean that some areas of the Tasman Sea are as much as 2°C warmer than 60 years ago.[33]

1.4 Hazards and vulnerabilities for Victoria

It is apparent that projected warming for 2030 represents the upper coping limit for most ecosystems. As temperatures rise, so will environmental vulnerabilities and exposure to hazards. Risks faced will include impacts of intense storms, flash flooding and sea-level rise, loss of biodiversity and primary production, along with the migration of pest species and the increased ability of pest species to survive the warmer climate and drought impacts.

Our oceans and climate change

Long-term, slow-onset changes such as changes to the oceans around Australia will also expose vulnerabilities in natural and human systems.

Oceans are one of the primary drivers for weather and climate in Australia.

Monitoring of rising sea levels is of paramount importance for coastal communities. Changes to ocean circulation patterns mean that some areas of the Tasman Sea are as much as 2°C warmer than 60 years ago.[33] Effects of these changes in the ocean will be clearly seen in changes to marine ecosystems off our coasts. There are biodiversity hotspots of global importance that will be subject to rising temperatures at the sea surface and changing currents. Distributions of species will change as fish move southwards towards cooler waters and the impacts will be both ecological and economic.

Mushroom Reef.

Image courtesy of Parks Victoria and Museum of Victoria.

Our rainfall

In Victoria, it is expected that we will see an increase in mean temperatures. However, there is uncertainty surrounding the level of rainfall changes in our corner of Australia, but regardless of this there is still high confidence that our state will become drier as extreme events (very intense bursts of rainfall and heatwaves) will become more common.[34]

The best estimates currently say that it is likely that Victoria will experience a decrease in mean rainfall levels. Under a mixed fossil and renewable fuels scenario (A1B), the most likely change by 2050 is a decrease in mean rainfall of 6% (although this change may be as high as 14% or as low as no change at all). When natural variability is included with human-induced changes the range of possibilities becomes larger - from a possible decrease of 17% to an increase of 5% (Figure 6).[35]

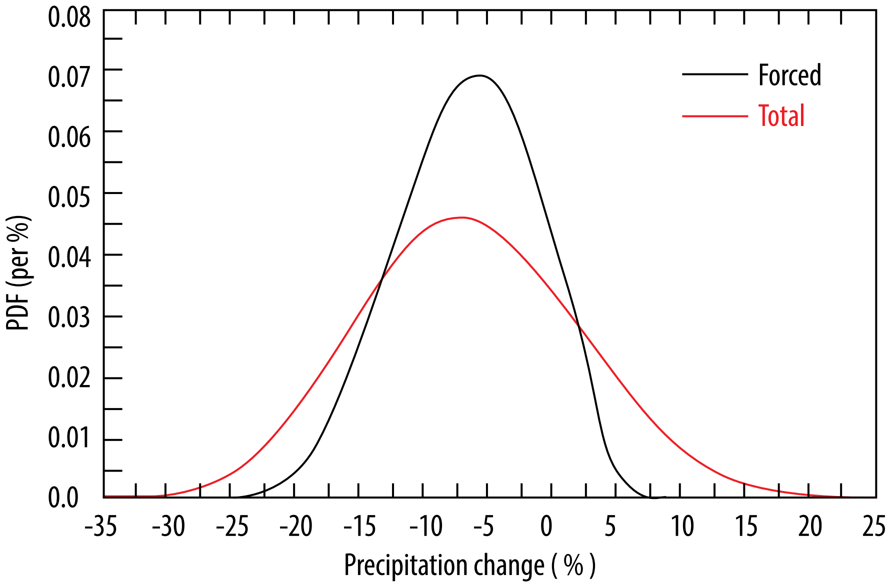


Figure 6: Projected precipitation change in central Victoria for 2050 under a mixed fossil and renewable fuels scenario (A1B), represented by Probability Density Functions (PDF) for "Forced" (greenhouse warming alone) change, and for "Total" (greenhouse warming and natural decadal variations) change. Source CSIRO.

Although there are likely to be decreases in average rainfall we are also expected to experience an increase in the intensity of the highest 1% of rainfall events. In other words, there will be more dry days but the days when it does rain will be wetter. These changes will be most pronounced in summer and autumn.[36] This means we will continue to have the kind of extreme rains we saw in February and March of 2011 (Figure 7) and 2012 and that events of this nature may become more severe. This possibility must be a key factor of future planning.

2010-11 Flooding

$836M in insurance claims

123,077 hectares of grazing pasture damaged

345,645 deceased livestock (330,184 poultry)

189 public housing properties damaged

239 schools effected

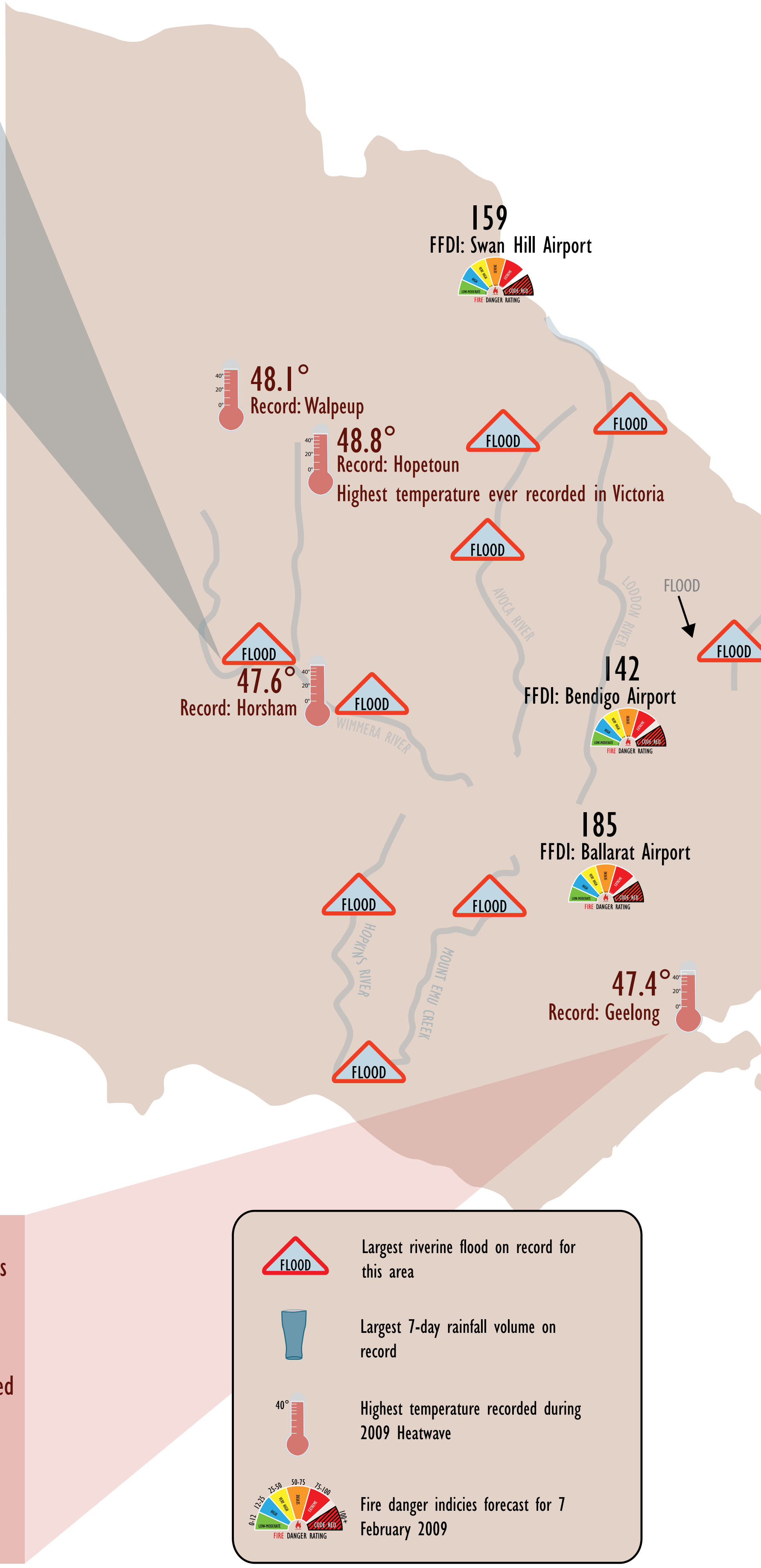


Figure 7: Record-breaking Weather 2009/12.
Distribution of record breaking weather events in Victoria since 2009.[37]
Source Bushfires CRC, BoM, Department of Health, Vic and Comrie Flood Review, CfES developed infographic.

January-February 2009 Heatwave

12-15° increase over normal maximum temperatures

25% increase in emergency cases (46% over the hottest 3 days

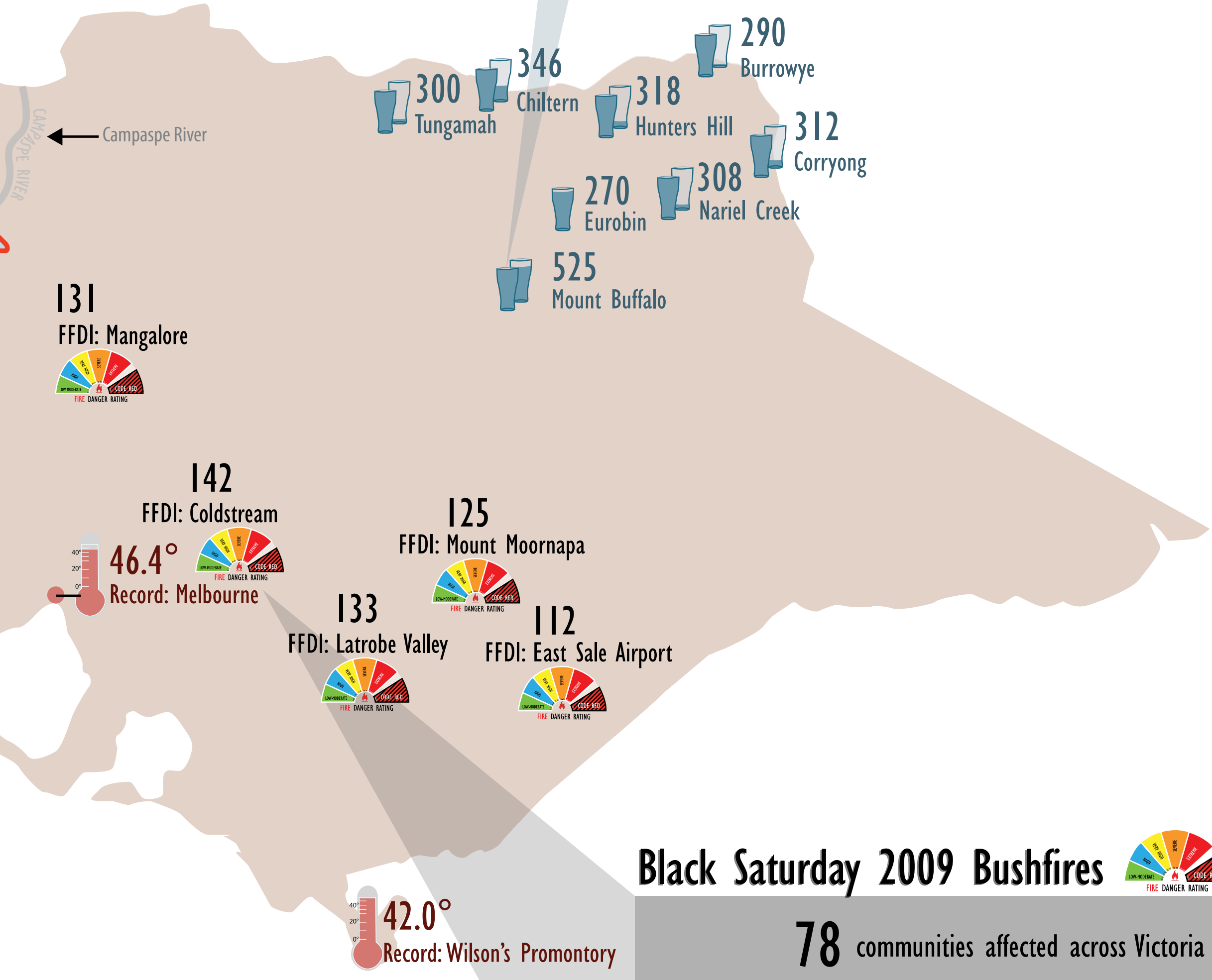
34 fold increase in cases with direct heat-related conditions (61% of cases in people 75+)

374 excess deaths

3 days above 43°, unprecedented

2012 Record-breaking Rainfalls

6+	rivers experiencing major flooding
130+	road closures
#1	wettest 7-day period on record for any month
24	number of 7-day rainfall records broken in Victoria
90.25	average number of years of previous high 7-day rainfall



Black Saturday 2009 Bushfires

78	communities affected across Victoria
388,000	hectares burnt
2,298	houses destroyed
$926M	in economic losses (after government aid)
173	deaths

