Chapter 25. Australasia

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Executive Summary

The regional climate is changing (*very high confidence*). The region continues to demonstrate long term trends toward higher surface air and sea-surface temperatures, more hot extremes and fewer cold extremes, and changed rainfall patterns. Over the past 50 years, increases in regional average temperature can be attributed at least in part to increasing greenhouse gas concentrations *(high confidence)* and changes to rainfall in some parts of the region may also be partially so attributed (*medium confidence*). [25.3.2, 25.3.3, 25.3.4]

Regional warming is projected to continue through the 21st century (*virtually certain*) associated with other changes in climate. Warming is expected with *high confidence* to be associated with more frequent hot extremes, less frequent cold extremes, and increasing extreme rainfall and flood risk in many locations. Annual average rainfall is expected to decrease with *high confidence* in south-western Australia and with *medium confidence* elsewhere in southern Australia and the north and east of New Zealand, and to increase with *medium confidence* in the south and west of New Zealand. Tropical cyclones in the region are projected to increase in intensity but decrease in numbers (*medium confidence*), and fire weather is projected to increase in south-eastern Australia (*high confidence*) and New Zealand (*medium confidence*). [25.3.1-.5, 25.3.8, 25.3.9]

Uncertainty in projected rainfall changes remains large for many parts of Australia and New Zealand, which creates significant challenges for adaptation (*high confidence*). Projections for average annual runoff in south-eastern Australia range from little change to a 40% decline for a 2°C global warming. The dry end of these scenarios would have severe implications for agriculture, rural livelihoods, ecosystems and urban water supply. Adaptive management practices, rather than reliance on central estimates, are crucial to deal with this uncertainty (*very high confidence*). [25.3.4, 25.6.1, Box 25-3]

Recent extreme climatic events have revealed significant vulnerability of some ecosystems and many human systems to current climate variability (*very high confidence*), and the frequency and/or intensity of such events is projected to increase in many locations (*medium* to *high confidence*). For example, high sea surface temperatures have repeatedly bleached coral reefs in north-eastern Australia (since the late 1970s) and more recently in western Australia (2011). Floods in Australia (2010, 2011, 2012) and New Zealand (2010, 2011) caused severe damage to infrastructure and settlements and 35 deaths; the Victorian heat wave (2009) increased morbidity and heat-related mortality, and intense bushfires destroyed over 2,000 buildings and led to 173 deaths; widespread drought in south-east Australia (1998-2008) and many parts of New Zealand (2007-2009) resulted in mental health problems in some areas of Australia and in economic losses in both regions. [25.3.2, 25.3.4, 25.3.5, 25.6.3, 25.6.9, Box 25-6, Box 25-10]

Without adaptation, further climate change is projected to substantially affect water resources, coastal ecosystems, infrastructure, agriculture, and biodiversity (*very high confidence*). Freshwater resources are projected to decline in the highly populated south-east and the far south-west of Australia and for rivers originating in the eastern and northern parts of New Zealand; rising sea levels and increasing frequency of heavy rainfall events are projected to increase erosion and inundation, with consequent damages to many low-lying ecosystems, infrastructure and housing; rainfall changes and rising temperatures will shift agricultural production zones; and many endemic species will suffer from range contractions and some may face local or even global extinction. [25.6.1, 25.6.2, 25.6.3, 25.6.5, Box 25-2]

Some sectors in some locations have the potential to benefit from projected changes in climate and/or to capitalize on proactive adaptation measures (*high confidence*). Examples include reduced morbidity from winter illnesses and reduced energy demand for winter heating in New Zealand and southern parts of Australia, and increased spring pasture growth in cooler regions except where soil nutrients or rainfall are limiting. [25.6.5, 25.6.7, 25.6.9]

Adaptation is already occurring and adaptation planning is becoming embedded in planning processes, albeit mostly at the conceptual rather than concrete implementation level (*high agreement, robust evidence*). Many solutions for reducing energy and water consumption in urban areas, e.g. greening cities and recycling water, have already been implemented which have co-benefits for adapting to climate change. Planning for sea-level rise and, in Australia, reduced water availability, is becoming widely adopted, although implementation of specific policies remains piecemeal and open to legal and process challenges. [25.5, Box 25-2, Box 25-3, Box 25-9]

Adaptive capacity is generally high in many human systems, but implementation of effective adaptation responses faces major constraints especially at local and community levels (*very high confidence*). Efforts to understand and enhance adaptive capacity and adaptation processes have increased since AR4, particularly in Australia. Constraints on implementation arise from: uncertainty of projected impacts; limited financial and human resources to develop and implement effective policies and rules; limited integration of different levels of governance; lack of binding guidance on principles and priorities; different values and beliefs relating to the existence of climate change, objects and places at risk; and attitudes towards risk. [25.5.1, 25.5.2, Box 25-1]

Indigenous peoples in both Australia and New Zealand have higher than average exposure to climate change due to greater share of land-based activities, and face particular constraints to adaptation (*medium confidence*). Social status and representation, health, infrastructure and economic issues, and engagement with natural resource industry constrain adaptation and are only partly offset by intrinsic adaptive capacity (*high confidence*). Some proposed responses to climate change may provide economic opportunities, particularly in New Zealand related to forestry. Torres Strait livelihoods are vulnerable even to small sea level rises (*high confidence*). [25.4.3, 25.6.10]

We identify eight 'regional key risks' based on a consideration of the severity of potential impacts for different levels of warming, uniqueness of the systems affected, and limits to adaptation (*high confidence*). These risks differ in the degree to which they can be managed via adaptation and mitigation, and some are more likely to be realized than others, but all warrant attention from a risk-management perspective.

