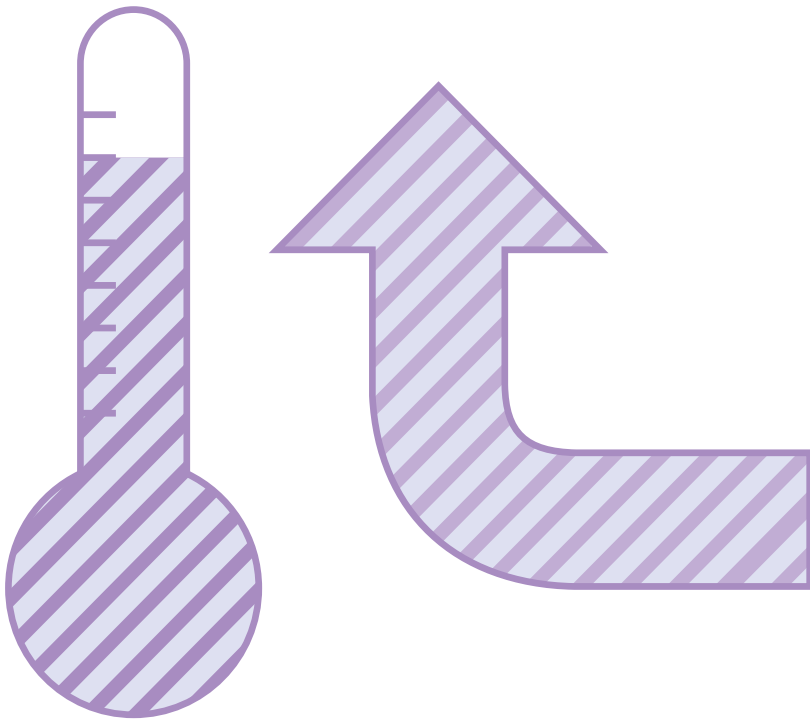




THE CRITICAL DECADE

Western Australia climate change impacts



Over many decades thousands of scientists have painted an unambiguous picture: the global climate is changing and humanity is almost surely the primary cause. The risks have never been clearer and the case for action has never been more urgent.

Our Earth's surface is warming rapidly and we can already see social, economic and environmental impacts in Australia.

Failing to take sufficient action today entails potentially huge risks to our environment, economy, society and way of life into the future. This is the critical decade for action.

This document accompanies *The Critical Decade* report and highlights the key impacts for Western Australia.

Key messages

- Western Australia, particularly the south-west, is vulnerable to climate change.
- Rainfall patterns in Western Australia have changed over the last 40 years. There is significant evidence that climate change has contributed to the marked drying trend in the southwest of the state. This has had serious implications for urban water supplies and agriculture.
- Sea levels along the west coast of Australia have been rising at more than double the global average. With significant part of the population living in coastal cities and towns, rising sea levels pose significant risks to Western Australia's coastal infrastructure and iconic sandy beaches.
- Western Australia is home to internationally recognised biodiversity, already stressed by habitat fragmentation and further threatened by a changing climate. Suitable habitat for a range of iconic species including the quokka, Carnaby's cockatoo and the tingle tree is likely to be substantially reduced as the climate changes. The world famous Ningaloo Reef, like other coral reefs, is highly sensitive to a changing climate. The reef, and the multi-million dollar tourism industry it supports, faces significant long-term risks from a changing climate.
- This is the critical decade for action. The choices we make between now and 2020 will shape our future. To minimise climate change risks we must begin to decarbonise our economy and move to cleaner energy sources this decade. The longer we wait the more difficult and costly it will be. Western Australia has abundant potential for expanding renewable energy generation, with some of the best wind and solar resources in Australia.

1. Rainfall patterns in Western Australia have changed.

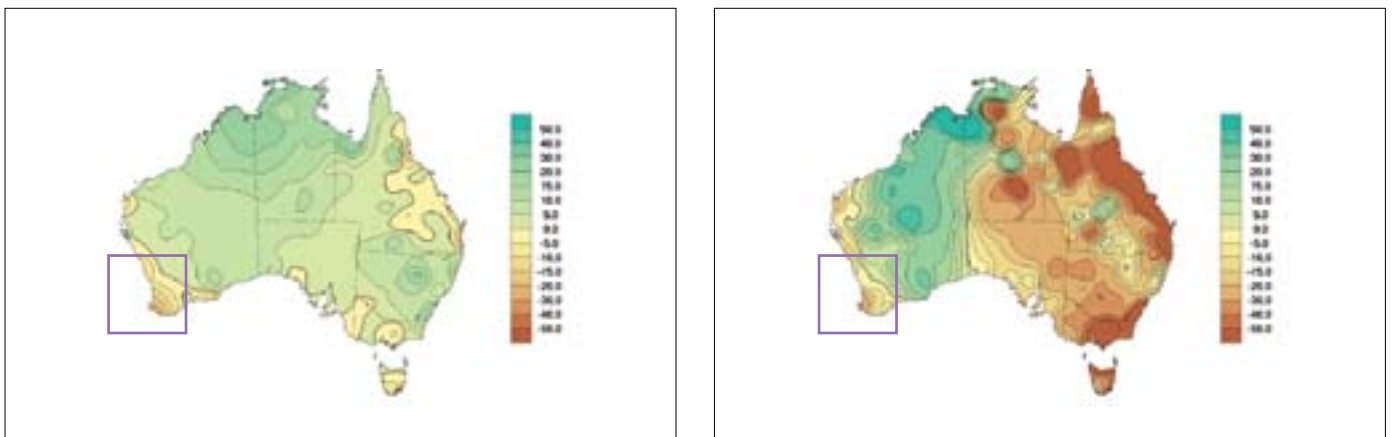
Significant changes in the pattern of rainfall over Western Australia have occurred over the past 40 years (Figure 1). There has also been a strong rise in average temperature across the state by about 0.8 degrees over the past century (Figure 2).