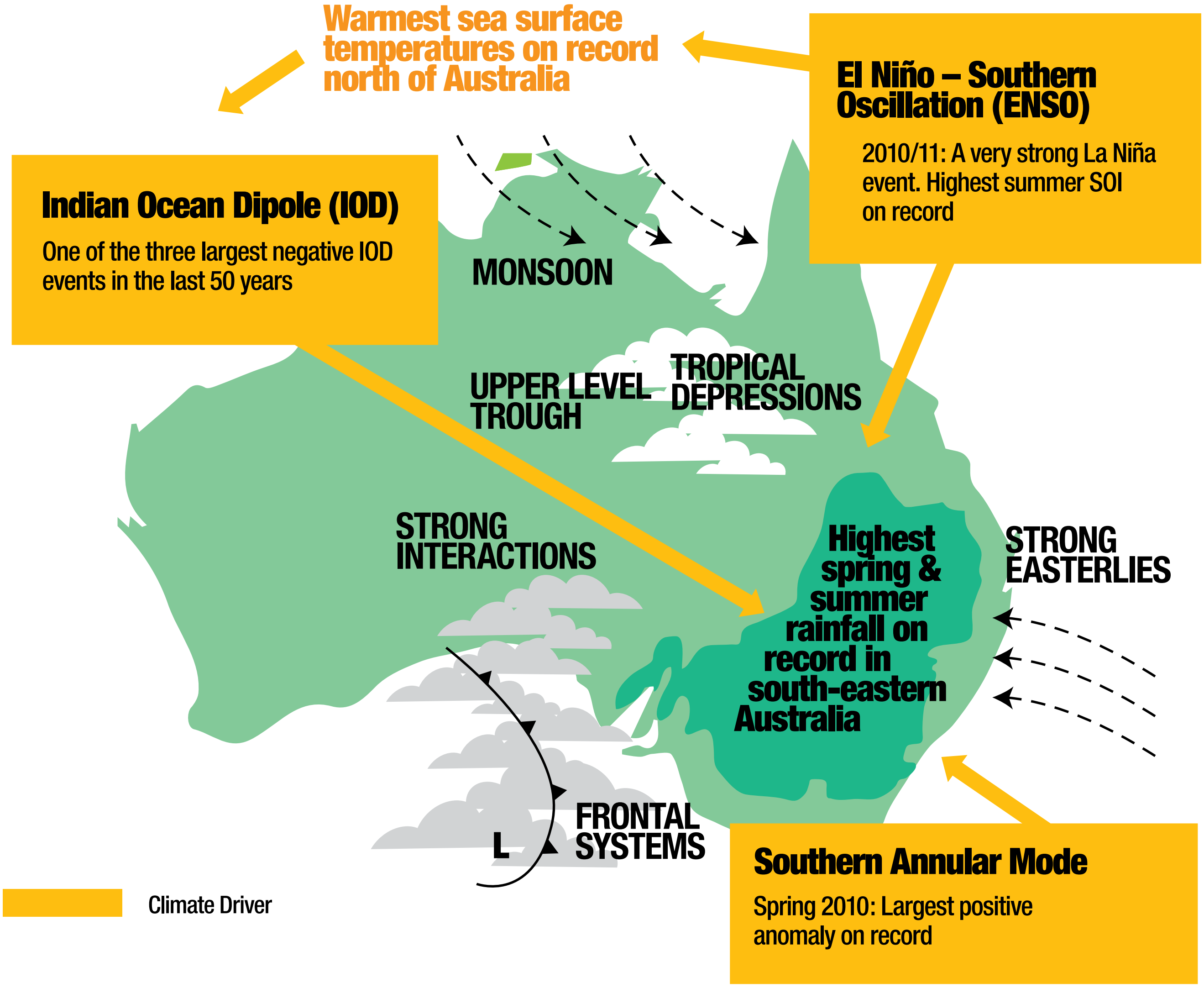
Explaining the Millenium Drought and 2010/11 floods

The model projections that show drier, hotter climates in Victoria may seem at odds with the cool, wet summers we saw in 2010 and 2011.

These episodes were driven by a number of factors, including the La Niña effect, and demonstrate that the weather can be highly variable on a year to year basis. La Niña is the positive phase of the El Niño Southern Oscillation. It is associated with cooler than average sea surface temperatures (SSTs) in the central and eastern tropical Pacific Ocean. La Niña is normally associated with higher than average winter, spring and early summer rainfall over much of Australia (Figure 8).

The South-Eastern Australian Climate Initiative (SEACI) researchers analysed the climate record and provide the following explanations regarding the Millennium Drought and 2010/11 floods.

> *Throughout this La Niña episode the greatest rainfall anomalies in south-eastern Australia were recorded in spring (247 mm, or 60% above the 20th century average) and in the 2010/11 summer when 303 mm was recorded (150% above the 20th century average). This is the largest summer total* ***ever recorded*** *(emphasis added) by a considerable margin.*
>
> *The impact of the strong La Niña was exacerbated by the Southern Annular Mode (SAM), which reached record positive values in late spring and early summer of 2010. In addition, one of the largest negative Indian Ocean Dipole (IOD) events of the last 50 years was recorded in 2010.*
>
> *SEACI researchers have analysed the observed climate record and found that the El Niño – Southern Oscillation and other large-scale modes of variability cannot explain the observed decline in autumn and early-winter rainfall in south-eastern Australia.*
>
> *SEACI researchers have, however, found a strong relationship between the rainfall decline in south-eastern Australia and the intensity of the subtropical ridge (STR), with the decrease in rainfall strongly associated with increasing surface pressure in the latitudes of the STR. The strengthening of the STR is estimated to account for around 80% of the recent rainfall decline in south-eastern Australia.*
>
> *Research indicates that there are changes in the Hadley Cell (and hence changes in the STR) associated with global warming. In particular, the STR has intensified with increasing global surface temperature. This result implies that the rainfall decline in south-eastern Australia may have some link to global warming. To investigate this, SEACI researchers conducted simulations of the global climate over recent decades using a global climate model and different external forcings (natural and anthropogenic). In these simulations, the climate model was only able to reproduce STR increases and other modifications of the Hadley Cell when anthropogenic forcings (e.g. greenhouse gases) were present in the simulation along with the natural forcings.*
>
> *This gives confidence that there is a link between the rainfall decline across south-eastern Australia and increasing greenhouse gas concentrations in the atmosphere.*[38]



Australia can continue to expect cool, wet years and whilst there may not yet be a full understanding of how climate change will affect these processes, the evidence indicates that it does.[40] There is confidence that these cool, wet years will occur in a context of a long-term climate that is both hotter and drier and we should not expect periodic, short-term wet years to recharge dry landscapes.[41]

Figure 8: In 2010/11 south-eastern Australia recorded record-breaking rainfall in spring and summer due to the combination of the positive phase of all large-scale modes of variability known to contribute to the year-to-year variability of rainfall: ENSO, IOD and SAM. Source SEACI. Modified by CfES.[39]

Overall, short-term projections indicate that there will be increases in acute hazards, while in the long-term, changes in baseline conditions will mean that vulnerable systems will need to adapt or risk being overwhelmed.

An increase in extreme events….

In Victoria, we are experiencing extreme events such as heatwaves, storms, drought and bushfire more often. These events are immediate and easily observed and raise questions about whether they are the result of climate change and how global climate change will affect our lives.

An increase in these events is consistent with a warming planet but, as already noted, linking individual events to climate change is problematic as this requires long-term climatic data sets of 30 years or more. Some analyses of this nature have been carried out in the UK and concluded it was "very likely that global anthropogenic greenhouse gas emissions substantially increased the risk of flood occurrence".[42] Such studies are rare, but are likely to become less so.

The increasing frequency of these events led the IPCC to produce a special report in 2011 that brought together the best scientific projections on changes in extreme weather at a global scale.[43]

The IPCC concluded that:

- It is "virtually certain (99-100% probability)" that heat extremes will increase and cool extremes will decrease.
- It is "very likely (90-100% probability)" that heat waves will increase over most land areas and extreme high water levels will occur with sea level rise.
- It is "likely (66-100% probability)" that increases in rainfall will occur over some land areas (medium confidence that they may also accompany a mean rainfall decrease in some areas), and tropical cyclone mean wind speed will increase but numbers of actual events will remain unchanged or decrease.

Overall, short-term projections indicate that there will be increases in acute hazards, while in the long-term, changes in baseline conditions will mean that vulnerable systems will need to adapt or risk being overwhelmed (Figure 9).

The economic strain

The effects of more frequent extreme weather events have been recognised as an issue by the financial industry, particularly the insurance sector. The sector recognises that mechanisms must be developed to manage and compensate for the consequences of these events. Insurance provides a key method for businesses and individuals to manage financial risk.

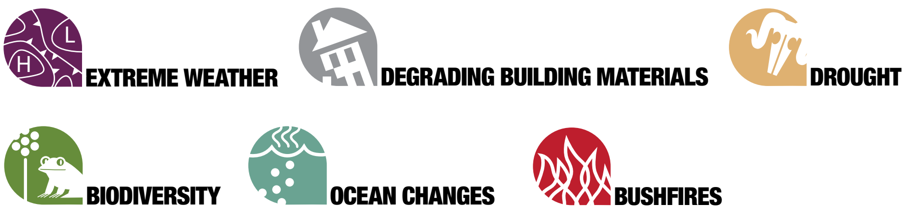
Economic losses amounted to some US$ 380bn in 2011 making it the most expensive natural disaster year to date, multiples more than the previous record (US$ 220bn) set in 2005. At US$ 105bn, insured losses also were at new high. The loss figures were dominated by 2011's earthquakes – in addition to Japan, above all the devastating event in New Zealand. However the year also saw the floods in Australia, Thailand, France and Italy and the tornado outbreak in the USA.

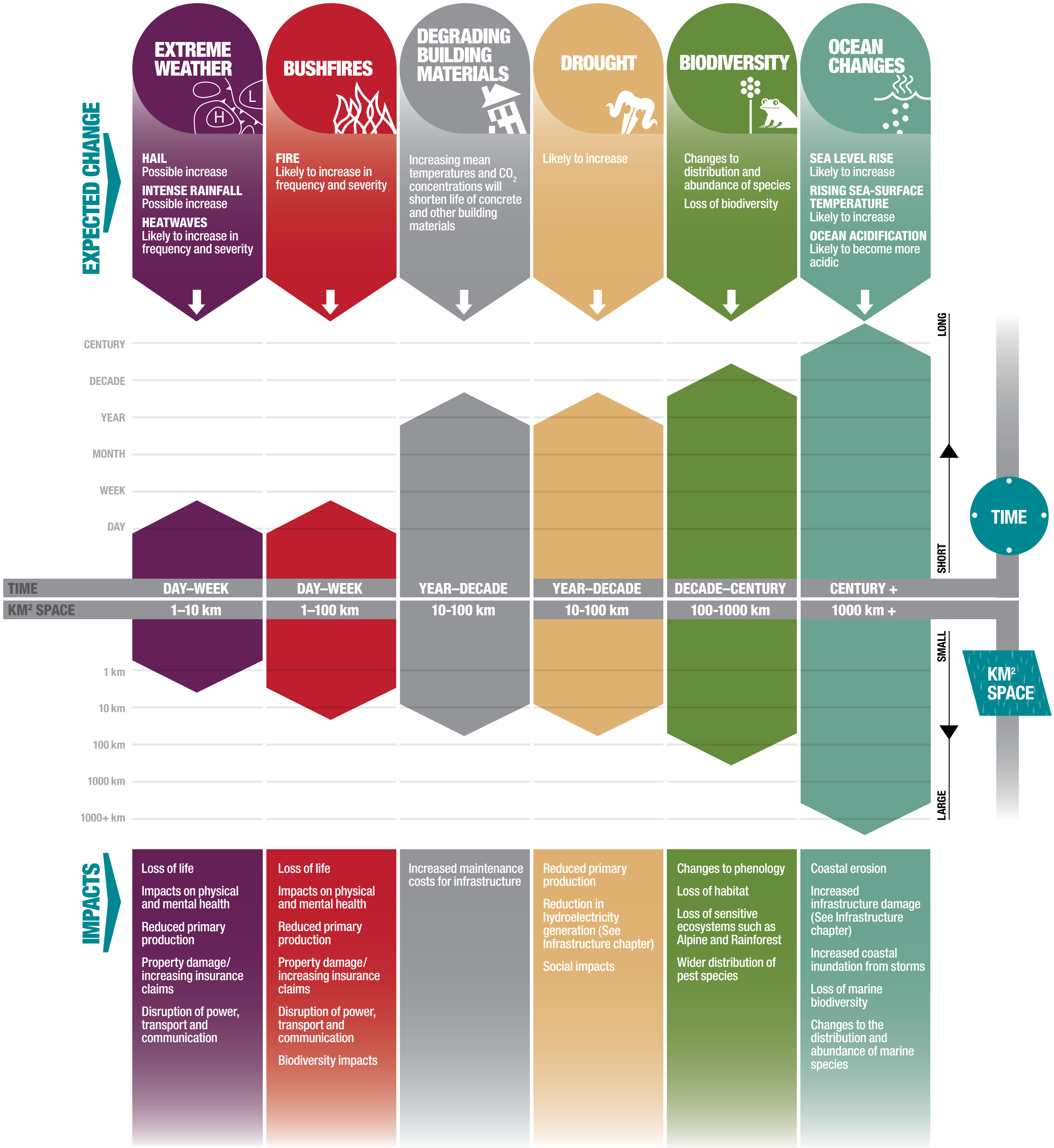
The reinsurer, Munich Re, in reporting these figures states that weather-related risks in the USA and Canada are constantly changing as a result of anthropogenic climate change and natural climate cycles like La Niña.[44]

Munich Re was considering the potential impact of climate change on business as early as the 1970's.

Economic losses amounted to some US$ 380bn in 2011 making it the most expensive natural disaster year to date...

Figure 9: Scale and onset time of climate change hazards in Victoria.
Source IPCC, CSIRO CfES developed infographic.





1.5 Our climate types

Köppen's scheme to classify world climates was devised in 1918 by Dr Wladimir Köppen of the University of Graz in Austria[45] and has achieved wide acceptance amongst climatologists. In 2000, the Australian Bureau of Meteorology produced a modification of the Köppen climate classification system,[46] to better address the relationship between climatic subdivisions, features of the natural landscape and the human experience of climate, and applied the modification to Australia.

Pursuant to the classification system, the climate types that typify south-east Australia (Victoria) are:

Subtropical: Moist climate that can be cool or warm.

Subclasses:

- No dry season
- Moderately dry winter

Temperate: Lower temperatures and higher rainfall than Grassland.