- Some potential impacts can be delayed but now appear very difficult to avoid entirely, even with combined global mitigation and proactive adaptation:
    - ***Collapse of coral reef systems in north-eastern and western Australia***, driven by increasing sea-surface temperatures and ocean acidification; the natural ability of reefs to adapt to the projected rates of change is very limited [Box 5-3, 25.6.3, 30]
    - ***Loss of montane ecosystems and some endemic species in Australia***, driven by rising temperatures and loss of seasonal snow cover, increased fire risk and drying trends; fragmentation of landscapes, limited dispersal and evolutionary capacity limit adaptation options [25.6.2]
- Some impacts have potential to be severe but can be moderated or delayed significantly by combined global mitigation and a portfolio of available adaptation measures:
    - ***Increased frequency and intensity of flood damage to settlements and infrastructure***, driven by increasing extreme rainfall but the amount of change remains uncertain; in many locations, continued reliance on increased protection alone would become progressively less feasible; more integrated planning responses are well understood but face implementation constraints [Box 25-2, 25.6.3, Box 25-10]
    - ***Systematic constraints on water resource use in southern Australia***, driven by rising temperatures and reduced cool-season rainfall; integrated responses encompassing management of supply, recycling, water conservation and increased efficiency across all sectors are available but face implementation constraints [25.3.3, 25.6.1, Box 25-3]
    - ***Increase in morbidity and infrastructure failure during heat waves in Australia***, driven by increased frequency and magnitude of extreme temperatures*;* vulnerable populations include the elderly, children and those with existing chronic diseases; ageing trends and prevailing social dynamics constrain effectiveness of adaptation responses [25.6.9]
    - ***Increased damages to ecosystems and settlements, economic losses and risks to human life from wildfires***, driven by drying trends and rising temperatures; local planning mechanisms and public education can assist with adaptation and are being implemented in regions that have experienced major events [25.3.8, 25.6.7, 25.6.9, Box 25-7]
- Some potential impacts have a low or currently unknown probability but cannot be ruled out even under mitigation scenarios; these impacts would present major challenges if realized:
    - ***Widespread damages to coastal infrastructure and low-lying ecosystems such as wetlands and Kakadu National Park*** **<u>if</u>** ***sea level rise were to exceed 1m***; sea level rise in excess of 1m becomes increasingly likely beyond 2100; managed retreat is a long-term adaptation strategy for human systems but options for natural ecosystems are limited due to the high rate of change and lack of suitable space for inland migration [*WGI 13.ES;* Box 25-2, 25.3.7, 25.6.2, 25.6.3, 25.6.10]
    - ***Significant reduction in food production particularly in the Murray-Darling Basin*** **<u>if</u>** ***scenarios of severe drying were realised****;* more efficient water use, allocation and trading would increase the resilience of systems in the near term but cannot prevent significant reductions in agriculture

production and severe consequences on ecosystems at the dry end of the projected range [25.3.3, 25.6.1, 25.6.5, Box 25-6]

Significant synergies and trade-offs exist between alternative adaptation responses, and between mitigation and adaptation responses; interactions occur both within Australasia and between Australasia and the rest of the world (*very high confidence*). Increasing efforts to mitigate and adapt to climate change imply increasing complexity of interactions, particularly at the intersections among water, energy and biodiversity where availability of suitable land acts as constraint, but tools to understand and manage these interactions remain limited. Flow-on effects from climate change impacts and responses outside Australasia have the potential to outweigh some of the direct impacts of climate change within the region, particularly economic impacts on trade-intensive sectors such as agriculture (*medium confidence*), but they remain amongst the least explored issues. [25.7, Box 25-11]

Australia is significantly more vulnerable to climate change than New Zealand (*high confidence*). Many ecosystems, agricultural production and urban infrastructure in Australia are exposed to greater changes and are closer to coping thresholds than those in New Zealand. However, Australia has devoted significant effort since the AR4 to understand its vulnerability and develop adaptation options, while the apparent resilience of New Zealand is based on only a limited number of studies in some sectors. [25.5, 25.8, 25.9]

Understanding of future vulnerability of human and mixed human-natural systems to climate change remains limited due to incomplete consideration of socio-economic dimensions (*very high confidence*). Future vulnerability will depend on factors such as wealth and its distribution across society, patterns of ageing, access to technology and information, labour force participation, and societal values. These dimensions have received only limited attention and are rarely included in current vulnerability assessments, and frameworks to integrate social and cultural dimensions of vulnerability with economic losses are lacking. [25.4, 25.5, 25.9]

25.1. Introduction

Australasia is defined here as lands, territories, offshore waters and oceanic islands of the exclusive economic zones of Australia and New Zealand. Both countries are relatively wealthy with export-led economies. Both have Westminster-style political systems and have a relatively recent history of non-indigenous settlement (Australia in the late 18th, New Zealand in the early 19th century). Both retain significant indigenous populations.

Chapter 25.2 summarises major conclusions from the AR4 (Hennessy *et al*., 2007); 25.3 assesses observed and projected future climate changes including, where possible, attributions; 25.4 considers the socio-economic context of impacts and vulnerabilities; 25.5 describes current adaptation frameworks and links to decision-making; 25.6 and subsections present climate change impacts and adaptation options for specific sectors. Sections 25.7-8 summarise and integrate across sectors. Finally, 25.9 identifies key uncertainties, research and data needs.

25.2. Major Conclusions from Previous Assessments

The principal findings of the IPCC Fourth Assessment Report (AR4) (Hennessy *et al*., 2007) were as follows.:.:

- Consistent with global trends, Australia and New Zealand had experienced warming of 0.4 to 0.7°C since 1950 with changed rainfall patterns and an average sea-level rise of 70mm; there had also been a greater frequency and intensity of droughts and heat waves, reduced seasonal snow cover and glacial retreat.
- Impacts from recent climate changes were evident in increasing stresses on water supply and agriculture, and changed natural ecosystems; some adaptation had also occurred in these sectors but vulnerability to extreme events such as fire, tropical cyclones, droughts, hail and floods remained high.
- The climate of the 21st century would be warmer (*virtually certain*), with changes in extreme events including more intense and frequent heat waves, fire, floods, storm surges and droughts but less frequent frost and snow (*high confidence*), reduced soil moisture in large parts of Australian mainland and eastern New Zealand but more rain in western New Zealand (*medium confidence*).

- Significant advances had occurred in understanding future impacts on water, ecosystems, Indigenous people and health together with an increased focus on adaptation; potential impacts would be substantial without further adaptation, in particular for water security and coastal development, loss of biodiversity, increased risks to major infrastructure, but more variable impacts on agriculture and forestry across the region including potential benefits in some areas.
- Vulnerability would increase mainly due to an increase in extreme events, but to a variable degree as human systems were considered to have a higher adaptive capacity than natural systems.
- Hotspots of high vulnerability included, by 2050 under a medium emissions scenario:
  - significant loss of biodiversity in areas such as but not restricted to alpine regions, the Wet Tropics, the Australian south-west, Kakadu wetlands, coral reefs and sub-Antarctic islands;
  - water security problems in the Murray-Darling basin, south-western Australia and eastern New Zealand; and,
  - potentially large losses in areas of rapid coastal development in south-eastern Queensland and in New Zealand from Northland to the Bay of Plenty.