Most of the state, especially the northwest, has experienced a trend towards a wetter climate. Whether this trend will continue is not clear. However, the frequency and intensity of heavy rainfall events is likely to increase as the climate continues to warm. This poses large risks for Western Australia's extensive mining industry, as demonstrated by the loss of between \$5 and 9 billion in export coal revenue because of the early 2011 floods in Queensland (ABARES 2011a; QRC 2011; RBA 2011).

The southwest corner of the state has become markedly drier, with a 15% reduction in rainfall since the mid-1970s. The drying trend has continued through the past year. While much of eastern Australia experienced record high levels of rainfall during the 1 August-31 December 2010 period, much of southwest Western Australia experienced record dry weather.

There is strong evidence in southwest Western Australia that climate change is making a significant contribution to the drying trend. Rain bearing fronts typically sweep across south-western Australia from the Southern Ocean in autumn and winter. Over the last 40 years, this pattern, related to the Southern Annular Mode, has been driven southward off the continent by a warming climate, and so contributes to the observed drying trend.

Figure 1. Trend in total annual rainfall (mm/10 years) for the 1900-2010 and 1970-2010 periods. Southwest WA is shown by the box.



Source: Bureau of Meteorology

2. Declining rainfall and higher temperatures have serious implications for agriculture and urban water supplies in the southwest.

This drying trend is particularly important as most of the state's population and much of its agricultural activity occur in the southwest corner. The impact of the drying trend on the Perth water supply is now well known (Box 1).

The drying trend has important consequences for the Western Australian wheatbelt. The growing season has become shorter and drier in the northeastern part of this area, and yields in this region have declined (Stephens et al. 2009). By 2050, changing rainfall and higher temperatures could result in yield losses of more than 30% (van Gool 2009).

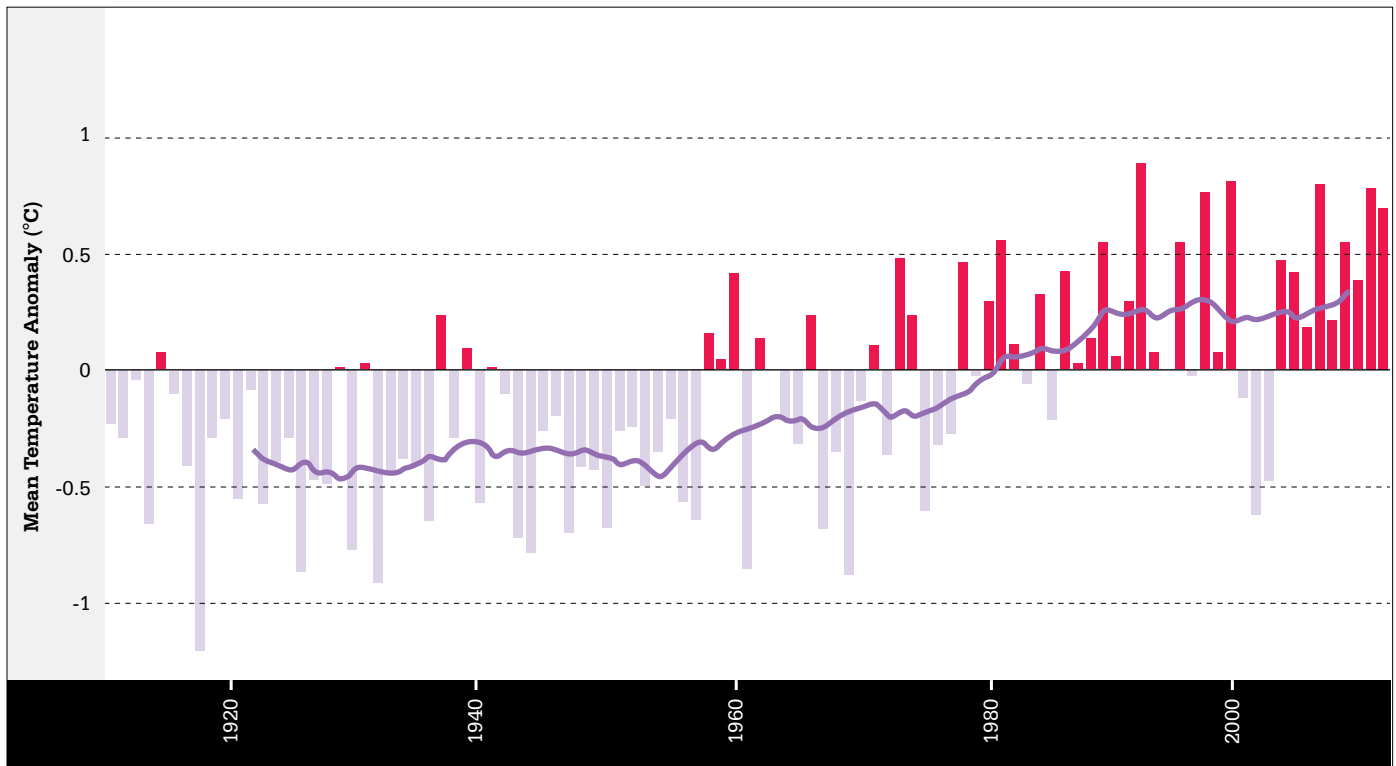
Despite the significant drop in rainfall over the past three decades, many Western Australian farmers have adapted and have improved average wheat yields (Farre et al 2009). These gains have been achieved through improvements in technology and management practice, including the