Subclasses:

- No dry season (hot summer)
- Moderately dry winter (hot summer)
- Distinctly dry (and hot) summer
- No dry season (warm summer)
- Distinctly dry (and warm) summer
- No dry season (mild summer)
- Distinctly dry (and mild) summer
- No dry season (cool summer)

Grassland: Dry climate with warm to hot temperatures.

Subclasses:

- Hot (persistently dry)
- Warm (persistently dry)

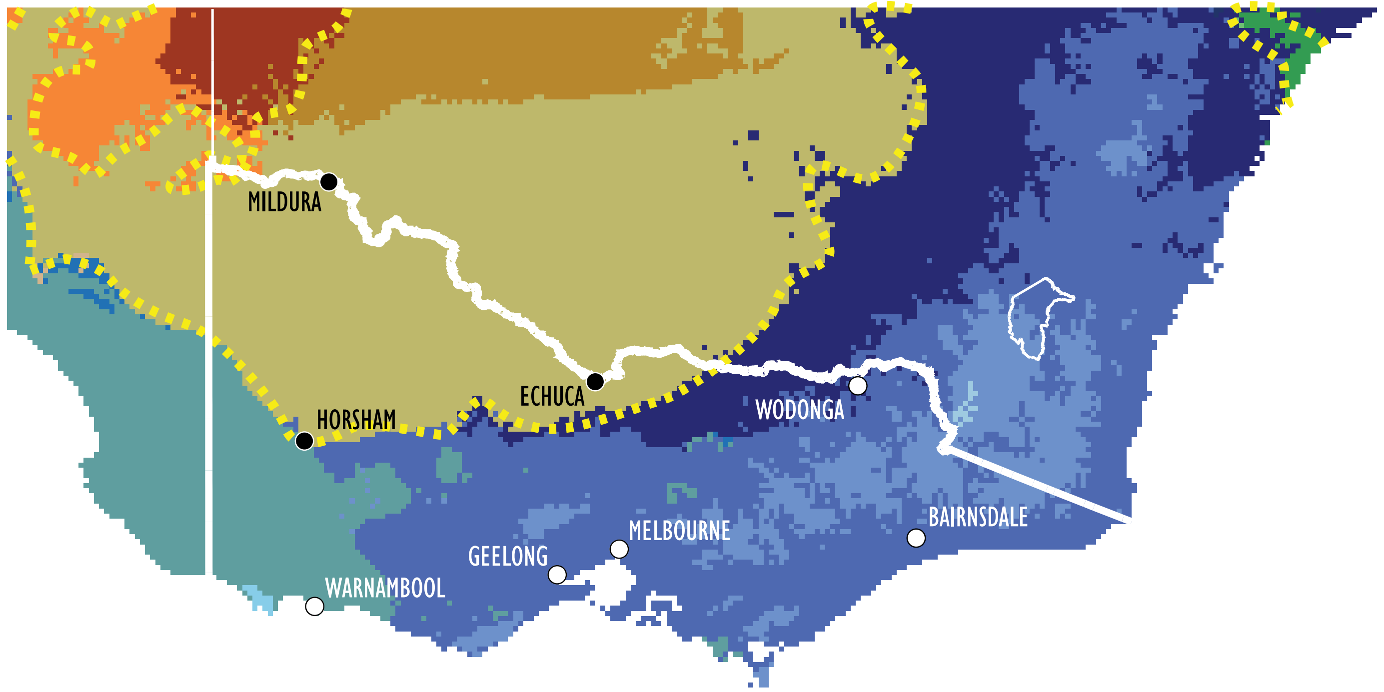
Desert: High temperatures; persistently dry - typical of much of the interior of Australia.

Subclasses:

- Hot (persistently dry)
- Warm (persistently dry)

When mapped for the 30-year period between 1975 and 2004 (Figure 10) the data show that Victoria is dominated by two broad climate types: ***Grassland*** in the northern plains and ***Temperate*** in the southern and mountain areas. Our state borders on the ***Desert*** climate type in the northwest, close to Mildura.

Baseline Climate: 1975-2004



TEMPERATE

- * TE no dry season (hot summer)
- TE moderately dry winter (hot summer)
- TE distinctly dry winter (hot summer)
- * TE distinctly dry (and hot) summer
- * TE no dry season (warm summer)
- TE moderately dry winter (warm summer)
- TE distinctly dry winter (warm summer)
- * TE distinctly dry (and warm) summer
- * TE no dry season (mild summer)
- TE moderately dry winter (mild summer)
- * TE distinctly dry (and mild) summer
- * TE no dry season (cool summer)

GRASSLAND

- * GR hot (persistently dry)
- GR hot (summer drought)
- GR hot (winter drought)
- * GR warm (persistently dry)
- * GR warm (summer drought)
- GR warm (winter drought)

SUBTROPICAL

- * ST no dry season
- * ST distinctly dry summer
- ST distinctly dry winter
- ST moderately dry winter

DESERT

- * DE hot (persistently dry)
- DE hot (winter drought)
- * DE warm (persistently dry)

Boundary between broad climate classes

* Climate class appears on map

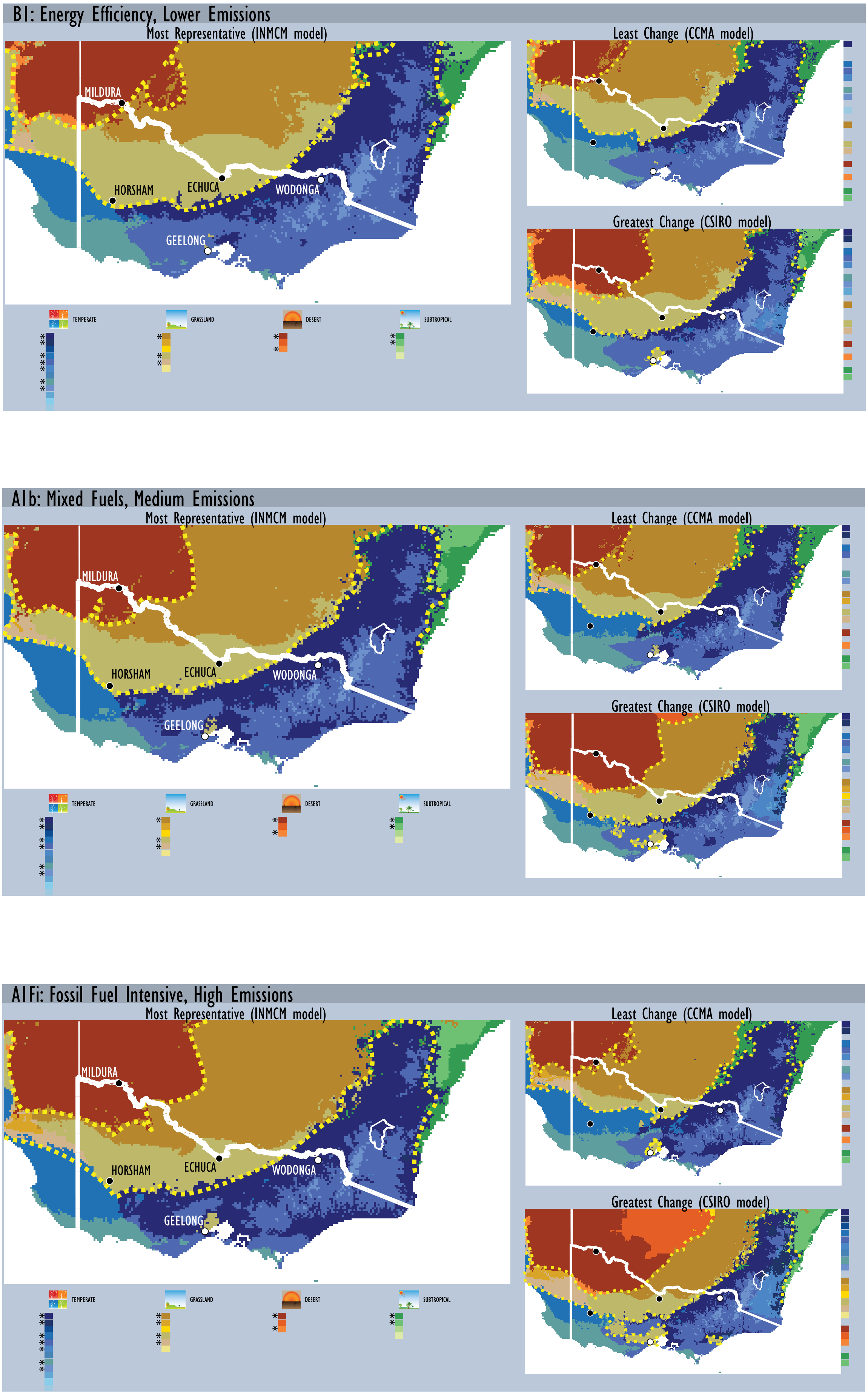


Figure 10:
Modified Köppen climate classification for southeastern Australia for the period 1975-2004 compared to modelled outcomes for the year 2050 under IPCC scenarios A1FI, A1b and B2.
Source BoM, CSIRO, CfES developed infographic.

Future Climate in Victoria

At our request CSIRO has provided us with Victorian climate change data from the output of 23 global climate models. Use of these 23 models - which projected the outcomes of 3 IPCC scenarios (A1FI, A1B and B1) and set them within the context of the modified Koppen climate classification - allows us to examine, compare and contrast potential ranges of climate change outcomes in Victoria.

Climate models are complex computer simulations founded on the basic laws of physics, chemistry and fluid motion and they have been used for weather forecasting, understanding climate and determining climate change possibilities. The first climate model was developed in 1969 by Drs Syukuro Manabe and Kirk Bryan. In 1975 Drs Manabe and Richard T Wetherald first applied modelling to simulate climate change.[47]

Each of the models developed by climate scientists represents potential future climate processes a little differently depending on assumptions. These differences do not indicate disagreement between researchers but rather reflect uncertainties in how best to represent complex processes.

We tracked the modelled results for Victoria and mapped the outcomes across the state for 2050 (Figure 10).

The Australian Bureau of Meteorology's modified climate classification system has been applied to the data, in order to determine how the output of the various models is reflected in the range of possible future climate classes in the state.[48]

This work has not been undertaken before.

Consideration of the results from an examination of each of the 23 models illustrates a best assessment of the possible variations in climate associated with climate change scenarios.

Projections show a range of magnitude in changes, but most of them indicate a southward movement of the Temperate and Grassland climate and movement of Desert climate into the northwest of the state. This movement reflects rising temperatures and a general decrease in rainfall in most of the 23 models.

In the material which follows we present a mid-range case that is most representative of the range of outcomes. We also present the cases that show the most and the least possible change.

Change in Victoria over time according to the three scenarios

The range of modelled results indicate that, if global greenhouse gas emissions continue on their present path, the shifts in climate type in a given region may vary in magnitude. This range of possible outcomes is mainly driven by uncertainties in the response of rainfall patterns to global warming. Whilst all the models agree that temperatures will rise, there is greater uncertainty in the response of rainfall patterns.

The majority of outcomes show less rainfall across the state.

Taking all the model projections and summarising them for south-east Australia, we find that by 2050 the projection is for a substantial decrease in the *Temperate* climate area and this is matched by an increase in *Desert* climate (Figure 11).

A relatively small change is anticipated in the extent of broad *Grassland* climate, but there is a shift from the warm subclass to the hot subclass in the area under study. This demonstrates a rise in mean temperatures.

An increase in the extent of *Subtropical* climate is projected as this zone is expected to move southward. New South Wales mainly feels this impact, but the projected movement may be of importance in Victoria in the second half of the 20th century as climate zones continue to move southward.

The ecosystem impacts of these changes will be complex but are likely to include: reduced snow cover, changes in fire dynamics, more invasive species and changes in ranges of species currently present in Victoria, either southwards or to higher altitudes.[49] It is expected that many vulnerable species will experience contractions of their current ranges.[50]

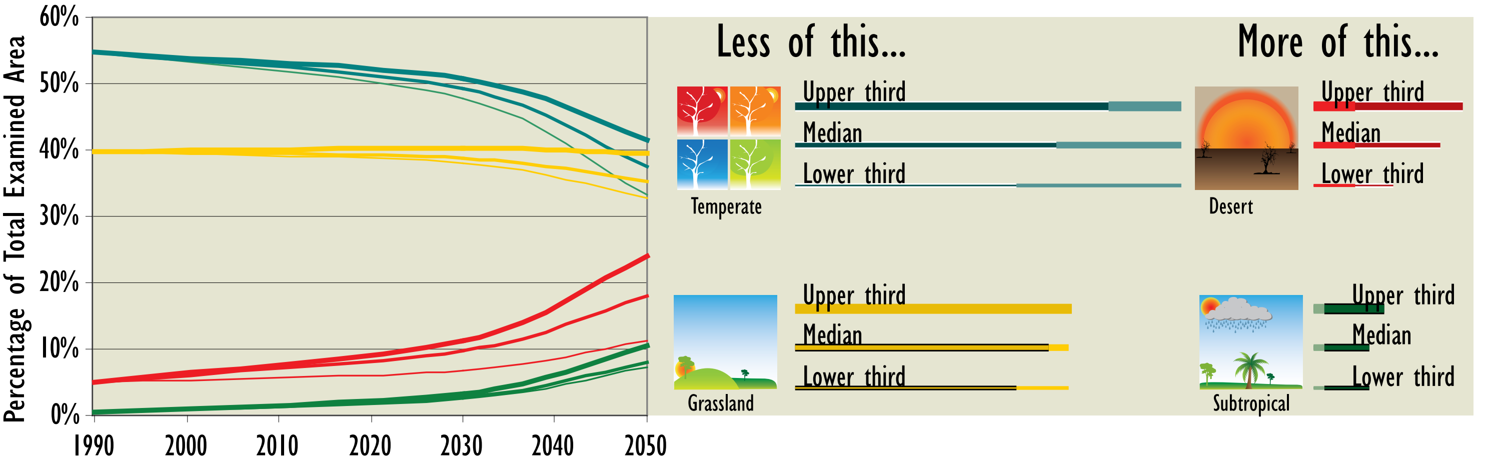


Figure 11: Projected change in area covered by *Subtropical, Temperate, Grassland* and *Desert* climates in SE Australia in 2030 and 2050 compared to 1990 under an unabated use of fossil fuels scenario (A1FI). The plots summarise the output of 23 global climate change models and show the median change across all models and the range of the middle 33% of changes. Source BoM, CfES developed infographic.