25.3. Observed and Projected Climate Change

Understanding of observed and projected climate change has received significant attention since AR4, particularly in Australia, with a focus on better understanding the causes of observed rainfall changes and more systematic analysis of projected changes from different models and approaches. Most studies are based on CMIP3 models and SRES scenarios, but CMIP5 model results are discussed where available (see also AR5 WGII Chap 21 and WGI Chap 14).

25.3.1. Temperature

Australian and New Zealand land temperatures have warmed significantly over the past 100 years *(very high confidence)*, by +0.94ºC over Australia and +0.91ºC over New Zealand (Fawcett *et al*., 2012; Mullan *et al*., 2010). Warming has been greatest since 1950 over subtropical inland Australia, and higher in the north than the south of New Zealand. Sea surface temperatures have also increased in the Australasian region (BoM, 2011; Mullan *et al*., 2010), by 0.07°C per decade from 1910-2010 for New Zealand, by 0.11-0.12°C per decade since 1950 for northwest and northeast Australia, and up to 0.2°C per decade in the region of the East Australian Current (Lough, 2008; Lough and Hobday, 2011).

A significant part of the warming over Australia since 1950 can be attributed with *high confidence* to increasing greenhouse gas concentrations (Karoly and Braganza, 2005), with spatial variations related to atmospheric circulation variations (Cai *et al*., 2006; Hendon *et al*., 2007; Nicholls *et al*., 2010). New Zealand warming has been partially attributed (*medium confidence*) to increasing greenhouse gas emissions after accounting for the effect of circulation variations (Dean and Stott, 2009).

Further warming this century over Australasia is *virtually certain;* warming is projected to be greatest over inland Australia, and least in coastal areas and over New Zealand *(high confidence)* (AR5 WGI Chap 11, 12; CSIRO and BoM, 2007; Moise and Hudson, 2008). Projected mean warming across Australia by 2030 (relative to 1990) is 0.5-1.5°C under A1B for a range of CMIP3 models, and 1.0-2.5°C (B1) and 2.2-5°C (A1FI) by 2070 (CSIRO and BoM, 2007). CMIP3-based projected warming over New Zealand by 2040 (relative to 1990) is 0.3 to 1.4°C and by 2090 is 1.1 to 3.4°C under A1B based on 12 models (MfE, 2008c). For B1 and A1FI scenarios, the range is 0.2–0.9 and 0.5–2.0°C by 2040 and 0.7–2.3 and 1.6–5.1°C by 2090, respectively. CMIP5 results (see WGI Atlas, Figures AI.82-85) are broadly consistent with these projections but have not been used in any impact studies assessed here. Figure 25-1 shows observed and modelled past and projected future annual average temperatures over Australia and New Zealand (including their exclusive economic zones), including modelled past temperatures if there had been no anthropogenic influence on the climate system but only natural drivers of variability and change.

[INSERT FIGURE 25-1 HERE
Figure 25-1: Observed and modelled past and projected future annual average temperatures over Australia (left) and New Zealand (right). The areas covered include both land (mainland and Cocos, Christmas, Norfolk, Heard and McDonald Islands for Australia, and Cook Islands, Niue and Tokelau for New Zealand) and exclusive economic zone territory. Black lines show annual average values from observational datasets, namely GISTEMP (Hansen *et al*., 2010), HadCRUT3 (Brohan *et al*., 2006), and MLOST (Smith *et al*., 2008b). The coloured bands show the 10-90th percentile range of annual average values from 32 simulations from 12 climate models from the CMIP3 and CMIP5 projects (Meehl *et al*., 2007; Taylor *et al*., 2011a) run under different scenarios of changes in external drivers. The pink band shows simulations driven with observed changes in all known external drivers over the 1901-2005 period; the blue band shows simulations driven with observed changes in natural external drivers only (volcanic eruptions and changes in solar irradiance). The green band shows simulations running over 2006-2050 driven under either the SRES A1B (for CMIP3) or the RCP4.5 (for CMIP5) emissions scenarios. All regional values are plotted as anomalies relative to their 1901-2005 average in the case of observed data, or from the average of the respective simulations driven with past changes in all known observed external drivers. Observed values suffer in some areas from sparse monitoring coverage.]

25.3.2. Temperature Extremes

Since 1950, cool extremes have become rarer and hot extremes more frequent and intense *(high confidence)* (Chambers and Griffiths, 2008; Gallant and Karoly, 2010; Nicholls and Collins, 2006; Trewin and Vermont, 2010). For Australia, these trends are at least partially attributable to anthropogenic influence *(medium confidence)* as they are consistent with the trend in mean temperature (Alexander *et al*., 2007; Nicholls and Collins, 2006; Trewin and Vermont, 2010) and correspond well with CMIP3-model simulations for the 20th century (Alexander and Arblaster, 2009). Land-cover change (Deo *et al*., 2009; McAlpine *et al*., 2007) and CO_2-driven reduced evapotranspiration (Cruz *et al*., 2010) may have also contributed to high temperature extremes during droughts.

Hot days and nights will become more frequent and cold days and cold nights less frequent during the 21st century (*high confidence*). For Australia, this includes by the end of the century a strong increase in warm nights (90th percentile of T_{min}), fewer frosts (below 0°C), and longer heat-waves (at least five consecutive days with maxima at least 5°C above the 1961-90 mean) (Alexander and Arblaster, 2009; CSIRO and BoM, 2007; Tryhorn and Risbey, 2006). Similar trends are projected for extremes in New Zealand (Griffiths *et al*., 2005), i.e. significant increases in the frost-free area (Tait, 2008) and days with temperatures above 25°C (MfE, 2008c).

25.3.3. Precipitation

Southwest Australia has become markedly drier since the 1970s and autumn/winter rainfall declined in the southeast since the mid-1990s (Hope *et al*., 2010) *(very high confidence)*. The years 2001 to 2010 witnessed record dry conditions in many parts of inland eastern Australia (Potter *et al*., 2010). The decline in winter rainfall in the southwest is related to synoptic circulation changes *(very high confidence)* (Bates *et al*., 2008; Frederiksen and Frederiksen, 2007; Hope *et al*., 2006) and partly attributable to anthropogenic climate change *(high confidence)* (Cai and Cowan, 2006; Frederiksen *et al*., 2011; Hope *et al*., 2006; Timbal *et al*., 2006) plus natural variability and land use change (Timbal and Arblaster, 2006). The immediate mechanism driving the autumn/winter drying in Australia's southeast remains unclear (Cai and Cowan, 2008a; Cai *et al*., 2011; Nicholls, 2010; Smith and Timbal, 2010; Ummenhofer *et al*., 2009b), but some modeling evidence supports a partial contribution from increased greenhouse gases (Timbal, 2010). For poorly understood reasons, northwest Australia has become wetter since the 1950s (Jones *et al*., 2009). Mean annual rainfall over New Zealand increased over 1950-2004 in the south and west of both islands and decreased elsewhere, related to increasing westerly winds *(very high confidence)* (Griffiths, 2007). Summer rainfall declined over much of New Zealand over 1979–2006, related to variations in ENSO and the Southern Annular Mode (Ummenhofer *et al*., 2009a).