adoption of no-till cultivation, which conserves soil moisture (Agtrans Research 2009), as well as reductions in waterlogging and the spread of dryland salinity (Ludwig et al. 2009). This example demonstrates that the realised impacts of climate change do not only come from changes in the climate system, but are also dependent on management changes and adaptive measures that people may take directly in response to climate change.

However, recent experience shows how a drier climate could reduce crop yields, pointing towards limits to our adaptive capacity. Following the very dry conditions that occurred across the Western Australian wheatbelt in 2010, production of wheat and other winter crops in 2010-11 was around 43% lower than production for the previous season (ABARES 2011b).

The scale of the challenge for farmers to adapt to a changing climate will increase significantly as temperature rises, and will become more severe at 1.5 or 2 degrees above pre-industrial temperatures.

Figure 2. The long-term trend in Western Australia's average temperature, measured as the difference from the 1961 to 1990 average. This graph shows that from around 1950 there has been a steady temperature rise – approximately 0.8°C – in Western Australia. Most human-caused carbon dioxide emissions have occurred since 1950.



Source: Bureau of Meteorology.

Box 1: Risks to Perth's water supply

The 15% drop in rainfall in southwest Western Australia may not sound very dramatic. However, for urban water resources, the critical factor is runoff – the water that is captured in dams and other storages, rather than changes in rainfall itself. The relationship between the two is nonlinear; for a given change in rainfall – either increase or decrease – the consequent change in runoff is amplified two- or three-fold. Thus, a 15% reduction in rainfall could lead to a drop of up to 45% in amount of water that flows into the city's dams.

Figures 3 and 4 show the trends in annual stream flow into Perth dams from 1911 to the present. Although there is much variability from year-to-year, the average flow

rate dropped to half its previous level – 177 gigalitres – over the 1975-2000 period. There have been further reductions in inflow over the past decade, with the 2006-2010 average only 57.7 gigalitres per year. The inflow in 2010 was 13 gigalitres, and in 2011, inflow up to August was less than half that normally expected (Water Corporation 2011).

The water supply for Perth, Mandurah and a number of other towns comes from a combination of surface, groundwater and desalination. A second desalination plant currently under construction will increase the contribution of desalination to the total supply to about 30% (Water Corporation 2011). The capacity of the new plant is being doubled in response to the recent very low dam inflows.

Figure 3. Change in water inflows into Perth dams.

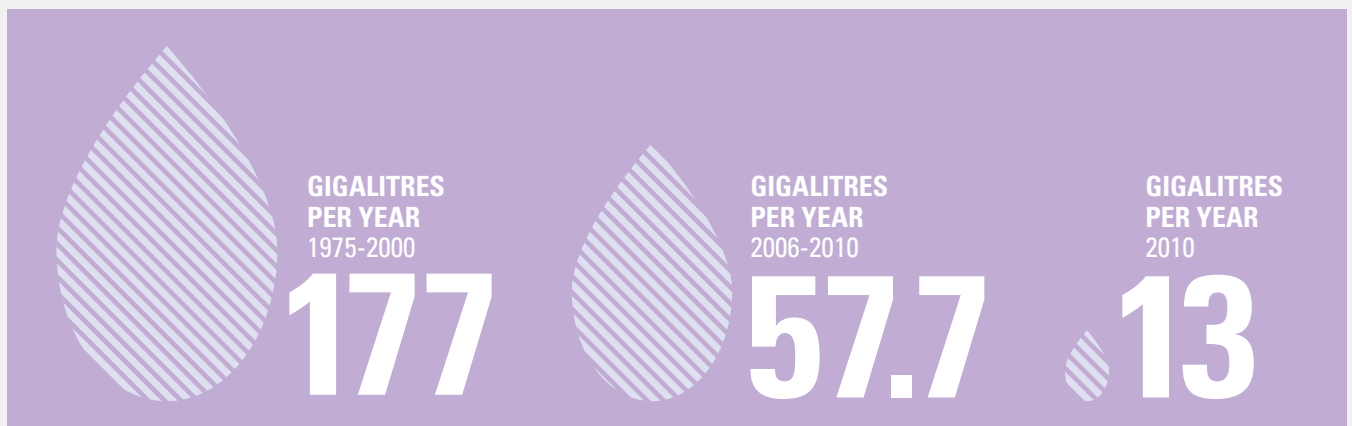
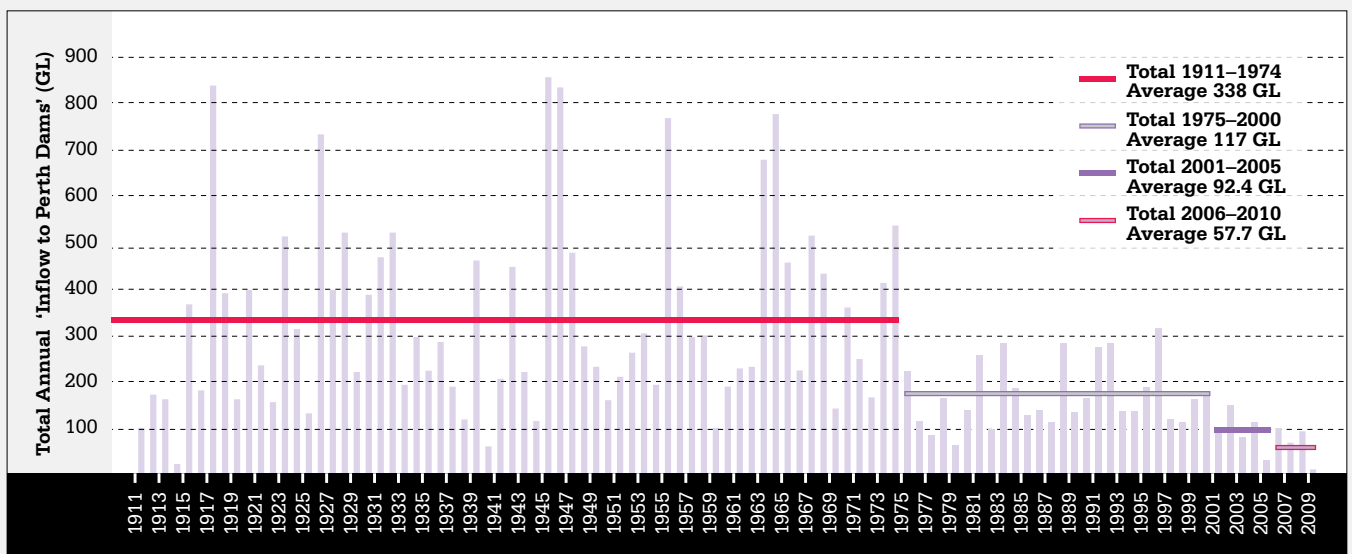