We will also see the emergence of a dry *Grassland* zone to the west of Melbourne and an increasingly hot climate over Melbourne itself.

Temperatures will rise, rainfall will decrease

From the perspective of Victorian settlements, there are several striking outcomes present in these modelling projections for south-eastern Australia.

Among these are the southward movement of a *Desert* climate into the Mallee. We will also see the emergence of a dry *Grassland* zone to the west of Melbourne and an increasingly hot climate over Melbourne itself. We examined these areas in more detail by analysing the possible changes in three communities: *Mildura, Avalon* and *Melbourne CBD* (Figure 12).

Mildura

At present, Mildura sits in a *Warm Grassland* climate. As temperatures rise, most models show movement of hot-dry climate types into the northwest of Victoria by 2050. Under the A1FI scenario, 57% of models show *Hot Desert* climate over Mildura, while the rest show *Hot Grassland*. Under the A1B scenario, the proportion of models showing *Hot Desert* climate over Mildura falls slightly to 52% and under the B1 scenario, only five models show this outcome. Even under the B1 scenario, all models show a change from the climate currently experienced.

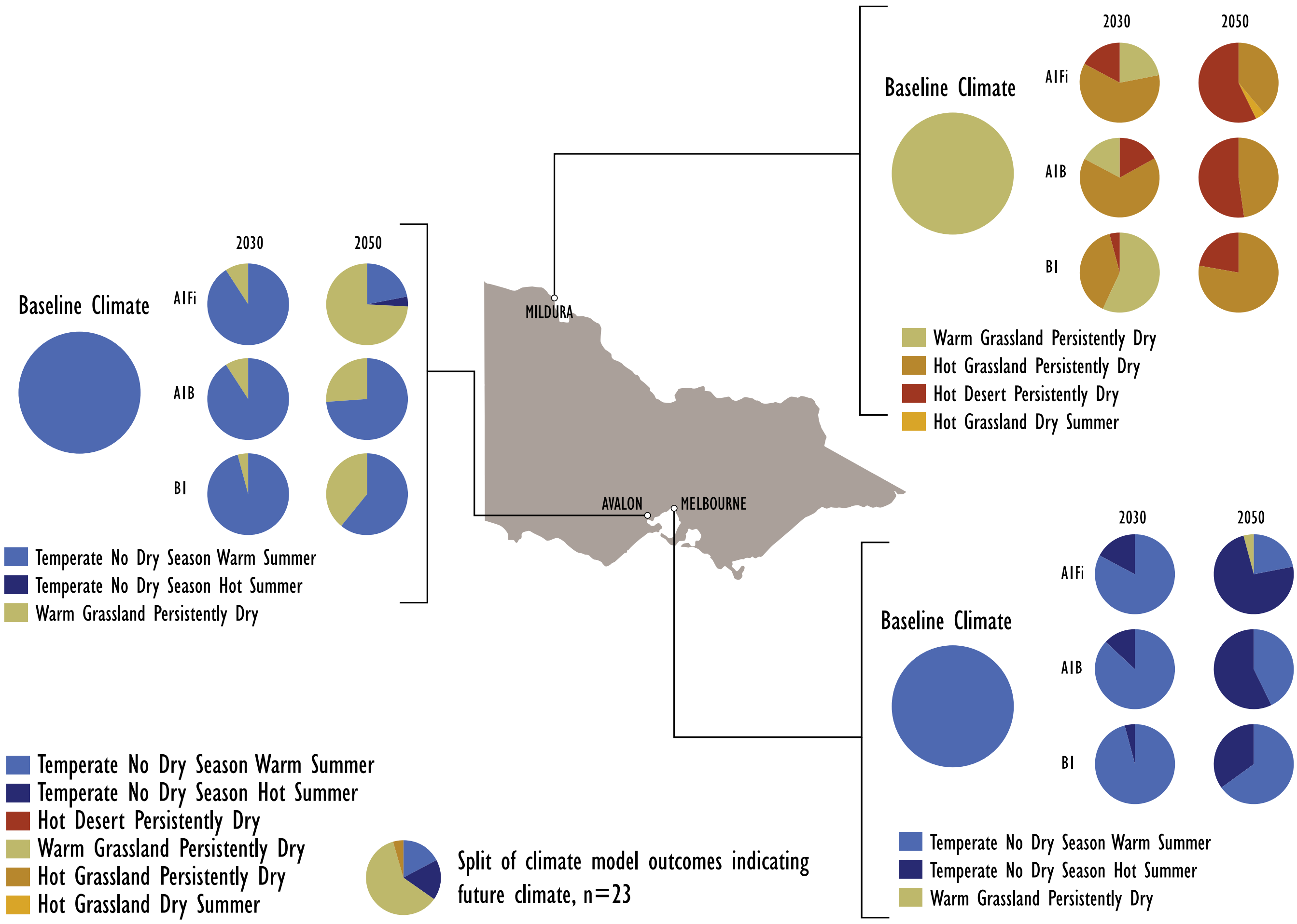
Avalon

Avalon lies to the west of Melbourne in an area of the state that is particularly dry. As mean global temperatures increase, this dryness will become more pronounced and, in the consensus model (A1FI), the area around Avalon shows a shift from the present *Temperate* climate, to a drier *Warm Grassland*. Figure 11 shows how the scenarios influence this transition. By 2050, under the A1FI scenario, the *Warm Grassland, Persistently Dry* climate class is the most likely outcome (found in 17 of 23 models).

Melbourne CBD

Melbourne's CBD has an observable urban heat island effect, wherein the expanse of urban infrastructure acts to raise temperatures several degrees above the surrounding area. In the next 40 years, the model outputs suggest that this effect will act to create a climate class around the city that is observably warmer. This can be seen in the mid-case map for the A1B scenario (Figure 12) where Melbourne has *a Temperate Hot Summer* class, compared to *Temperate Warm Summer* class in the surrounding areas.

Comparison of the model outputs indicates that, under the A1FI scenario, *Temperate Hot Summer* is the most likely outcome (found in 17 of 23 models) and transition to *Grassland* class is also a possibility by 2050.



The discussion of the 23 models and projections presents a number of possible climate change outcomes in Australia. The differences in outcomes according to the SE Australia scenarios provide us with a powerful reminder of the importance of immediate and committed action to limit global greenhouse gas emissions.

Figure 12: Climate trends in 2050 for Mildura, Avalon and Melbourne CBD based on the 23 global climate models for the IPCC emissions scenarios A1FI, A1B and B1. Source BoM, CfES developed infographic.

This work reinforces our research. In a warming world, warmer and drier Australian climates will migrate southward.

Analogue Township Model

The threat of a global mean temperature rise of 4°C has also been examined in detail by CSIRO. Scientists have concluded that if there were a rise of 4°C globally, we could expect increases of 3 to 5°C in coastal areas and 4 to 6°C inland. Decline in rainfall would be likely in southern Australia, especially in winter. Near complete loss of snow cover could be expected in alpine regions.[51]

To provide an appreciation of the potential for change in highly localised terms, CSIRO has developed an 'analogue township' model. This approach examines the projected future climate conditions for selected towns and cities and finds locations in Australia where such conditions already exist.

Research like this gives us a complementary view to the changing climate classifications shown earlier. Where the climate classification maps show us how climate zones will migrate southwards, this work presents possible changes as if the climate remained stationary and towns moved northwards. Using this method, we can look to other communities for guidance on how best to adapt to future climates.

There are a range of possible futures with a global 4°C temperature rise, due to different model results. Analogue towns have been identified for several such outcomes.

With a small rise in temperature and increase in rainfall, Melbourne is expected to have a climate similar to the one we currently see in Wyalong, NSW. Under the hottest, driest outcome, Melbourne should expect to experience the climate of Leeton NSW.

The full range of analogue township expected future climates is shown in Figure 13 where we have represented Melbourne and Nhill.

This work reinforces our research. In a warming world, warmer and drier Australian climates will migrate southward.

Victorian communities will need to consider strategies to deal with this change across a broad range of lifestyles and sectors. Innovation is likely to be a key factor for our continued wellbeing and prosperity.

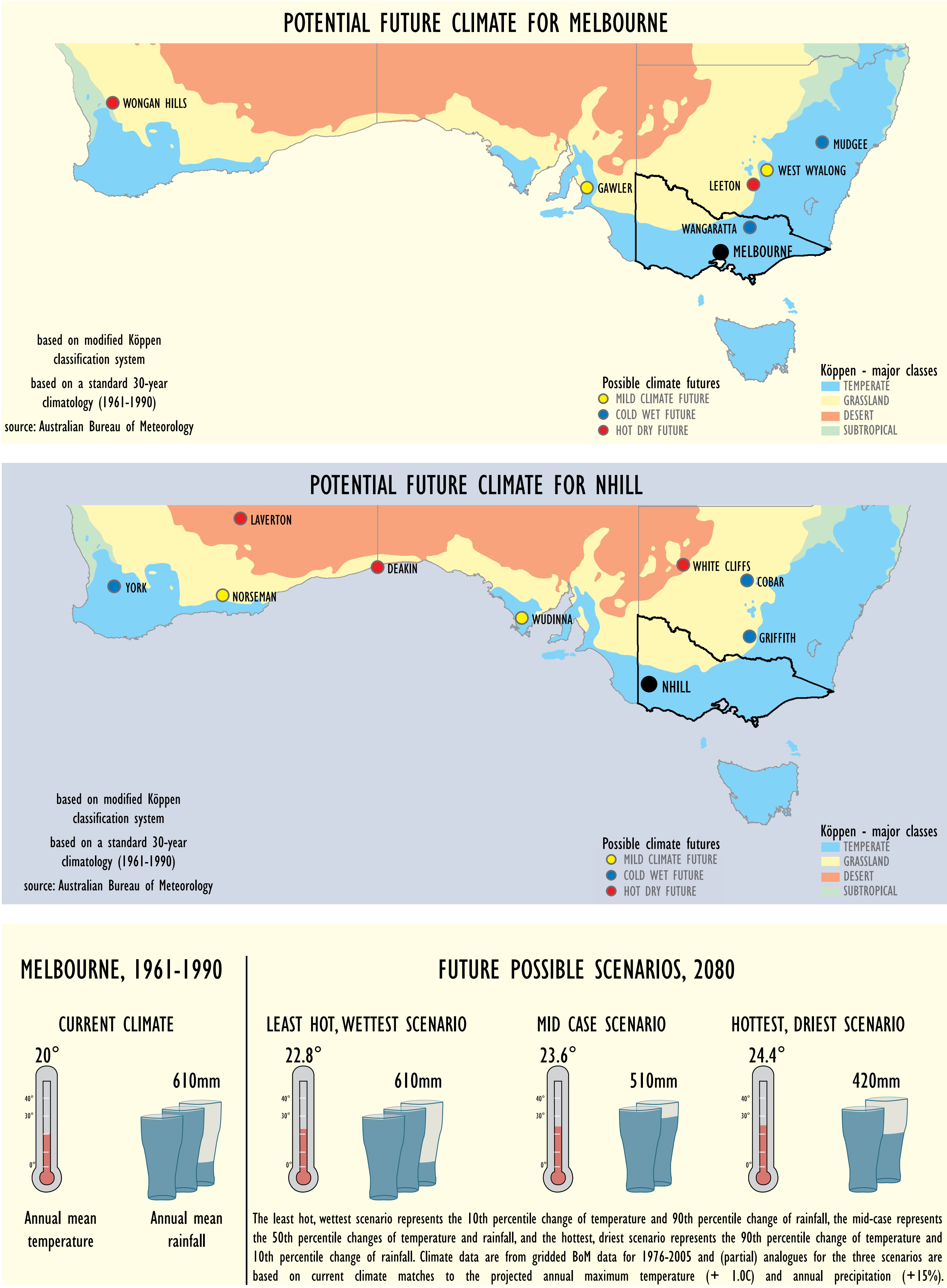


Figure 13:
Possible climates for Melbourne and Nhill in 2080 – assuming an increase of 4°C of mean global warming.
Red indicates the hottest, driest scenario' yellow the mid-range scenario and; blue the least hot, wettest scenario. Source CSIRO.

CHAPTER **TWO** - BIODIVERSITY AND CLIMATE CHANGE

Climate change is predicted to compound existing pressures on Victoria's biodiversity and ecosystems.[53]

This chapter discusses the impacts of climate change on Victoria's biodiversity and primary production. Pressures other than climate change (and management responses) will be discussed in the upcoming *Biodiversity and Land Foundation Paper*. The impacts of drought and flood on primary production are discussed in Chapter Four.

Biodiversity is critically important to our wellbeing.

> 'There is an increasing recognition that protecting other species is a smart strategy for the long-term benefit of humans … our crops, domestic animals, pharmaceuticals and other chemicals, building materials, fuels and many other products … come from other species, ecosystems and biodiversity … regulate the atmosphere, maintain soil fertility, promote food production, regulate water flows, control pests and manage waste disposal.'[52]

Climate change is predicted to compound existing pressures on Victoria's biodiversity and ecosystems.[53] The capacity of natural ecosystems to adapt to climate change will be improved if existing threats are addressed.

Projections of significant shifts in local climates, and increases in disturbances such as bushfires and storms, will impact on Victoria's natural ecosystems and primary production industries alike. Impacts will not be limited to Victoria's terrestrial environments, with ocean warming, acidification and sea level rise predicted to impact on marine ecosystems.

Strathbogie butterflies.

CfES image.

2.1 Biodiversity and ecosystem health

Australia's unique and 'megadiverse'[v] natural environments are already responding to climate change.