Annual rainfall is projected to decline further in southwestern Australia *(high confidence)* and elsewhere in southern Australia (*medium confidence)*, with the strongest reduction occurring during the winter half-year (*high confidence*), but with significant spread among models. This is based on multiple lines of evidence from CMIP3 results (CSIRO and BoM, 2007; Moise and Hudson, 2008), observed and modeled synoptic processes (Cai and Cowan, 2006; Frederiksen *et al*., 2011), downscaling (Timbal and Jones, 2008), and CMIP5 models (Figure 25-2; WGI Atlas Figures AI 86-87). In eastern and northern Australia, the direction of future change remains uncertain *(very high confidence)* (CSIRO and BoM, 2007; Watterson, 2012). By 2030 (relative to 1990), projected changes are -15% to +10% in northern areas of Australia and -10% to little change in southern areas in the CMIP3 models under A1B (CSIRO and BoM, 2007) . By 2070 annual average changes are around twice those projected for 2030, and larger still under A1FI (-30% to +20% in central, eastern and northern areas, and -30% to +5% in the southwest) and in some seasons (e.g., winter decreases of up to 40% in the south west) (CSIRO and BoM, 2007). Available results from CMIP5 models (see Figure 25-2 and WG1 Atlas) are broadly consistent with CMIP3.

[INSERT FIGURE 25-2 HERE
Figure 25-2: Projected multi-model mean change in rainfall for 2080-2099 relative to 1980-1999 for RCP8.5 and 18 CMIP5 models. Dots [carets] indicate where the models agree (>90% red; >67% black) that there will [will not] be a substantial (>10%) change (from Moise *et al*., 2012).]

For New Zealand, statistical downscaling based on CMIP3 models gives *medium confidence* that annual average rainfall will increase in the west and south and decline in the east and north (MfE, 2008c), consistent with direct CMIP5 results (Figure 25-2), with annual averages dominated by winter and spring trends related to increased westerlies (see Section 25.3.6). However, the range of projected rainfall changes across 12 CMIP3 models (A1B emissions) is large; with changes between -5 and +15% by 2040 and -10 and +25% by 2090 (compared with 1990) in the south and west and between -15 and +10% by 2040 and -20 and +15% by 2090 for the east and north of the country (MfE, 2008c). Using the same models and the A2 emission scenario, winter rainfall for the west and south of the South Island is projected to change by -6 to +30% by 2040 and +12 to +56% by 2090 (compared with 1990), while winter rainfall for the east of the North Island is projected to change by -18 to +8% by 2040 and -28 to -2% by 2090 (Reisinger *et al*., 2010).

25.3.4. Precipitation Extremes

Depending on location, rainfall extremes have either increased or decreased (Alexander *et al*., 2007; Gallant *et al*., 2007; Griffiths, 2007; MfE, 2008c; Ummenhofer *et al*., 2009a). The direction of change mostly mirror trends in mean rainfall (see 25.3.4), although with a tendency for Australia for extreme rainfall to change at a faster rate than mean rainfall (Alexander *et al*., 2007). Alexander and Arblaster (2009) found reasonable agreement between observed trends and simulated trends in the CMIP3 ensemble with greenhouse gas forcing for 1957-1999.

The intensity of daily extremes or the proportion of rainfall in extreme categories is projected to increase where mean rainfall increases *(high confidence)* but also where it decreases *(medium confidence)* (Alexander and Arblaster, 2009; MfE, 2008c; Rafter and Abbs, 2009). Fine-scale regional modelling shows a tendency for short duration (sub-daily) rainfall to increase more rapidly than longer duration (daily and multi-day) rainfall (Abbs and Rafter, 2009). Based on modeling and theory, increases to extreme rainfall for New Zealand of up to 8% per 1°C increase in temperature have been projected, although potentially with significant regional variations (Carey-Smith *et al*., 2010; MfE, 2008c, 2010a) and large inter-model differences.

25.3.5. Drought

The historical frequency of drought in Australia, using a rainfall based index, shows no significant trends (Hennessy *et al*., 2008a) *(high confidence),* but there is evidence that regional warming has increased the intensity of recent droughts in south-eastern Australia in hydrological terms (*medium confidence*) (Cai and Cowan, 2008b; Cai *et al*., 2009b; Nicholls, 2006). Drought occurrence is projected to increase with *high confidence* in southern Australia (Hennessy *et al*., 2008a; Kirono and Kent, 2010; Kirono *et al*., 2011) and with *medium confidence* in eastern New Zealand (Clark *et al*., 2011), with large inter-model variations due mainly to uncertainty in precipitation changes. Analysis based on the CMIP3 ensemble, for example, shows drought occurrence in 2070 under A1B ranging from little change to five times increase in southern areas of Australia and between a halving and around 2-3 times increase in northern areas (Kirono and Kent, 2010; Kirono *et al*., 2011). The time spent in drought in eastern and northern New Zealand is projected to double or triple by 2030–2049 (to more than two months per year for parts of Northland and much of Gisborne, Canterbury and Otago), compared with 1980–1999 (median projection using 19 CMIP3 models and the B1, A1B and A2 scenarios) (Clark *et al*., 2011).

25.3.6. Winds

Observed wind changes over Australia remain unclear, with opposite changes observed at 2 and 10m (McVicar *et al*., 2008; Troccoli *et al*., 2012). Storm activity overall has declined over south-eastern Australia since about 1885 *(medium confidence)* (Alexander *et al*., 2011). Mean westerly flow over New Zealand increased during the late 20th century (1978–1998) but weakened after 2000, linked to atmospheric circulation changes (Mullan *et al*., 2001) (Parker *et al*., 2007) and a strengthening of the lower stratospheric polar vortex related to photochemical ozone losses (Thompson and Solomon, 2002). Over New Zealand, extreme westerly episodes and southerlies slightly increased while extreme easterlies decreased since 1960 (Dean and Stott, 2009; Salinger *et al*., 2005).