Figure 4. Trend in total annual stream flow into Perth dams 1911-2010.



Source: Western Australian Water Corporation.

3. Rising sea levels will exacerbate existing vulnerability to flooding and beach erosion

On average, sea level has risen globally by about 20 cm since the late 1800s, and by 3.2 mm a year since the early 1990s, affecting many coastal communities. Sea levels along the west coast of Western Australia have been rising between 7.1 and 7.4 mm per year since the early 1990s, about double the global average, but with considerable variability from year to year (Figure 6).

Average global sea level is projected to increase by a further 0.5 m to 1.0 m this century. A sea-level rise of 50 cm will lead to very large increases in the frequency of coastal flooding; flooding that is currently considered a 1-in-100 year event would occur every year in most parts of WA and even more frequently in Perth (Figure 7).

Flooding events are likely to damage cities, towns and the supporting infrastructure in low-lying coastal areas and will lead to erosion of sandy beaches (Figure 8). At Fremantle, where there are very long sea-level records, the rise of 20 cm since the late 1800s has been accompanied by a three-fold increase in recorded flooding from high sea level events (Church et al. 2006).

An estimated 18,700 to 28,900 residential buildings in Western Australia may be at risk of flooding towards the end of this century – with a value of between \$4.9 billion and \$7.7 billion, assuming a 1.1 m rise in sea level (DCC 2009). Up to 2,100 commercial buildings – a number similar to that of Victoria and higher than all other states – and up to 9,100 km of roadway are at risk from a 1.1 m sea-level rise (DCCEE 2011).

Box 2: Impacts in Mandurah

Mandurah has been one of the fastest growing urban areas in Australia over recent decades. While the majority of development during that period has been on land above 3 m elevation, there has been a more than 40% increase in development in low lying areas (below 3 m).

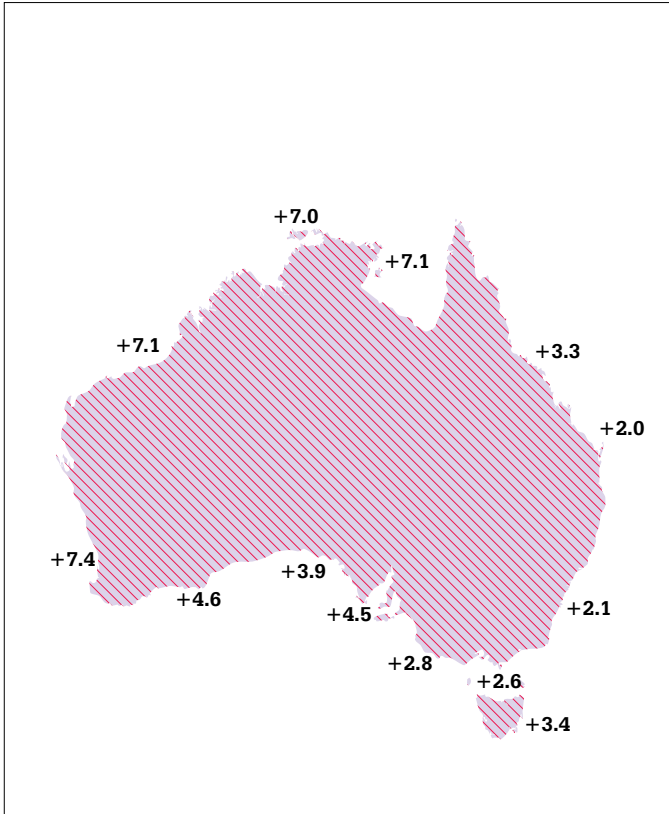
Compared to other local government areas (LGAs) in Western Australia, the southwest LGAs of Mandurah, Busselton, Rockingham and Bunbury are at the greatest risk of inundation as sea levels rise (DCC 2009). Figure 5 shows the risks for Mandurah. The sandy coastline between Mandurah and Bunbury is also particularly vulnerable to erosion, threatening structures, such as residential buildings, that have been built on sand dunes close to sea level.