Species are moving to higher elevations in alpine regions, some species' ranges are expanding southward to cooler climates, migratory birds are arriving earlier and departing later, mating seasons are occurring earlier, and coral bleaching appears to be occurring at elevated rates.

These responses not only indicate that climate change is already affecting biodiversity, but that this is occurring significantly faster than expected and with modest temperature change (< 1°C) when compared with projections.[54]

A warming of 1 to 1.5°C is already understood to put natural ecosystems at risk, and increase the likelihood of extinction of species vulnerable to climate change. A rise of over 2°C is likely to greatly accelerate extinctions and wide-scale changes to natural ecosystems.[55]

Although most Victorian species appear able to withstand short-term climatic variability, longer-term shifts in climate and the increased frequency or intensity of extreme events will provide a significant challenge to the survival of many species because of their limited capacity to adapt to changing environments.

If the adaptive capacity of species is exceeded, migration to more suitable conditions will be a necessity. A compounding factor in Victoria is that the high level of habitat fragmentation will limit the migration opportunities of the less-mobile species. Species inhabiting high-altitude or southerly habitats will have limited scope to migrate.

A warming of 1 to 1.5°C is already understood to put natural ecosystems at risk, and increase the likelihood of extinction of species vulnerable to climate change. A rise of over 2°C is likely to greatly accelerate extinctions and wide-scale changes to natural ecosystems.[55]

v 7-10% of all species on earth occur in Australia.

For areas exposed to severe climate shifts, it is possible that significant localised extinctions will occur.

Pest plants and animals will also change their distribution in response to climate change, increasing competitive pressures on native species.

Climate change impacts will vary from ecosystem to ecosystem - some will be less resilient than others. Ecosystems such as rainforest, wetlands, alpine areas and coastal and marine habitats have been identified as being at greatest risk in Victoria. Impacts will also differ between terrestrial, freshwater, and coastal and marine environments because the main drivers of change will vary.

What makes a species vulnerable to climate change?

Victorian flora and fauna species with the following characteristics are believed to be highly vulnerable to climate change:[56]

- Restricted in geographical and climatic range;
- Small population sizes or limited to small and/or isolated areas of habitat;
- Reliant on continuous habitat for migration and dispersal;
- Sensitive to changes in competition;
- Reliant on ecosystems that are already stressed by other impacts such as clearing;
- Reliance on complex interactions with other species for reproduction, dispersal or growth;
- Reliance on 'narrow' food source;
- Reliance on critical environmental cues for migration and breeding;
- Low levels of genetic variability;
- Low reproductive output; and
- Poor dispersal capacity.

Spotted Tree Frog.

Image courtesy of Glen Johnson.

Red-tailed Black Cockatoo.

Image courtesy of Wayne Bigg. http://www.redtail.com.au

Mountain Pygmy-possum.

Image courtesy of Fredy Mercay.

Primary Production and Carbon Storage

In addition to impacts on natural ecosystems, climate change also threatens agriculture, forestry and fisheries through impacts on water resources, land health, agricultural yields, increased damage from wildfires and storms, and changes to the distribution and abundance of commercial species.

Future land-use patterns and the location of primary industries in Victoria may have to alter in order to adapt to climate change. Changes to the distribution of primary production will have socio-economic implications for individual businesses, industries, towns, schools and regions.

Climate change related ecosystem changes will influence the amount of carbon storage in the natural environment, having implications for the management of carbon stocks and future carbon management projects.

Figures 14 and 15 illustrate the complexity of the flow-on effects of climate change.

Changes to the distribution of primary production will have socio-economic implications for individual businesses, industries, towns, schools and regions.

Mountain Ash.

Image courtesy of Department of Sustainability and Environment.

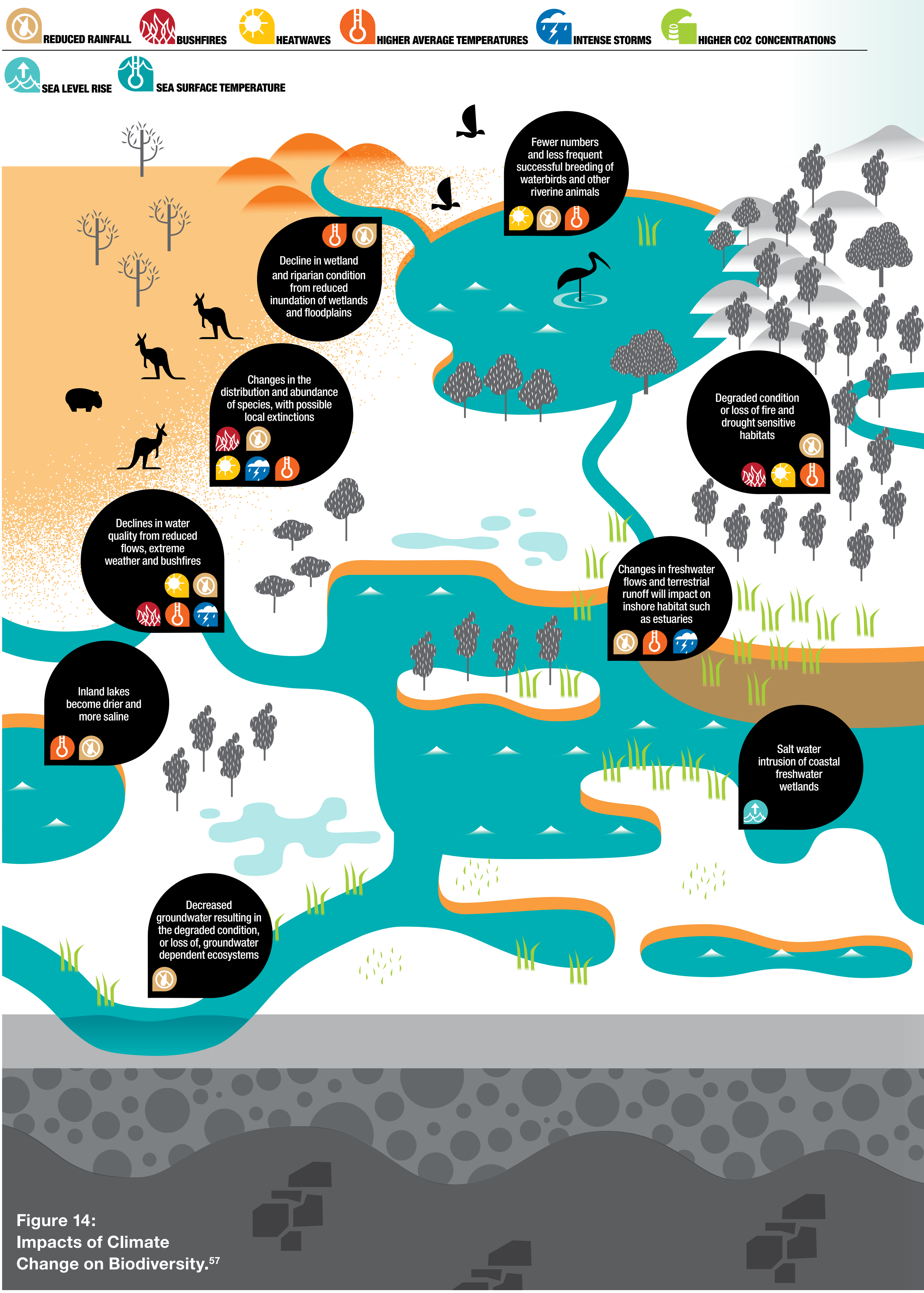
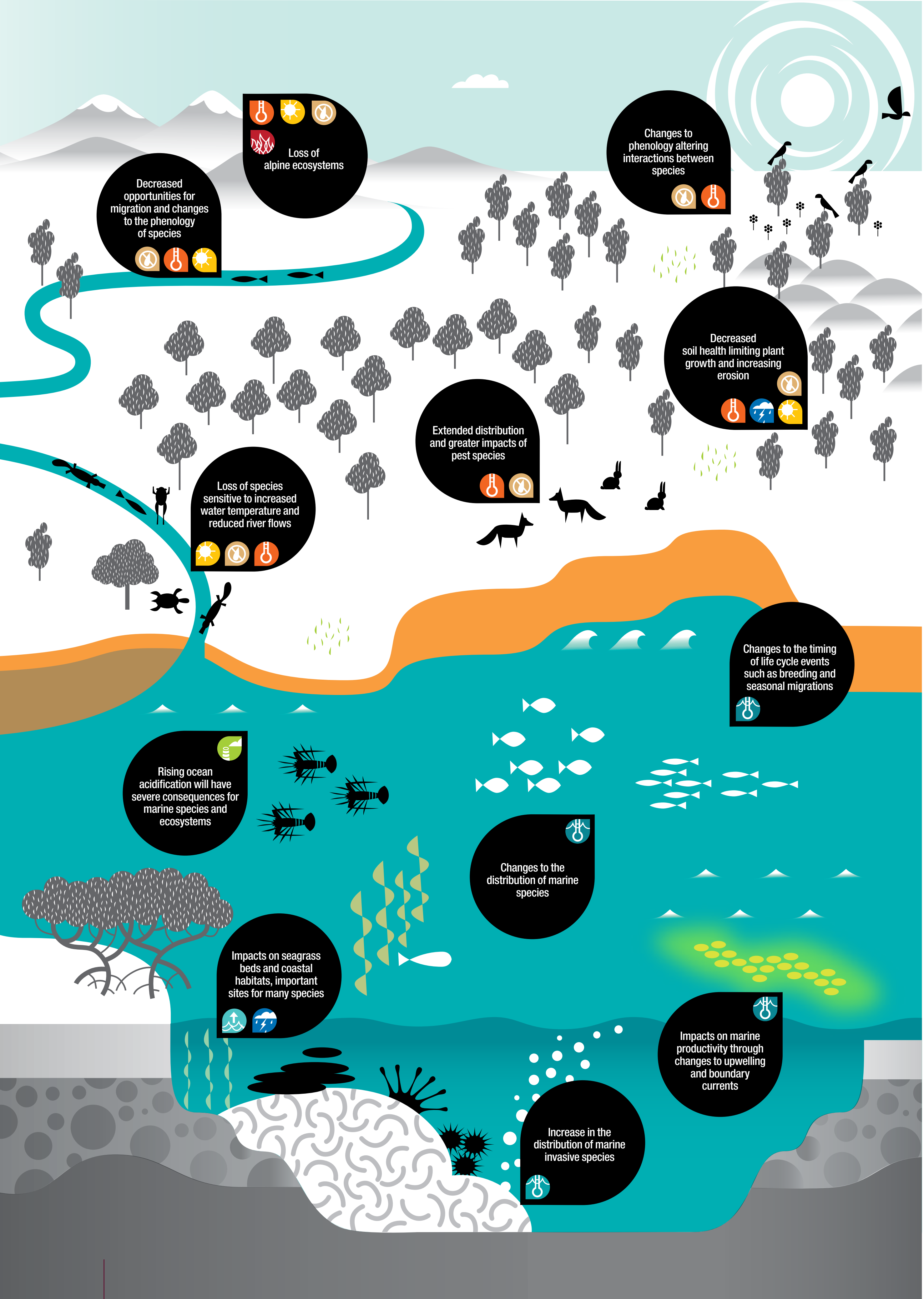


Figure 14: Impacts of Climate Change on Biodiversity.[57]


Loss of alpine ecosystems
Decreased opportunities for migration and changes to the phenology of species
Changes to phenology altering interactions between species
Decreased soil health limiting plant growth and increasing erosion
Extended distribution and greater impacts of pest species
Loss of species sensitive to increased water temperature and reduced river flows
Changes to the timing of life cycle events such as breeding and seasonal migrations
Rising ocean acidification will have severe consequences for marine species and ecosystems
Changes to the distribution of marine species
Impacts on seagrass beds and coastal habitats, important sites for many species
Impacts on marine productivity through changes to upwelling and boundary currents
Increase in the distribution of marine invasive species