Mean wind speeds for 2081-2100 relative to 1981-2000 are projected to increase at latitudes 20-30°S across Australia with decreases or little change elsewhere, except for winter increases across Bass Strait and Tasmania, (McInnes *et al*., 2011a) (*medium confidence)*. These predictions are consistent with projected southward movement of storm tracks away from southern Australian latitudes (Frederiksen *et al*., 2011). For New Zealand, averaged over six emission scenarios, westerly winds are projected to increase by approximately 10% by 2090, compared with 1990, with the strongest increase in winter, and some decreases in summer and autumn (MfE, 2008c) *(medium confidence)*. Results from a regional modeling study indicate that extreme winds will follow the same pattern (Mullan *et al*., 2011).

25.3.7. Mean and Extreme Sea Level

Mean sea level has risen by around 1-2mm/year in the region over the past century and will continue to rise for at least several more centuries (*very high confidence;* AR5 WGI Chap13). From 1920 to 2000 the average relative sea level rise (SLR) around Australia was about 1.2 mm/year (Church *et al*., 2006). In New Zealand, the average rate of SLR was 1.7±0.1 mm/yr over 1900-2009, across four main ports and six regional stations (Hannah and Bell, 2012). With an estimated 0.5 mm/yr for crustal rebound in the New Zealand region (Hannah, 2004), this yields an absolute SLR estimate of approximately 2.1 mm/yr. Satellite estimates over 1993-2009 show a much faster mean absolute rise in regional sea level (CSIRO and BOM, 2012), partly reflecting changes in atmospheric circulation patterns (Hannah and Bell, 2012; Power and Smith, 2007). Future projected regional sea-level is strongly determined by global sea level changes (see AR5 Chapter 13 WG1), although there is evidence that in the eastern Australasian region SLR may exceed the global rate (Church *et al*., 2011).

Australian extreme sea levels have also risen at approximately the rate of global rise (*high confidence*) (Menendez and Woodworth, 2010), possibly higher at some sites (Church *et al*., 2006). Projected mean SLR will lead to large increases in the frequency of extreme sea level events across Australasia (*very high confidence*), with changes in significant wave height and storms playing a more minor role. Over southeastern Australia, a SLR of 0.1 m increases the frequency of an extreme sea level event by a factor of between 5 and 10, even allowing for a decrease in the frequency of driving storms (McInnes *et al*., 2009, 2011b; McInnes *et al*., 2012). For the tropical east coast of Australia the impact of a 10% increase in tropical cyclone intensity on the 1 in 100 year storm tide is small compared with a 0.3 m increase in mean SLR (Harper *et al*., 2009).

25.3.8. Fire Weather

Fire weather has increased in Australia since 1973 *(high confidence),* with 24 of 38 stations showing significant increases in annual 90th percentiles of the McArthur Forest Fire Danger Index (Clarke *et al*., 2012). Very high fire danger days are projected to increase with *high confidence* in south eastern Australia, with changes of 2-13% and 10-30% by 2020 and of 10-50% and 20-100% by 2050 simulated under B1 and A2 emissions scenarios, respectively, relative to the period 1973-2007 (Lucas *et al.*, 2007). In Canberra, for example, the current 17 days would increase to 18-23 days in 2020 and 20-33 days in 2050 (Lucas *et al.*, 2007). Projections for other regions are less clear. Climate model simulated changes to weather systems and sea surface temperature patterns have also been shown to increase fire weather occurrence (Cai *et al.*, 2009a; Hasson *et al.*, 2009). In New Zealand, projections from 16 CMIP3 models under A1B emissions indicate an increase in very high and extreme fire danger days of between 0 and 24 days (up to 400% increase) by 2040 and 0 to 38 days (up to 600% increase) by 2090 (relative to 1990) for eastern areas (Pearce *et al.*, 2011b). Projections for other regions, except the west coast of the South Island, range from little change to a doubling (+0 to +17 days) of very high and extreme fire danger days by century's end.

25.3.9. Tropical Cyclones and Other Severe Storms

Observations of extreme events such as severe thunder storms, tornadoes and tropical cyclones are significantly affected by data availability and biases due to changes in population, and measurement quality, quantity and practice (Kuleshov *et al.*, 2010; Mills, 2004). Recent studies, suggest no change in the number of tropical cyclones or the proportion of intense storms in the Australian region over 1981-2007 (Kuleshov *et al.*, 2010) *(medium confidence)*. Since the late 19th century, however, landfall of cyclones has diminished (Callaghan and Power, 2011) and there have been more cyclones to the west, relative to the east (Hassim and Walsh, 2008) since 1980. Tropical cyclones in the region are projected to increase in intensity but decrease, or stay similar, in numbers *(medium confidence)* based on global studies (see WGI Chapter 14). This is supported by regional modeling (Abbs, 2012), which predicts approximately 50% decrease in occurrence of tropical cyclones for the Australian region for 2051-2090 relative to 1971- 2000 but increases in associated rainfall and in the proportion of storms with the most extreme winds, and a small southward shift in their occurrence.

Single studies project decreases in cool season tornadoes in southern Australia (Timbal *et al.*, 2010) and increases in hail in the Sydney region (Leslie *et al.*, 2008). Regional modeling indicates severe weather systems are projected to increase by 3–6% over most of New Zealand by 2020-2100 relative to 1970-2000 under A2 emissions (Mullan *et al.*, 2011).

25.3.10. Snow and Ice

Late-season snow depth declined significantly at three of four sites in the Snowy Mountains during 1957-2002 (Hennessy *et al.*, 2008b) *(high confidence)*, attributed to regional warming enhancing late season ablation (Nicholls, 2005), but annual maximum depth has shown no significant trends. Both depth and duration are projected to decline in future (*high confidence*). The area in mainland Australian with an average annual snowcover of at least thirty days is projected to decline by 14 to 54% by 2020, and by 30 to 93% by 2050, allowing for emission and model uncertainty (Hennessy *et al.*, 2008b).