Figure 5. Image of Mandurah with simulated coastal flooding from a sea-level rise of 1.1m.



Source: DCCEE (www.ozcoasts.org.au)

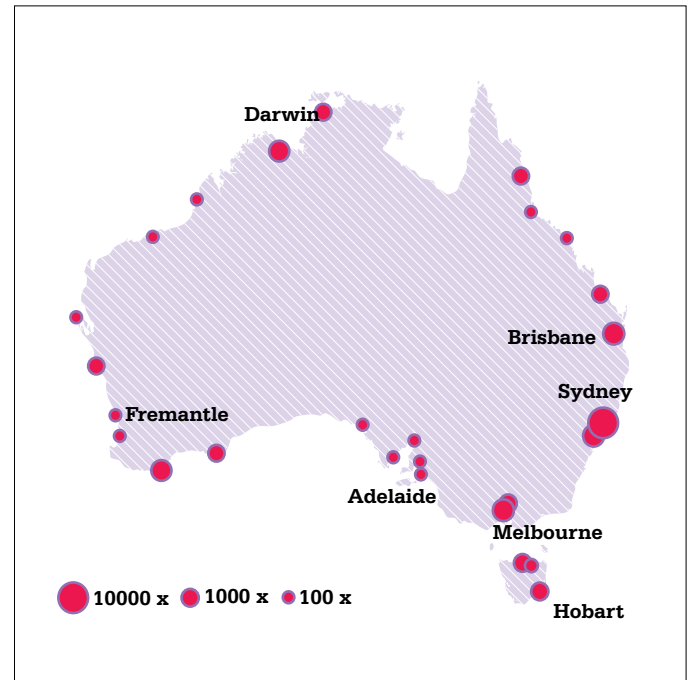
Figure 6. Local sea-level rise in mm/year around Australia from the early 1990s to 2010.



Source: National Tidal Centre 2010.

Figure 7. Estimated increase in the frequency of high sea-level events caused by a sea-level rise of 50 cm.

A rise of 50 cm will lead to a very large increases in the frequency of coastal flooding; in WA flooding that is currently considered a 1-in-100 year event would occur every year.



Source: ACE CRC 2008.

Figure 8. Rising sea levels lead to very large increases in the frequency of coastal flooding and greater beach erosion, particularly in vulnerable low-lying areas such as the Swan River, pictured and sandy beaches such as in Mandurah, pictured.



Photo credit: Don Ward; City of Mandurah.



4. Biodiversity will be at risk in southwest WA

Western Australia is home to eight of Australia's fifteen national biodiversity hotspots and Australia's only international biodiversity hotspot, recognised by Conservation International. The Southwest Australia Ecoregion is one of only five Mediterranean climate systems to be listed as globally significant.

The ecological value of the southwest region lies the diversity of plants and animals found nowhere else in the world. The region has the highest concentration of rare and endangered species on the continent. The concentration of endemic species – those that evolved in the region and that are generally found nowhere else – is particularly high. More than 60 endemic vertebrates are found here, including the honey possum, quokka, red-capped parrot (Figure 9), western swamp tortoise and sunset frog. Some of these species, such as the numbat (Figure 9), were once more widespread but have become extinct elsewhere in Australia. Areas particularly rich in endemic plant species include the Fitzgerald River National Park – home to over 1800 plant species of which over 70 are found nowhere else; and the Stirling Range National Park (Figure 10) – home to over 1500 plant species, of which nearly 90 are found nowhere else.

Some plants and animals in southwest Western Australia appear to be already responding to climate change. Bird migration is, amongst other factors, cued by temperature change. Consequently the arrival and departure times of migratory birds has significantly altered consistent with changes expected under a changing climate (Chambers 2005, 2008). Extreme heatwaves have caused widespread mortality in the already-endangered Carnaby's cockatoo (Figure 9) (Saunders et al. 2011).

Many of the ecosystems in the region are already stressed due to massive habitat loss, with around 75% of native vegetation cleared for agriculture and human settlements. Clearing has left a legacy of environmental problems such as weed invasion, inappropriate fire regimes, overgrazing, feral animals and both dryland and freshwater salinity. These problems threaten the species and ecosystems in the region, even without the additional stress of climate change. Salinity alone threatens over 470 plant species within the wheatbelt region of the southwest as well as freshwater fish.

Figure 9. Rare and threatened species, such as Carnaby's cockatoo, the red-capped parrot and the numbat, will be particularly vulnerable to climate change stresses.