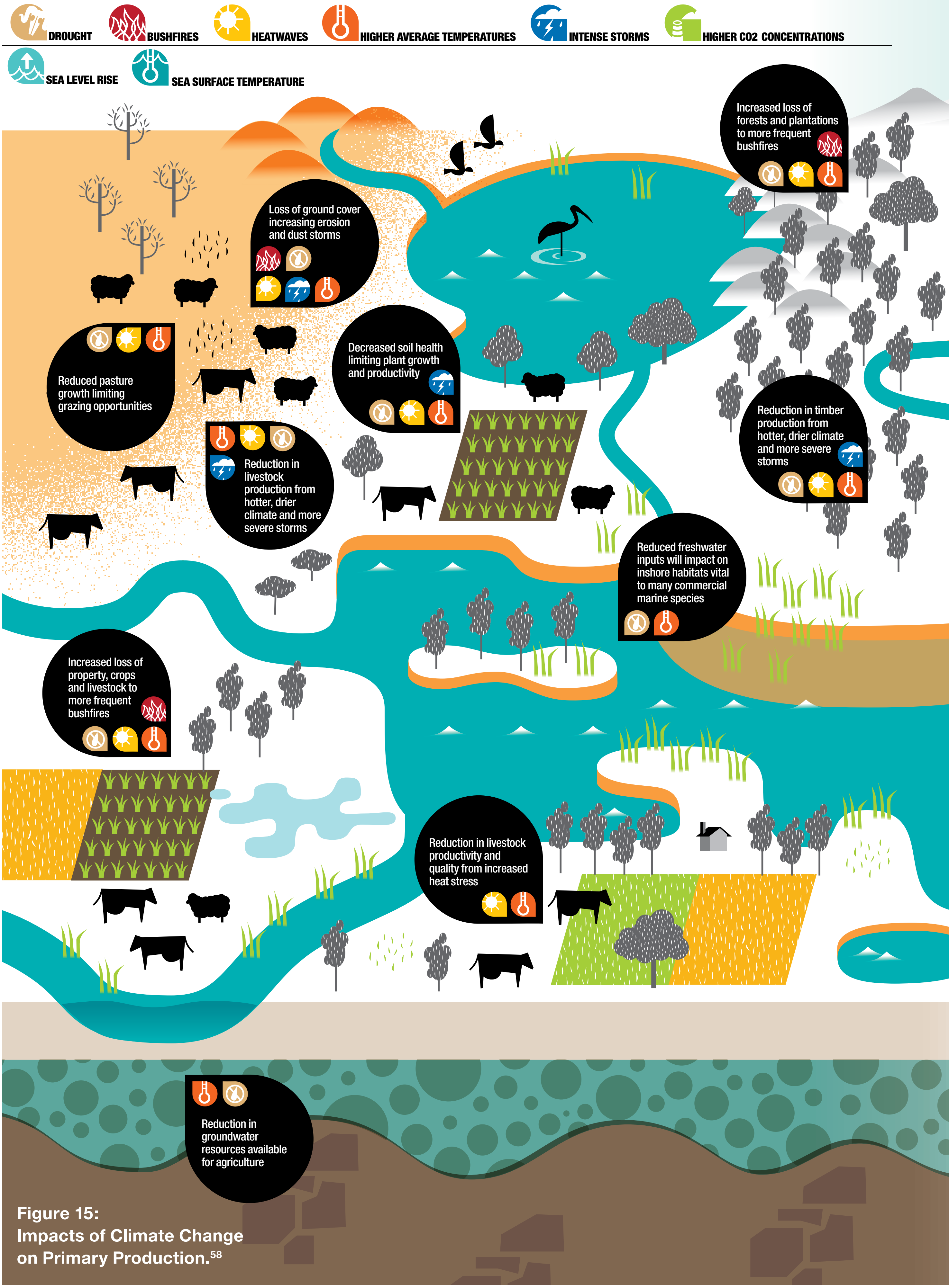


Figure 15: Impacts of Climate Change on Primary Production.[58]


Reduction in water resources available for agriculture
Increases in pests and disease reducing yields and raising management costs
Possible increase in crop and forestry yields when not limited by other climate change impacts
Relocation of agricultural industries to more suitable areas
Reduction in crop yields from hotter, drier climate and more severe storms
Less frequent frosts reducing the yield and quality of crops that require chilling for production
Rising ocean acidification will impact on many commercial species
Migration or loss of marine species will affect the viability of current fisheries
Impacts on seagrass beds and coastal habitats important recruitment sites for many commercial species
Range extensions of marine pests threatens fisheries such as Rock Lobster and Abalone

Victorian waters lie at the meeting point of the Southern and Pacific Oceans creating a unique environment that supports over 12,000 species of plants and animals, with 80% occurring nowhere else on earth.[59]

2.2 Victorian Observations

Marine Ecosystems – South East Australia Hotspot for Biodiversity and Climate Change Impacts

Victoria's marine and coastal environment is one of the most diverse in the world.

Victorian waters lie at the meeting point of the Southern and Pacific Oceans creating a unique environment that supports over 12,000 species of plants and animals, with 80% occurring nowhere else on earth.[59] Habitats include reefs, kelp forests, deep sponge gardens, sandy plains, seagrass meadows, and open water.

The marine and coastal environment provides many social and economic benefits for Victorians including recreation and tourism, and commercial fisheries. Recreational fishing alone is estimated to contribute over $2 billion each year to Victoria's economy (this figure includes inland and marine fishing.[60]

Victorian marine waters have been identified as being extremely vulnerable to climate change. In 2010, sea-surface temperatures in the Australian region were the highest on record.[61] Southern Australia has experienced some of the fastest increases in ocean temperatures globally[62] with sea surface temperatures shown to have risen 2°C off Australia's south east coast since 1925.[63]

This rise in temperature is mainly due to the southern extension of the East Australian Current (Figure 16). Changes in climactic conditions have strengthened the current by 20% in the last 50 years,[64] increasing its southward penetration by 350 km.[65] The current brings warmer and saltier waters from northeast Australia down the east coast and its strengthening has caused warming at a rate of 0.023°C year, approximately four times the global ocean warming average.[66]

The changes in current strength and rising sea temperatures are likely to have severe consequences for marine ecosystems in Victoria.

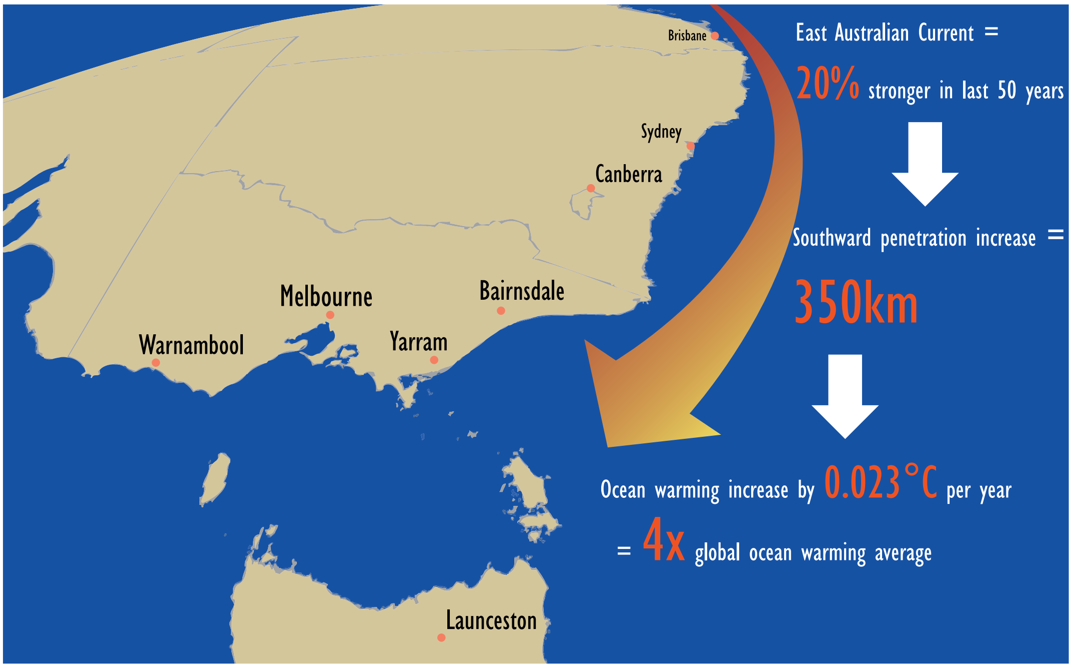


Figure 16: Changes to the East Australian Current.[67]
CfES developed infographic.

Other predicted climate change impacts include acidification, changes to wind patterns, sea level rise, and reduced inflows from inland waters.

Impacts of Climate Change on Victoria's Marine and Coastal Biodiversity

Climate change is likely to have profound affects on Victoria's marine and coastal biodiversity. Impacts will include changes in the distribution and abundance of species and habitats, local extinctions, changes to ecosystem function, connectivity and productivity.

The severity of the impact of climate change on marine and coastal ecosystems will depend on the ability of species to adapt to environmental changes. Of particular concern are impacts on phytoplankton and zooplankton species. These are key to marine food webs and changes to their distribution and abundance will have significant consequences for marine ecosystems.[68]

Species unable to adapt will have to migrate to more suitable habitats.

It is predicted that a 1°C increase in ocean temperature may require some marine species to migrate hundreds of kilometres southwards to seek optimal conditions.[69] Major problems will be experienced by those species unable to move long distances, and species and ecosystems will be subjected to increased competition from new arrivals.

Of concern, even mobile species may find themselves with limited scope or ability to migrate because of the lack of suitable habitat to the south of the Australian mainland.[70]

The impact of climate change on a species will also differ depending on life-stage. Marine species typically have complex life cycles requiring different habitats over time. For example, some fish species use mangroves and seagrass beds during juvenile stages and then move offshore as adults.[71] Climate change in coastal waters and associated impacts on mangroves and seagrass beds will affect young life stages with flow-on effects for adult populations.

Grey Mangrove.

Image courtesy of Parks Victoria and Museum of Victoria.

Some of the associated changes in environmental conditions may enable some species to expand their range, providing new opportunities for fisheries.

However, not all species will be affected negatively by climate change, some of the associated changes in environmental conditions may enable some species to expand their range, providing new opportunities for fisheries.

Recreational and commercial fishers have observed range expansions for pelagic fish species such as mahi mahi (*Coryphaena hippurus*), yellowfin tuna (*Thunnus albacares*), cobia (*Rachycentron canadum*) and stripey tuna (*Katsuwonus pelamis*).

Observed Marine Biodiversity Changes

Ocean warming has been observed as most pronounced in south-eastern Australia.

We have witnessed:

- the southern movement of seaweed to cooler waters, including range shifts of macroalgae and associated species and the decline of giant kelp (Macrocystis pyrifera)[72]
- southward range extensions documented for 45 species of fish on the south-east coast, representing 15% of coastal fishes in temperate south-eastern Australia[73]
- the sea urchin, *Centrostephanus rodgersii*, has extended its southern range by 160 km per decade over the past 40 years, from New South Wales to eastern Tasmania. Being a voracious grazer, the urchin has consumed vegetation, such as kelp forests, leaving behind bare rock[74]
- a decrease in populations of the southern rock lobster
- changes to the distribution and abundance of estuarine habitats such as mangrove, seagrass and saltmarsh. Mangrove stands are increasing in area at the expense of saltmarsh, and seagrass habitats are declining. These coastal habitats are important as breeding or nursery areas, and this disturbance impacts a range of fish and other species.[75]

Leathery Kelp - Ecklonia radiata.

Image courtesy Friends of Beware Reef.

MDN_Brittlestar (Ophiomyxa australis).

Image courtesy of Parks Victoria and Museum of Victoria.

MDN_Eelgrass (Heterozostera sp).

Image courtesy of Parks Victoria and Museum of Victoria.

The Black Bream - links between terrestrial and marine ecosystems

Many marine and coastal species are reliant on terrestrial processes linked through estuaries.

With climate change projected to reduce freshwater flows and terrestrial runoff in Victoria, inshore habitats are likely to undergo significant changes such as increased salinity, decreased nutrients and other inputs, and changes to estuary openings. This will have consequences for species that rely on inshore habitats for breeding, migrations, spawning habitats, and nursery areas.

Estuarine fish such as black bream (*Acanthopagrus butcheri*) are highly susceptible to changes in terrestrial rainfall. Black bream is important to both recreational and commercial fishers in the Gippsland Lakes. However, black bream catch in Gippsland Lakes has declined markedly over the last decade, due to drought.[76]

Juvenile Black Bream.

Image courtesy Department of Primary Industries.

The breeding cycle is complex. Research has shown that the Gippsland Lakes population of black bream is strongly linked to changes in river flows.

Black bream spawn in response to the location of the salt wedge and the length of the halocline which is the vertical stratification where freshwater and saline water meet. The salt wedge moves in response to freshwater flows in the river. Black bream then disperse their eggs in different locations along the river depending on where the salt wedge is located.[77]

Under drought conditions, reduced river flows greatly decrease the potential spawning area of black bream.[78] Added to this is the impact of the movement of the saltwater wedge further upstream, as this increases the distance between suitable spawning and rearing habitats in the lake's seagrass beds.

Climate change will have significant implications for black bream populations with the likely further reductions in freshwater flows leading to increased estuarine salinity. Successful breeding of black bream in the future will depend on the location of the salt wedge in relation to suitable spawning/rearing habitats in the river.[79]

This can be managed through the release of environmental flows to improve the success of black bream spawning, but will depend upon the availability of water for such flows.

Ocean acidification will impact on commercial species such as rock lobsters.

Threats to fishery - primary production

Impacts on marine biodiversity and ecosystems will have significant consequences for Victoria's fisheries.

Predicted impacts include:

- As fishery distribution and abundance changes and ecosystems shift the sustainability and profitability of fisheries and associated industries will come under question.[80]
- Range extension of species such as the sea urchin (*Centrostephanous rodgersii*) has serious implications for the sustainability of rock lobster and abalone fisheries in Victoria.[81]
- Ocean acidification will impact on commercial species such as rock lobsters.
- Increasing strength of south-easterly winds is likely to increase seasonal upwelling along the coast of western Victoria, leading to increased ocean productivity. This may improve fish stocks such as sardines off the coast of western Victoria but have significant adverse impacts on marine ecosystems.[82]
- Changes in freshwater flows and terrestrial runoff will impact on commercial species that rely on inshore habitats for breeding, spawning habitats, and nursery areas.[83] Reduced freshwater flow events have been shown to affect estuarine fish catches, with drought conditions correlated to reduced catches.[84]

Rock Lobster.

Image courtesy Friends of Beware Reef.

Management of Climate Change impacts on Victorian Marine Waters

To reduce the impacts of climate change, it is vital to address the existing pressures on marine and coastal ecosystems.

Stressors such as overfishing, invasive species and habitat disturbance are likely to exacerbate impacts of, and be exacerbated by, climate change, reducing the ability of species to adapt to environmental changes. Consequently, fishing regulation and habitat protection are key areas for adaptation strategies, for both biodiversity and primary production.[85]

It is asserted broadly across the scientific community, both nationally and internationally, that one approach to improve marine biodiversity protection is through the extension of protected areas.

These areas can improve resilience. This allows populations to increase, both naturally and by the restocking of commercial fisheries (by protecting biodiversity and habitat and by providing marine refugia).

Victoria has 13 Marine National Parks and 11 smaller Marine Sanctuaries.

Currently these protected areas cover only 5.3% of Victoria's coastal waters, compared to 18% of protected areas of Victoria's land.

However, the extension of protected areas alone does not ensure the effective conservation of marine ecosystems because these areas can be compromised by a range of external pressures. For example, sea urchins have been linked to significant damage to protected areas such as Beware Reef in the south-eastern coast.