Ice volume in New Zealand declined by almost 50% during the 20th century, with glacier volume reducing by at least 25% since 1950 (Anderson *et al.*, 2006a; Anderson and Mackintosh, 2006; Chinn, 2001; Clare *et al.*, 2002). However, circulation patterns have been shown to enhance or outweigh these multi-decadal trends over time scales of up to two decades (Purdie *et al.*, 2011; Willsman *et al.*, 2010). Consistent with this, ice volume in many fast response time glaciers (e.g. Fox and Franz Josef) showed significant losses up to the 1970s, gains after the mid-1980s and further losses since 2000 (Zemp *et al.*, 2008). Snowline elevations are projected to rise, and winter snow volume and the duration of days with low elevation snow lying are projected to decrease (*high confidence*) (Fitzharris, 2004; Hendrikx *et al.*, submitted; MfE, 2008c). Based on 12 CMIP3 models and the A1B emission scenario, average peak snow accumulation is projected to decrease by 3 to 44% at 1000m asl, and change by between +8 and -22% at 2000m by 2040, compared with 1990. By 2090, peak accumulation is projected to decline at all elevations (by 32-79% at 1000m and by 6-51% at 2000m). The average elevation where snow duration exceeds three months is projected to rise from 1550m in 1990, to 1550-1750m by 2040 and 1700-2000m by 2090 (Hendrikx *et al.*, submitted).

25.4. Socio-Economic Trends Influencing Vulnerability and Adaptive Capacity

25.4.1. Demography

Socio-economic dimensions are important drivers of adaptive capacity and vulnerability of human and human-natural systems (AR5 WGII Chapters 2, 11-13, 16, 20) Populations in Australia and New Zealand are projected to grow and age significantly over at least the next several decades (*very high confidence*). Australia's population (22.4 million in 2010) is projected to grow to 31-43 million by 2056, and 34-62 million by 2101 (ABS, 2008). New Zealand's population (4.4 million in 2010) is projected to grow to 4.8-6.7 million by 2061 (Stats NZ, 2011c). Regional growth drivers are immigration (Carr, 2010; Hugo *et al*., 2010; Ridout *et al*., 2010) and mortality and fertility changes (ABS, 2008; Stats NZ, 2011c). The number of people aged 65 and over is projected to double within the next two decades (Stats NZ, 2011c; Treasury, 2010).

More than 85% of the Australasian population lives in urban areas and their satellite communities (ABS, 2008; Stats NZ, 2004), mostly in coastal areas (DCC, 2009; Stats NZ, 2010b). The population is extremely dynamic: around half of all people move house at least once every five years (ABS, 2010a; Stats NZ, 2006). Urban concentration and depletion of remote rural areas is expected to continue (Mendham and Curtis, 2010; Stats NZ, 2010c), but some coastal non-urban spaces also face increasing development pressure (Freeman and Cheyne, 2008; Gurran, 2008).

25.4.2. Economic Activity and Consumption Patterns

The economies of Australia and New Zealand rely on natural resources, agriculture, minerals, manufacturing and tourism, but the relative importance of these sectors differs between the two countries. Agriculture and mineral/energy resources accounted, respectively, for 11% and 54% (Australia) and 56% and 5% (New Zealand) of total exports in 2009/2010 (ABARES, 2010; Stats NZ, 2011b).

Real GDP has grown by an average of 3.3% p.a. between 1970 and 2010 in Australia and 2.4% p.a. between 1970 and 2003 in New Zealand, with annual GDP per capita growth of 1.9% and 1.3%, respectively (ABS, 2011; Stats NZ, 2011a). Primary energy supply grew at lower rates of about 1.1% p.a. between 1971 and 2008 in both countries (OECD, 2011). GDP is projected to grow on average by 2.5-3.5% p.a. in Australia and about 1.9% p.a. in New Zealand to 2050 (Bell *et al*., 2010; Treasury, 2010), but subject to sigificant short-term fluctuations.

Australia and New Zealand abstracted an estimated 930 and 940 m^3 of water per capita in 2007. These are the third/second highest rates in the OECD, with about half used for irrigation (OECD, 2011). Aggregate domestic material consumption more than doubled in Australasia between 1975 and 2005, driven mainly by increasing wealth and, to a lesser extent, population growth (Schandl and West, 2010).

25.4.3. Social Change

Climate change impacts are generally expected to fall disproportionately on the poor and marginalised (AR5 WGII chapters 11, 13). Poverty rates and income inequality in New Zealand and Australia are in the upper half of OECD countries; both measures increased significantly in New Zealand between the mid-1980s and mid-2000s (OECD, 2011). Measurements of poverty, inequality and exclusion, however, are highly contested and anticipating future changes and effects on adaptive capacity remain difficult.

More than 20% of Australian and New Zealand residents are born overseas from varied cultural backgrounds (OECD, 2011). Indigenous peoples currently constitute about 2% and 15% of the Australian and New Zealand population, but the Australian indigenous population is growing faster than the average (ABS, 2010b; Biddle and Taylor, 2009; Stats NZ, 2010a). Indigenous people in both countries have lower average levels of income and educational attainment, implying adaptive capacity could be influenced strongly by future changes in socio-economic status and social inclusion (25.6.10).

25.4.4. Use and Relevance of Socio-Economic Scenarios in Adaptive Capacity/Vulnerability Assessments

Demographic, economic and socio-cultural conditions are expected with *very high confidence* to influence vulnerability and adaptive capacity of individuals and communities (see also Box 25-1). Australian examples include changes in the number of people and percentage of elderly people at risk (Baum *et al*., 2009; Preston and Stafford-Smith, 2009a; Preston *et al*., 2008), the density of urban settlements and exposed infrastructure (Preston *et al*., 2008; Preston and Jones, 2008), population-driven pressures on water demand (CSIRO, 2009a), and economic and social factors affecting individual ability to cope with, recover from, and plan for, natural hazards (Brunckhorst *et al*., 2011; Dwyer *et al*., 2004).

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Box 25-1. Socio-Cultural Constraints and Opportunities for Adaptation

Australians generally perceive themselves to be at higher risk from climate change than New Zealanders and citizens of many other countries, which may reflect recent climatic extremes and their impacts (Agho *et al*., 2010; Ashworth *et al*., 2011; Gifford *et al*., 2009; Milfont *et al*., in press; Reser *et al*., 2012). However, beliefs about climate change and the risks it poses vary over time, are uneven across society and depend on political preferences and gender (Leviston *et al*., 2011; Milfont, 2012; ShapeNZ, 2009), which can constrain or increase the willingness of communities and businesses to consider adaptation options (Alexander *et al*., 2012; Ashworth *et al*., 2011; Gardner *et al*., 2010; Gifford, 2011; Reser *et al*., 2011; Reser and Swim, 2011).