Photo credit: Carnaby's cockatoo – Flickr/Ken and Nyetta



Photo credit: Red-capped parrot – Flickr/ Sandra L Chung



Photo credit: Numbat – Tourism Australia

Climate change, together with existing stresses from land clearing and human inhabitants, is likely to have a substantial negative impact on the extraordinary diversity of the southwest. Projected reductions in rainfall, for example, will affect groundwater refuges for freshwater animals. Projected hotter and drier conditions will cause changes to fire regimes, resulting in reduced habitat availability for animals and will disadvantage many plants that reproduce only by seed (see Box 3).

Most plants and animals in the region have very limited opportunity to adapt to rapid climate change especially those species that rely on cool, wet habitats. Under projected climate change, warmer and more arid conditions are expected to shift southwards and westwards. There is a possibility that the coolest and wettest climate zones on the south coast may disappear altogether. There is very limited scope for species to migrate upwards into cooler and wetter refuges, except for the Stirling Ranges. The extensive land transformation that has occurred in the region will further limit the opportunity for animals or plants to establish themselves in other regions as the climate changes (Yates et al. 2010).

Modelling of local plants (such as banksias) and animals (such as the quokka) in Western Australia consistently shows that their available habitat may become significantly reduced as the climate changes (Figure 11) (Fitzpatrick et al. 2008; Yates et al. 2010; Gibson et al. 2010). Some species are projected to lose all of their suitable habitat by 2070 or earlier.

Figure 10. The Stirling Ranges, home to a large variety of unique plant species, may be a refuge for plants and animals with climate change.



Photo credit: Tourism Western Australia

Figure 11. Plants such as banksias, and animals such as the quokka, may lose much of their suitable habitat by 2070 or earlier as a result of the changing climate.



Photo credit: *Banksia brownie* – Tourism Western Australia



Photo credit: *Banksia verticillata* – Tourism Western Australia



Photo credit: Quokkas – Wikimedia Commons/Hesperian

Box 3: Tingle trees further endangered

The Red Tingle tree (*Eucalyptus jacksonii*) (Figure 12) is found only in southwest Western Australia. It is one of the tallest trees in the state, measuring up to 26 m around the base and growing to a height of 75 m; Red Tingles can live for up to 400 years.

The Red Tingle tree already has a very narrow distribution which means it has a limited ability to adapt to a changing climate. They are now found primarily in Walpole-Nornalup National Park and in a few isolated sites outside the park in the Walpole area.

Projected hotter and drier conditions are likely to cause changes to fire regimes, as the conditions for large and intense fires will be more common. The Red Tingle regenerates only fairly weakly after moderate to high-intensity fires. Research by Wardell-Johnson (2000) indicates that Red Tingle populations may decline further with greater fire frequency in the future.

Figure 12. Red Tingle tree populations may decline further with future climate change.



Photo credit: Wikimedia Commons/Takver

5. Iconic Western Australian reefs, and the economies they support, face serious risks from climate change

The sea temperature along the western Australian continental shelf has risen by between 0.6 and 1 degree over the past 50 years (Pearce and Feng 2007). Coral-dominated ecosystems are sensitive to small rises in water temperature. When the sea temperature rises between 1 and 2 degrees above normal for a six-eight week period, corals may become 'bleached' (Figure 13). Corals can sometimes recover from a single bleaching event, but sustained or repeated bleaching can lead to starvation, disease and death. The flow on effects of these changes further up marine food chains, including impacts on fish and other species, are likely to be significant (Wilson et al. 2006). Ningaloo Reef recorded its first ever coral bleaching events during the present decade, with the most recent bleaching event a result of unusually high and prolonged temperatures (Box 4).

Oceans are also becoming more acidic because an increasing amount of atmospheric carbon dioxide is being absorbed by surface waters. Carbon dioxide absorbed by the ocean forms carbonic acid, thereby increasing ocean acidity (measured scientifically by a decline in pH). Acidity of surface waters has increased by about 30% since 1950 (Doney et al. 2009). These changes have pushed ocean chemistry outside where it has been for at least 400,000 years (Hoegh-Guldberg et al 2007). As carbon dioxide continues to build up in the atmosphere, pH and the carbon chemistry of seawater will continue to change. These changes will push ocean chemistry outside the conditions that have been seen for tens of millions of years (Pelejero et al. 2010).

Increasing ocean acidity affects the growth of corals and many other marine organisms because it reduces the number of carbonate ions available to build their skeletons. Tropical corals have already been affected by increasing ocean acidity; coral growth (calcification) rates have declined by 14-21% over the past two decades in the Great Barrier Reef (Cooper et al. 2008; De'ath, Lough and Fabricius 2009).

Corals are already responding to warming ocean waters, with some coral species off the WA coast moving south of their historical range (to cooler waters) (Greenstein and Pandolfi 2008) by around 100-200 km. The formation of whole new reefs in more southerly locations is not, however, expected. This is because the impacts of acidification become more pronounced in cooler waters, ultimately limiting reef formation. Large coral reefs like

Ningaloo take hundreds of years to develop and are unlikely to develop their southern range at a rate that can keep up with climate change.

Projections suggest that by 2050, the pH of ocean waters will decrease significantly (Orr et al. 2005; Raven et al. 2005). Increasing acidification, together with a significant risk that global temperature will increase to 2 degrees or more above pre-industrial levels, may result in many coral reefs becoming increasingly dominated by algae, losing much of their biodiversity and their attractiveness as a tourist destination (Figure 14).

This will significantly reduce the ability of coral reefs – such as Ningaloo – to support industries such as tourism and fishing, and will decrease their role in other important areas such as coastal protection against storms and large waves.