Therefore the management of pressures outside of protected areas is required. This includes the use of quotas and controls on fishing equipment to ensure the sustainability of fisheries, and the control of invasive species, particularly through the protection and restoration of natural predators.

Stressors such as overfishing, invasive species and habitat disturbance are likely to exacerbate impacts of, and be exacerbated by, climate change - reducing the ability of species to adapt to environmental changes.

Common Seadragons.

Image courtesy of Parks Victoria and Museum of Victoria.

2.3 Observed phenology changes in Victoria

Phenology is nature's calendar: the recurring plant and animal life-cycle stages such as the flowering, fruiting, egg laying, breeding and migrations. It is the study of these recurring life-cycle stages and their timing and relationship to climate and weather.[86]

Why is Phenology Important?

Many species rely on the timing of life-cycle stages to ensure optimal environmental conditions for growth and breeding, such as abundant food for raising young or flowering to coincide with pollinator emergence.

Changes to phenology can severely disrupt food webs by altering competition between species and disturbing the timing of predator-prey relationships (Figure 17). Ecosystem function, reproduction success (e.g. fewer offspring), and reduced adult survival can be significantly impacted. Changes to phenological patterns not only impact biodiversity and ecosystem health, but this also impacts agricultural production and the availability of natural resources such as fish stocks.

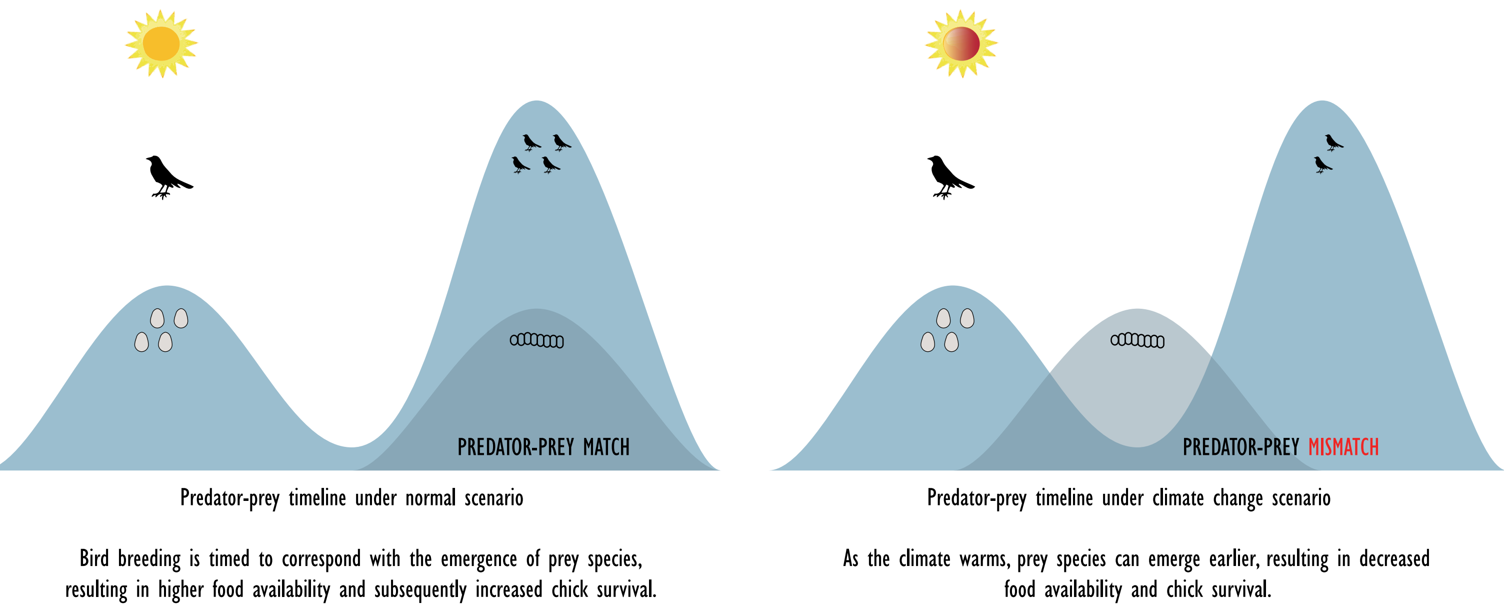


Figure 17: Climate change impacts on predator – prey relationships.[87]
CfES developed infographic.

The life-cycle stages of plants and animals provide some of the strongest evidence for climate change impacts on the environment and primary production. Phenology information can determine changes in the timing of seasonal activities and inform us about whether individual species and those they interact with are responding together or separately.

This information is vital for the effective management of natural resources as we contend with climate change.

The Victorian Experience of Phenological Change

Although the knowledge of phenology is poor in Victoria, examples of life-cycle changes associated with anthropogenic climate change are becoming evident.

Across Victoria, some 22 bird species and 46 plant species have been identified as having modified life-cycles in response to a warming climate.[88] Because these findings are based on limited assessments of those species with available data, the actual number of Victorian species with modified phenologies remains unknown.

For those species that have not demonstrated a shift in their phenology, it is unclear whether this is because they are unable to do so, or whether the climate threshold which will trigger a change has yet to be reached.

Phenology changes are also impacting Victorian agricultural harvests. For example, the yields of stone fruits, pear and apple trees rely on chilling to stimulate the bud break required for fruiting. In warmer years, reduced chilling has resulted in prolonged dormancy and reduced fruit quality and yield.

Climate change is also impacting on the Victorian grape and wine industry. For example, earlier grape flowering has impacted on wine quality due to advanced harvest dates. In southern Australia, wine grapes have been ripening earlier with grape maturation dates advancing about eight days per decade (1985–2009).[89] Increased warming and declines in soil water content have been identified as major drivers of this ripening trend.[90] Further warming is expected to significantly affect grape quality, leading to a decline in grape prices of up to 50% in some areas of Victoria.[91] Such changes are likely to lead to the development of new wine-growing regions and the planting of different grape varieties to adapt to climate change.

Phenology changes also impact on human health. Earlier and prolonged flowering of Victoria's plants has been documented as being linked to an increase in the occurrence of asthma, hay fever, allergic conjunctivitis and eczema.

Across Victoria, some 22 bird species and 46 plant species have been identified as having modified life-cycles in response to a warming climate.[88]

Nesting penguins spend considerable amounts of time on land in burrows, exposing them to high temperatures.

Phenology Case Studies

A: Impacts of Climate Change on Little Penguins, Phillip Island[92]

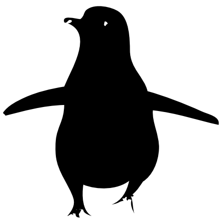
Little penguins (*Eudyptula minor)* at Phillip Island are one of Victoria's most popular attractions, generating hundreds of millions of dollars in tourism. This population has been monitored since the late 1960s and strong links are clearly evident between breeding timing and environmental conditions (Figure 18).

Timing of egg laying in this species is associated with regional sea surface temperatures. Warmer waters promote an earlier start to the breeding season. The timing of breeding has important implications for the population of the Phillip Island colony.

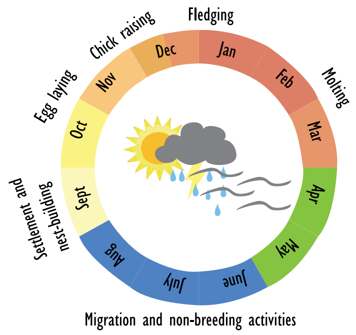
In those years where early breeding took place due to warmer temperature, more chicks were produced per pair. Chicks produced at this time were also heavier, increasing their chance of survival. In the years when breeding was delayed, the opposite was true. This would suggest that as Bass Straight warms, this penguin colony will thrive, at least in the immediate future.

However, the warmer conditions that lead to increased sea surface temperatures can also have negative impacts on little penguins. Nesting penguins spend considerable amounts of time on land in burrows, exposing them to high temperatures. Although their burrows provide some insulation, little penguins, like many seabirds, struggle with heat stress and mortality rates increase with prolonged exposure to air temperatures above 35ºC. The associated increase in risk of exposure to fire, a significant threat to the survival of populations of little penguins, also rises with a warming climate.

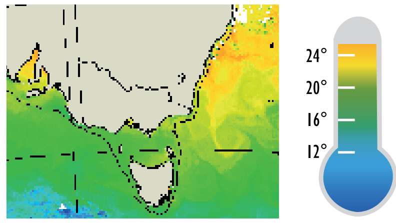
To overcome these risks, management actions including shading by increasing vegetation cover and appropriately designed and insulated artificial nesting burrows, significantly decreases such risks.



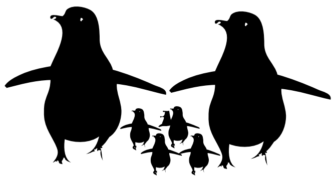
Phillip Island Little Penguins are a popular tourist attraction, generating hundreds of millions of tourism dollars for Victoria



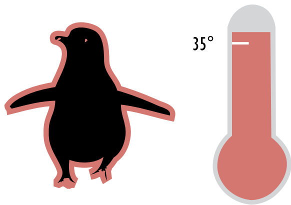
Monitoring of penguin populations since the late 1960s reveals a strong link to environmental conditions



Warmer sea surface temperatures correspond with an earlier start to the breeding season



Earlier breeding produces more and healthier chicks, however, climate change can also have a negative impact on nesting



Nesting penguins spend more time on land and in burrows, where heat stress and mortality can occur with prolonged exposure to temperatures above 35°C. Exposure to bush fires is also increased

Fortunately, monitoring and management, such as shade plantings and insulated artificial nesting burrows, can help decrease these risks

Figure 18:
Differing impacts of climate change on Little Penguins.[93]
CfES developed infographic.

Little Penguin.
Photo: © The State of Victoria, Department of Sustainability and Environment/McCann).

Red Ironbark.

Image courtesy of Elizabeth Donoghue.

B: Red Ironbark Flowering[94]

Red ironbark (*Eucalyptus tricarpa*) is a eucalypt species found in Victoria's dry box-ironbark forests and woodlands. Unusually, the red ironbark flowers throughout winter, providing a food source for many woodland birds, including the endangered Swift parrot (*Lathamus discolor*). Box-ironbark forests, including flowering red ironbarks, also produce 70% of Victoria's honey.

Between 1930 and 1981, the Forest Commission recorded the flowering and budding of red ironbark across Victoria. A study of these records showed that cooler maximum temperatures and wetter conditions clearly increased flowering. A further study also established that red ironbark flowering in the Rushworth Forest between 1945 and 1970, peaked mostly in June and that no flowering was recorded in 4 of the 26 years of study.

Between 1997 and 2007 woodland bird numbers and flowering events were studied in the Rushworth Forest. Warmer temperatures resulted in the failure of flowering in 4 of the 11 years under study. Three of those failures occurred between 2002 and 2007.

In response to changes in flowering frequency, the study showed that the population of woodland birds declined significantly.

Improving Phenology Knowledge

Phenology is a sensitive and easy to observe indicator of climate change. However, compared to the northern hemisphere, Australia has few long-term life-cycle studies. Work is underway to improve our knowledge of species responses to climate change.

One such initiative is ClimateWatch, Australia's citizen science phenological observation network (www.climatewatch.org.au). This is a major step for Australia. It provides a coordinated national indicator program to monitor the impacts of climate change.

As with other citizen science efforts discussed in this chapter, Climatewatch provides an important opportunity for Victorians to participate in climate change research, increasing awareness, understanding and knowledge of climate change impacts.

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2.4 Forest systems: climate change impacts on carbon storage[95]

Forest ecosystems play an important role in the global carbon cycle and global greenhouse gas balance by storing carbon in both trees and soil.

Carbon storage is dependent on a range of factors which are impacted by climate change, such as rainfall, soil moisture, nutrient availability, and disturbances such as bushfire. Land-use change (permanent clearing) and forest harvesting also affect carbon storage.

Victoria's forests store a considerable amount of carbon. In 2010, Victoria's carbon stock for publicly managed forested land was estimated between 680 and 775 million tonnes of carbon (or up to 2.8 billion tonnes of carbon dioxide equivalent). This represents roughly 25 years of Victoria's total annual greenhouse gas emissions (Figure 19).

Figure 19: Impacts of bushfire on carbon storage in Victorian forests. CfES developed infographic based on Department of Sustainability and Environment information.