Socio-cultural differences also influence the values assigned to places, activities and objects at risk from climate change. There is as yet *limited evidence* but *high agreement* that for some parts of society, projected climate change impacts on landscapes and ecosystems will cause significant losses. Examples include the value placed on winter snow cover in the Snowy Mountains (Gorman-Murray, 2008, 2010), conflicts between human uses and environmental priorities in national park management (Roman *et al*., 2010; Wyborn, 2009), and alternative uses of limited water resources in rural communities (Alston, 2010; Hurlimann and Dolnicar, 2011; Kingsford *et al*., 2011).

Some adaptation options are constrained significantly by social and cultural values (*high confidence*). For example, place attachment and differing values relating to near- versus long-term, and private versus public costs and benefits limit current support for managed retreat in coastal zones as an adaptation response (Agyeman *et al*., 2009; Hayward, 2008a; King *et al*., 2010), and socio-cultural values limit acceptance of water recycling or pricing (Hurlimann and Dolnicar, 2010; Kouvelis *et al*., 2010; Mankad and Tapsuwan, 2011; Miller and Buys, 2008; Pearce *et al*., 2007b). However, place attachment can also offer co-benefits between adaptation responses and improvements to mental well-being and socio-economic development, especially for indigenous communities (Berry *et al*., 2010, see also 25.12).

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Socio-economic considerations are increasingly being used to understand adaptive capacity of communities (Bohensky *et al*., 2011; Brunckhorst *et al*., 2011; Fitzsimons *et al*., 2010; Smith *et al*., 2008a; Smith *et al*., 2010; Soste, 2010) and construct scenarios of integrated environmental and socio-economic change, mostly to build regional planning capacity (CSIRO, 2006; Frame *et al*., 2007; Frame *et al*., 2009; Huser *et al*., 2009; Pettit *et al*., 2011; Pride *et al*., 2010; Taylor *et al*., 2011b; van Delden *et al*., 2011). Such scenarios, however, have only infrequently been used to quantify impacts or vulnerability.

The great majority of Australasian vulnerability studies make no or only limited use of socio-economic factors, consider only current but not future socio-economic conditions, and/or rely on postulated correlations between socio-economic indicators and climate change vulnerability. In many cases this seriously limits the confidence that can be assigned to conclusions regarding future vulnerability and adaptive capacity to climate change of human and mixed natural-human systems of Australasia.

25.5. Cross-Sectoral Adaptation: Approaches, Effectiveness, Constraints, and Limits

25.5.1. Frameworks, Governance, and Institutional Arrangements

Adaptation to climate change is driven by perceived and projected climate changes as well as evolving non-climate pressures, social and cultural values, perceptions of risk, and economic and political considerations. The opportunities for and effectiveness of adaptation depend heavily on institutional and governance arrangements that enable decision-makers to consider climate change information (AR5 WGII Chap 2, 14, 15, 16, 20; Downing, 2012).

The federal/central governments of Australia and New Zealand both promote a standard risk management paradigm to evaluate climate change response options and embed adaptation into existing decision-making practices, as part of the intended process of 'mainstreaming' (AGO, 2006; MfE, 2008c). Responsibility for development and implementation of adaptation policy is largely devolved to local and (in Australia) state governments, with support from federal/central government mostly via provision of information, tools and policy guidance.

The Council of Australian Governments agreed a national adaptation policy framework in 2007 (COAG, 2007). Australia's federal government established the collaborative National Climate Change Adaptation Research Facility (NCCARF) in 2008, which complements CSIRO's Climate Adaptation Flagship, and various federal grants have supported risk assessments and adaptation planning initiatives by local government and Natural Resource Management bodies. The federal government further supported a first-pass coastal risk assessment (DCC, 2009; DCCEE, 2011), as well as reports addressing impacts and management options for natural and managed landscapes (Campbell, 2008; Dunlop and Brown, 2008; Steffen *et al*., 2009), national and World Heritage areas (ANU, 2009; BMT WBM, 2011), and indigenous and urban communities (Green *et al*., 2009; Norman, 2010). The central government in New Zealand has updated and expanded tools to assess impacts and guidance on adaptation principles and actions consistent with regulatory requirements (MfE, 2008d, c, a, 2010a) and updated key directions for coastal management (Minister of Conservation, 2010; see also Box 25-2). Individual departments have commissioned impacts assessments (e.g. on biodiversity; McGlone and Walker, 2011), but no national-level risk assessment or adaptation policy framework has been developed.

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Box 25-2. Coastal Adaptation – Planning and Legal Dimensions

Sea level rise is a significant risk to Australia and New Zealand (*very high confidence*). The inability to rule out significant sea level rise and its persistence over many centuries (AR5 WGI Chapter 13), the location of population centres and infrastructure and intensifying coastal development (DCC, 2009; Freeman and Cheyne, 2008; see also 25.4) imply a significant exposure to inundation and erosion from sea level rise and storms this century. In Australia, a national review estimates that sea level rise of 1.1m would affect over A$226 billion of assets, including up to 274,000 residential and 8,600 commercial buildings (DCCEE, 2011), with additional intangible costs related to stress, health effects and service disruption (HCCREMS, 2010). No national-level quantitative assessment of inundation and erosion risks from sea level rise exists in New Zealand, but local case studies demonstrate significant assets and communities at risk, especially for sea level rises of more than 1m (Fitzharris, 2010; Reisinger *et al*., in press).

Responsibility for adapting to sea level rise in Australasia rests principally with local governments. Five of 7 Australian states have mandatory planning benchmarks by 2100 (Victoria and Queensland 0.8m; New South Wales and Western Australia 0.9m (WA by 2110); South Australia 1m), although local councils retain flexibility for their implementation. Only Queensland has mapped high risk coastal zones in which new development is prohibited except for a small number of specified marine and coast-dependent activities (Queensland Government, 2012). The

New Zealand government recommends a (non-binding) risk-based approach, using a base value of 0.5m sea level rise by the 2090s but considering the implications of greater rise of at least 0.8m, particularly where impacts could have high consequences or future adaptation options are limited, and a further increase of 0.1m per decade beyond 2100 (MfE, 2008a). The revised New Zealand Coastal Policy Statement (Minister of Conservation, 2010) mandates a minimum 100-year planning horizon for assessing hazard risks and discourages protection as the default response to increasing hazards.