Figure 13. Corals are sensitive to small rises in water temperature. When sea temperature rises 1 to 2 degrees above normal for an extended period corals are 'bleached', as occurred at Ningaloo reef over January-February 2011.

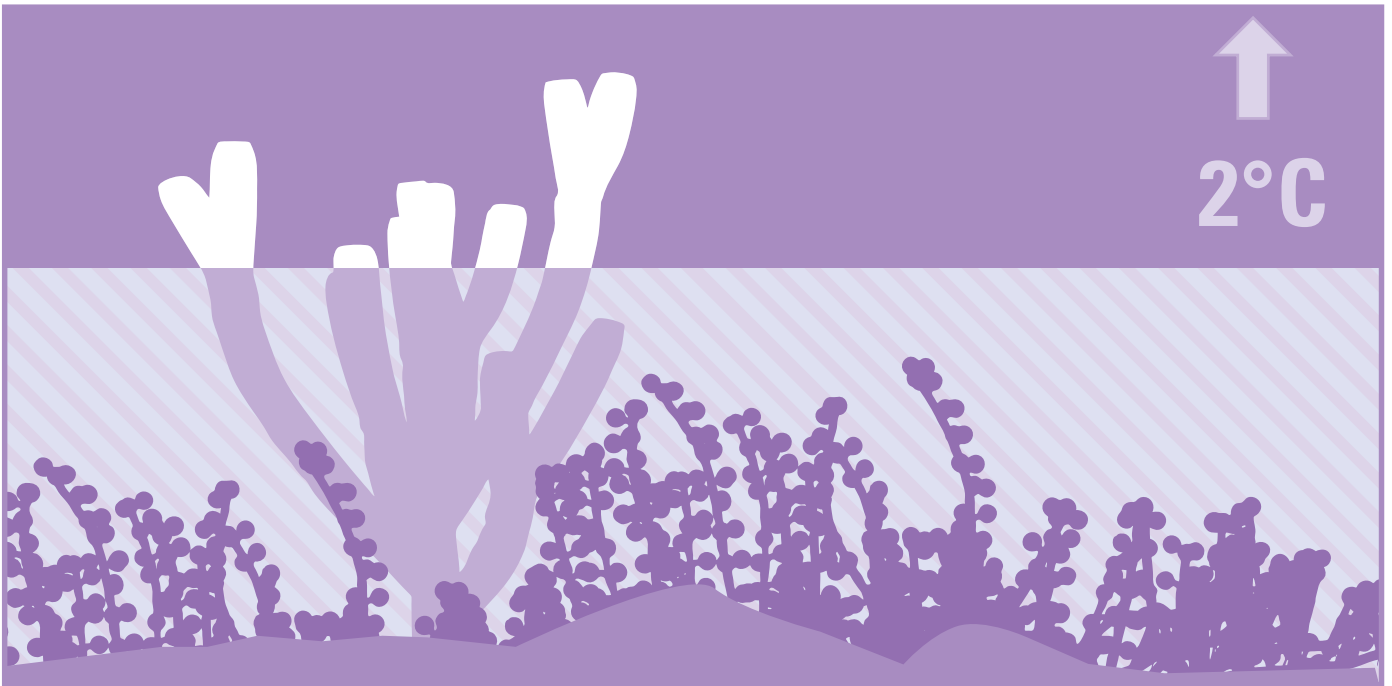


Figure 14. The Ningaloo reef, home to over 300 species of corals and a diverse range of marine species, may lose much of its biodiversity and attractiveness as a tourist destination.



Photo credit: Tourism Australia



Photo credit: Tourism Western Australia

Box 4: The Ningaloo Reef and coral bleaching

Ningaloo Reef is one of the longest fringing barrier reefs in the world. In 1987 the reef and surrounding waters were designated as the Ningaloo Marine Park, and in 2011 the area was world heritage listed by the United Nations (DSEWPC 2011).

Around 200,000 tourists come to Ningaloo each year. Ningaloo Marine Park is the reason 80% of tourists visit the area, spending an estimated \$127 million (Ningaloo Research Centre).

Ningaloo Marine Park has a diverse range of marine species and unique geological features. The reserve is located in a transition zone between tropical and temperate waters and sustains tropical and temperate plants and animals found nowhere else.

Ningaloo Reef supports an abundance of fish (over 460 species), corals (over 300 species), molluscs, crustaceans and many other species. Marine turtles, dugong and dolphins frequently visit the lagoon and whale sharks and manta rays are found on the outer reef. Recent research has revealed that a wide variety of bottom dwelling species are present in the reserve, including many previously unrecorded in Australia (DSEWPC 2011).

The first known bleaching event for the Ningaloo Reef was recorded in 2006 (DEC 2007). In January and February 2011, prolonged high sea surface temperatures caused coral bleaching across approximately 20% of the reef (Figure 15). Highly valued areas such as Bundegi and Coral Bay had higher levels of bleaching (up to 80% of total coral cover) in February. The mortality of corals following the mass bleaching is still being assessed and may exceed 30% in the most-affected areas. These bleaching events are unprecedented and are consistent with what is expected from rising ocean temperatures.

The high diversity of corals along Ningaloo reef provides some resilience to bleaching, as different corals each have different tolerance levels (DEC 2011). These differences in tolerance do not safeguard corals completely, as most tolerances will probably not extend much further than 2°C above present day temperatures.