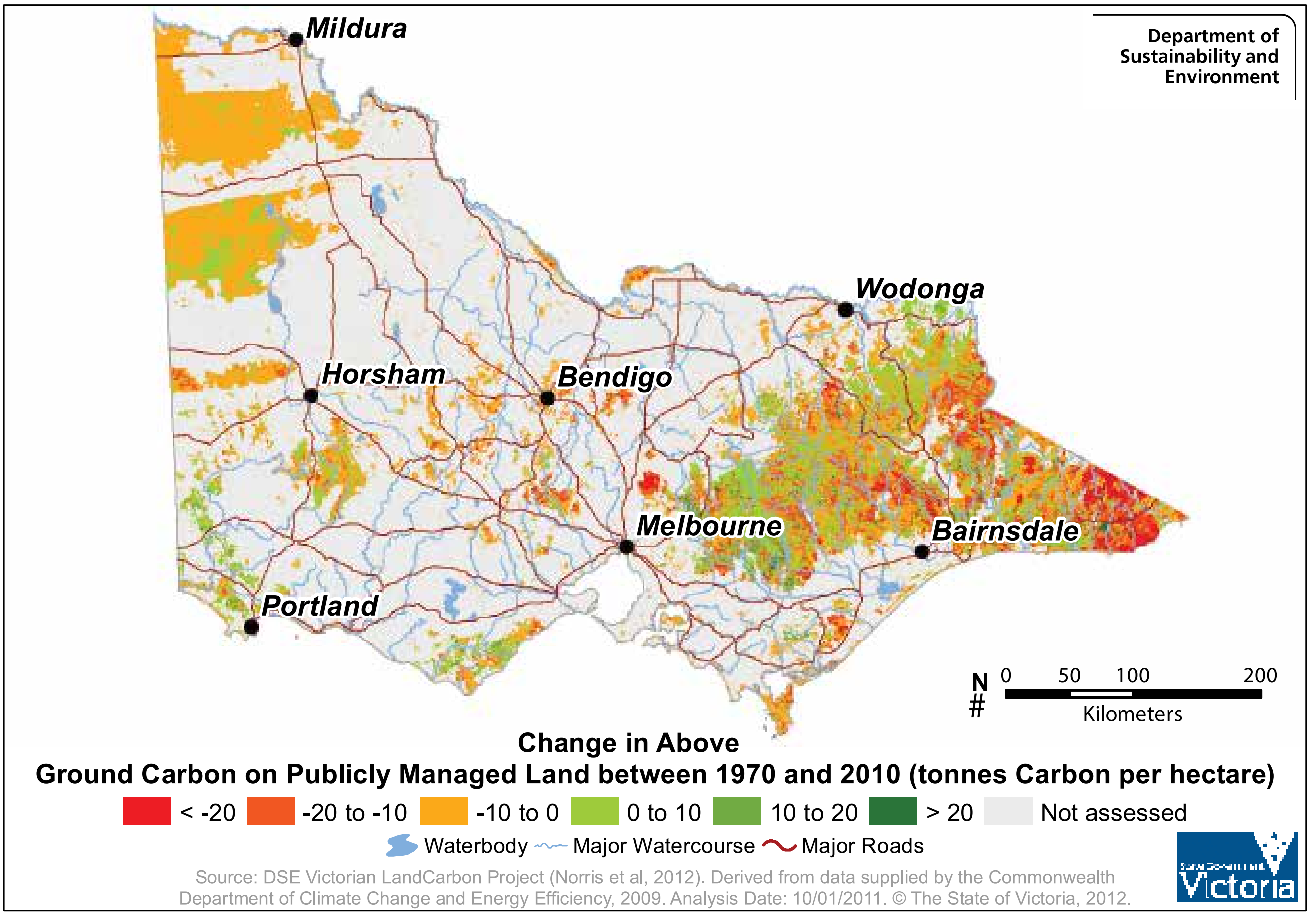
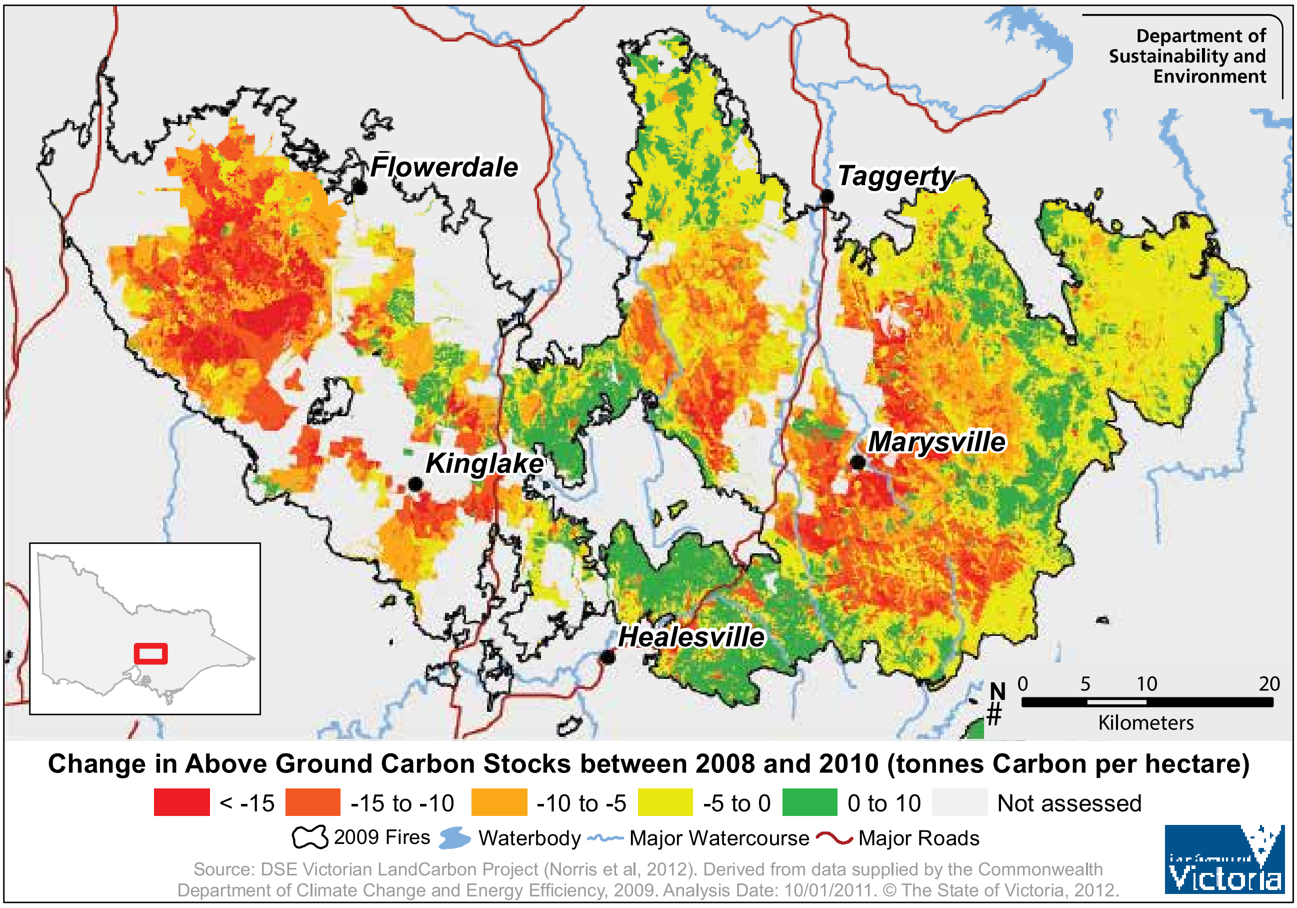


Figure 20: Change in above ground carbon on publicly managed land between 1970 and 2010 (tonnes carbon per hectare). Source Department of Sustainability and Environment.

The map in Figure 20 shows the changes in the modelled total above-ground carbon stock for Victoria's public land estate between 1970 and 2010. A strong west-to-east and north-to-south trend is evident. This largely follows the rainfall gradient.

In addition, the impact of recent fires appears across the Central Highlands and Alps, which have relatively low carbon stocks when compared to the largely unburnt areas of the State in East Gippsland and the Strezelecki Ranges.



The map in Figure 21 shows the area affected by the 2009 Black Saturday bushfires (revealed by showing the change between 2008 and 2010). The effect on carbon stocks resulting from a catastrophic bushfire event is considerable, with a change of more than 20 tonnes of carbon per hectare in some areas.

Whilst the post fire recovery of forests will increase carbon stocks, the projected increase in the occurrence and severity of fire as a result of climate change is of particular concern. It is unlikely that Victoria's forests can remain resilient to the impacts of increased fire frequency. Exceeding ecological fire tolerances would likely result in forests being altered in terms of structure, dominant species, and function, potentially storing less carbon over time.

Carbon stocks in Victoria are vulnerable to climatic variation and the occurrence of bushfires. This has important implications for the management of Victoria's carbon stocks with the ability of forests to take up carbon vital for the mitigation of climate change.

Figure 21: Change in Above Ground Carbon Stocks between 2008 and 2010 (tonnes Carbon per hectare). Source Department of Sustainability and Environment.

River Red Gums.

Image courtesy of Department of Sustainability and Environment.

2.5 Responding to climate change

Community-based environmental management and monitoring

Some 61% of Victoria's land is privately owned and managed. Community action is key to promoting resilience and adapting to the impacts of climate change on Victoria's environment.

The community already undertakes a variety of roles including on-ground works and monitoring.

Where government works closely with the community environmental management is improved and climate change adaptation will be more effective, embedded and swifter.

Building Ecosystem Resilience

Community Natural Resource Management

Victoria has a range of community-based land management and restoration organisations including individual Landcare collaborations (e.g. Project Platypus and the Blackberry Taskforce), Greening Australia, Trust for Nature, and Bush Heritage, as well as many private landholders who undertake their own management.

These groups undertake a range of works including restoration of habitat and control of pest plants and animals.

Multiple benefits, including building the resilience of natural ecosystems, improving land health, biodiversity conservation, increasing the area and connectivity of natural habitat, and increasing carbon capture possibilities flow on from these efforts, all of which are vital for addressing the impacts of climate change.

Some 61% of Victoria's land is privately owned and managed. Community action is key to promoting resilience and adapting to the impacts of climate change on Victoria's environment.

The value of community-based monitoring has been demonstrated by groups such as Waterwatch, ClimateWatch (see phenology section), Birds Australia, Sea Search, Reef Life Survey and Two Bays programs.

Building Knowledge - Community Monitoring

Effective and informed management of climate change impacts will rely on the availability of comprehensive data on environmental change and condition.

Information on the impacts of climate change on Victorian biodiversity and natural ecosystems is sparse, particularly in areas where access is limited. Marine ecosystems are particularly problematic and many knowledge gaps exist.[96] High quality community based monitoring can help address such knowledge gaps.

The value of community-based monitoring has been demonstrated by groups such as Waterwatch, ClimateWatch (see phenology section), Birds Australia, Sea Search, Reef Life Survey and Two Bays programs. Landcare groups and networks, along with individual volunteer Landcarers also contribute to the monitoring efforts. These community-based monitoring programs complement the work of government agencies, increasing the frequency and coverage of environmental observations, greatly improving the likelihood of the early detection of impacts and identifying the need for further investigation and management responses.

Early detection is critical for the effective management of climate change impacts such as changes in the distribution and abundance of species.

Citizen Scientists

Dedicated community group work is augmented by the citizen science efforts of bushwalkers, campers, bird watchers, recreational fishers, and even scuba divers. Reporting unusual observations such as the presence of new species, the absence of once common ones, or changes in ecosystem health such as the condition of vegetation, can help scientists understand the impacts of climate change.

To support citizen science, environmental agencies need to provide user friendly reporting structures for observational data.

Publicly accessible databases would encourage participation in citizen science, and well maintained databases would facilitate analysis of these community observations by scientists and environmental managers.

Case Study:
Community Monitoring of Marine and Coastal Ecosystems[97]

Sea Search and the Reef Life Survey, which partner with Deakin University and the University of Tasmania, provide an insight into the value of formal programs. Community and government agencies work to ensure quality marine and coastal monitoring outcomes which can then be incorporated into the management of marine parks and ecosystems.

Benefits include tracking the long-term impacts of climate change, information which will be of enormous value for the ongoing management of climate change impacts. Objectives include the promotion of environmental stewardship and education as well as the monitoring of natural values. Partnerships between recreational divers, research scientists, coastal managers and other citizen science programs are also strengthened.

Participants:

- explore the health of seagrass, mangroves, and intertidal and subtidal reef ecosystems
- provide early detection of threats like invasive species, poor water quality, and species range expansions
- monitor population trends for management of threatened species
- provide mapping and biodiversity surveys.

Success attends these two programs. Pests like the Long-spined Sea Urchin have been detected. Managers have become alert to the collapse of the Southern Rock Lobster population. Migration of northern species into southern waters has been mapped. A decline in Broad-leaf Seagrass (*Posidonia australis*) has been recorded. Increases in minimum winter water temperatures – a precursor to other work about climate change impacts – has been noted and reported.

Friends of Beware Reef.

Images courtesy Friends of Beware Reef.

Fish species that inhabit the reef permanently or in transit are monitored, along with mobile invertebrates such as starfish, urchins and nudibranchs.

Black Urchin - Centrostephanus rodgersii.

Image courtesy Friends of Beware Reef.

Short-tailed Sea Slug.

Image courtesy of Parks Victoria and Museum of Victoria.

Quality data, vital to scientific study and management, is routinely collected by these scientifically rigorous programs, Participants are trained, and quality control is exercised on all the aspects of the programs. Scientists provide ongoing assistance. Data collected by volunteers has been assessed as either comparable to that collected by scientists, or of a quality to inform the management practices of Victoria's marine parks.

Community members report the satisfaction they gain from being involved in such programs. *Friends of Beware Reef* is a *small* group of surveyors which prides itself on its local roots, is easily deployable in windows of good weather, and provides rigorous and credible data with scientific bona fides. A supervised dive and survey camp training program has been followed by assessment and evaluation. Checking of skills and data is scrupulous and ongoing.

Fish species that inhabit the reef permanently or in transit are monitored, along with mobile invertebrates such as starfish, urchins and nudibranchs.

Once collected, the data is available for use by scientists, parks management, planners and other interested agencies. To date the *Friends of Beware Reef* has documented:

- the proliferation of the Long-spined Sea Urchin along the length of the East Gippsland coast
- the colonisation of southern coastal reaches by warmer water northern species including the Round-belly Cowfish, Gunther's Butterflyfish, Girdled Scalyfin, Small-Scale Bullseye, Kapala Stingaree, turtles, sea snakes, and Blue-black Coral
- algal events becoming more common due to the upwelling of cold nutrient rich water off the continental shelf
- increasing minimum winter water temperatures - by as much as 13.5 degrees in one year
- the apparent collapse in the southern rock lobster population
- locating one exotic species of sea star - the Seven-arm Sea Star, (*Astrostole scabra*.) a New Zealand species.

'Education' about the marine environment is core business for the *Friends of Beware Reef*. Presentations (up to 30 per year) to the public, poster production, promotional and information rich video representations have been provided and the fish and invertebrate data base which they developed is continually updated.

It is the local roots of the *Friends of Beware Reef* which makes their work in this isolated and challenging environment absolutely invaluable to assist us to understand biodiversity susceptibility to climate change in this marine hotspot on Victoria's south eastern coast.