Climate change, particularly increasing temperatures and ocean acidity, pose significant long-term risks for the survival of coral reefs around the world.

Figure 15. Bleaching stress during the height of the underwater heatwave in Western Australia, with the hottest areas shown in pink.

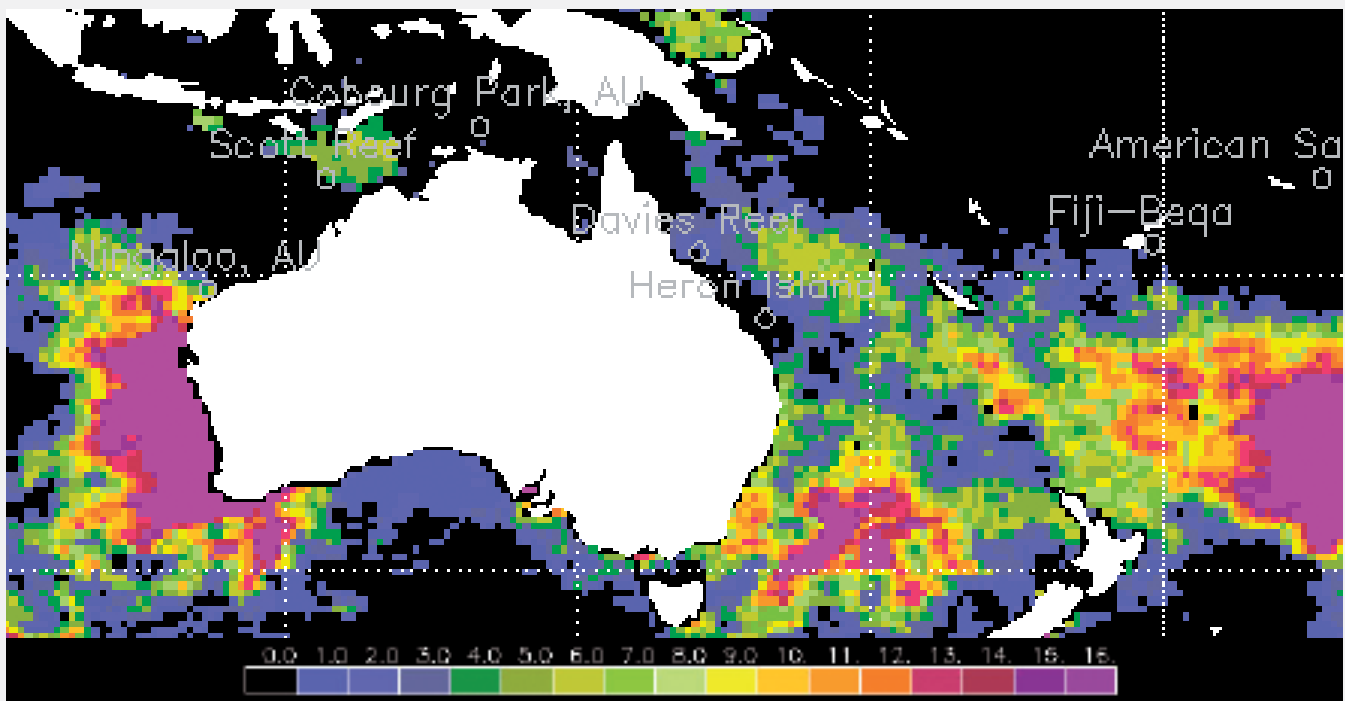


Photo credit: NOAA

5. This is the critical decade. Decisions we make from now to 2020 will determine the severity of climate change our children and grandchildren experience.

Without strong and rapid action there is a significant risk that climate change will undermine our society's prosperity, health, stability and way of life.

To minimise this risk, we must decarbonise our economy and move to clean energy sources by 2050. That means carbon emissions must peak within the next few years and then strongly decline.

The longer we wait to start reducing carbon emissions, the more difficult and costly those reductions become.

This decade is critical. Unless effective action is taken, the global climate may be so irreversibly altered we will struggle to maintain our present way of life. The choices we make this decade will shape the long-term future for our children and grandchildren.



Professor Will Steffen
Climate Commissioner



Professor Lesley Hughes
Climate Commissioner

With thanks to the Climate Commission science advisory panel; Professor Bruce Thom, Chair of the Australian Coasts and Climate Change Council and Professor Ove Hoegh-Guldberg.

Box 5: Opportunities in Western Australia

Western Australia has abundant potential for expanding renewable energy generation, from sources including wind, solar, wave, geothermal and bioenergy.

Wind is currently the main renewable source of electricity in Western Australia. The southwest has some of the best wind resources in Australia. Some of Australia's best solar energy resources are found in the Pilbara and northwest, and the midwest offers good resources in close proximity to areas of growing electricity demand and the electricity grid (Office of Energy).

Bioenergy sources are in earlier stages of investigation and development. A demonstration wave energy project is under construction near Perth. Mallee eucalypts, which have been established in the wheatbelt to help manage dryland salinity, could also provide biomass for electricity generation.

Reducing emissions from transport is also important. Perth has taken a lead amongst Australia's capital cities in extending its urban rail network, reducing road traffic and hence greenhouse gas emissions. The new line to Mandurah is a good example, greatly increasing the share of trips on public transport on that route (Figure 16).

Figure 16. The first train on the Mandurah railway line.



Photo credit: www.trains.chookman.id.au

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