Recent studies highlight institutional and governance challenges and opportunities for managing these risks. The incorporation of climate change impacts into local planning has evolved considerably over the past 20 years (Kay *et al.*, in press) but remains piecemeal (Gibbs and Hill, 2012) and based on a diversity of approaches. Many local governments lack the resources for hazard mapping and policy design. Political commitment is variable and there is strong industry pressure on local authorities to compensate developers for restrictions on current or future land uses, even where there is no legal obligation (Berry and Vella, 2010; LGNZ, 2008; McDonald, 2010; Reisinger *et al.*, 2011). Strategic regional-scale planning initiatives in rapidly growing regions, like southeast Queensland, allow the uncertain and long term challenges of climate change adaptation to be addressed in ways that are not typically achieved by locality- or sector-specific plans, but require effective coordination across different scales of governance (Low Choy *et al.*, in press; Smith *et al.*, in press).

Courts in both countries have played an important role in upholding planning measures. Results of litigation have varied and more litigation is expected as rising sea levels affect existing properties and adaptation responses constrain development on coastal land (MfE, 2008a; Rive and Weeks, 2011; Verschuuren and McDonald, accepted). In addition to coastal set-back zones aiming to limit further development in areas at risk, several councils have attempted to implement managed retreat policies, such as Byron Shire Council, Australia (BSC, 2010), and Environment Canterbury and Kapiti Coast District Council, New Zealand (ECAN, 2005; KCDC, 2010). These policies remain largely untested in New Zealand, but experience in Australia has already highlighted the potential for litigation and opposing priorities at different levels of government to undermine retreat policies (Abel *et al.*, 2011; DCC, 2010; Parliament of Australia, 2009). Studies of options for and constraints on retreat policies find that mandatory disclosure of information about future risks, community engagement and policy stability are critical, but that place attachment, existing-use rights, special interests, community resources, liability concerns and divergent priorities at different levels of government present powerful barriers (Abel *et al.*, 2011; Agyeman *et al.*, 2009; Alexander *et al.*, 2012; Berry and Vella, 2010; Hayward, 2008b; Leitch and Robinson, in press; McDonald, 2010; Reisinger *et al.*, in press).

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Several recent federal policy initiatives in Australia, while responding to broader socio-economic and environmental pressures, have strong links with efforts to reduce vulnerability to climate variability and change. These include the establishment of the Murray-Darling Basin Authority to address over-allocation of water resources (Connell and Grafton, 2011; MDBA, 2011), and a review of the ‘exceptional circumstances’ concept in drought policy (Productivity Commission, 2009). While these may be regarded as examples of ‘mainstreaming’ adaptation into broader policy initiatives (Dovers, 2009), they also demonstrate the difficulties in responding to multiple competing interests in the context of climate change (see also Box 25-3).

The private sector and individuals are also important adaptation actors (AR5 WGII Chap 16), but evidence of their drivers, constraints and processes is limited. Gardner *et al.*, (2010), surveyed public and private sector organisations and found large differences in preparedness, linked to knowledge and belief about climate change, external connections, size, familiarity with strategic planning, and planning horizons of organisations. Sector-specific examples of adaptation measures already undertaken by public and private sector bodies are included in 25.6 (see also Productivity Commission, 2012).

25.5.2. Constraints on Adaptation and Opportunities to Address Them

The AR4 found that human society in Australia and New Zealand has high and growing levels of adaptive capacity but also faces formidable environmental, economic, informational, social, attitudinal and political barriers. A rapidly growing literature since the AR4 confirms this finding and provides *high confidence* that effective implementation of adaptation in Australasia faces significant constraints, especially at the community level and for small or highly fragmented industries.

Uncertainty about the scale and timing of projected impacts and limited financial and human resources are identified frequently as significant operational constraints on effective adaptation (Gardner *et al*., 2010; LGNZ, 2007, 2008; Measham *et al*., 2011; Smith *et al*., 2008a). In addition, there is *high confidence* that governance and institutional arrangements, such as unclear legislative frameworks, institutional fragmentation, and limited vertical and horizontal integration of different actors with unclear responsibilities, contradictory policies and development goals, underpin and compound operational constraints (Abel *et al*., 2011; Britton, 2010; Gardner *et al*., 2010; Gero *et al*., 2012; Measham *et al*., 2011; Parsons Brinkerhoff, 2009; Preston *et al*., 2011; Productivity Commission, 2012; Ross and Dovers, 2008). For example, there is *robust evidence and high agreement* that the absence of a consistent information base and binding guidelines that clarify governing principles constrains adaptation, especially in small and resource-limited local authorities that need to balance special interest advocacy with longer term community interests, and creates a high reliance on individual leadership subject to short-term political change (Abel *et al*., 2011; Britton, 2010; Brown *et al*., 2009; Glavovic *et al*., 2010; McDonald, 2011; Norman, 2009; Preston and Kay, 2010; Rive and Weeks, 2011; Rouse and Norton, 2010; Smith *et al*., 2008a; Smith *et al*., 2010). As a result of these decision-making structures and processes, planners tend to rely more heavily on single numbers for climate change projections that can be argued in a court of law (Reisinger *et al*., 2011), which increases the risk of maladaptation because the full range of potential futures and cumulative lock-in of developments to increasing risk remains unexplored (Lawrence and Quade, 2011; McDonald, 2010; Reisinger *et al*., in press; Stafford-Smith *et al*., 2011).

Reviews of public- and private-sector adaptation plans and strategies in Australia provide *high agreement* and *robust evidence* of a strong effort in institutional capacity building, but differences in assessment methods and weaknesses in whether and how strategic goals are actually translated into specific policies and responses (Gardner *et al*., 2010; Kay *et al*., in press; Measham *et al*., 2011; Preston and Kay, 2010; Preston *et al*., 2011). Similarly, reports for and by local governments in New Zealand mostly focus on identifying impacts and climate-related hazards but few as yet commit to policies and binding methods for near-term implementation of adaptation responses (e.g. Britton, 2010; Fitzharris, 2010; HRC, 2012; KCDC, 2010; O'Donnell, 2007).

These findings highlight that assessments that focus predominantly on future impacts (mid- to late-century) can inhibit actors from implementing near-term adaptation actions, as distant impacts are easily discounted and difficult to prioritise, especially in competition with near-term non-climate pressures. Recent guidance on adaptation planning in Australia (Balston, 2011), consistent with guidance in New Zealand (MfE, 2008b), emphasises a high-level identification of sectors and locations at risk, followed by an exploration of decisions to be taken in the near term that would influence current and future vulnerability. More detailed assessment can then focus on this smaller, more tractable subset of decisions, taking into account not only the lifetime of the decision/asset in question but also the time required for effective implementation of specific adaptation actions and processes (Stafford-Smith *et al*., 2011).

Adaptation goals and means depend strongly on beliefs of communities and decision-makers about climate change, the value assigned to places, objects and services potentially at risk, and societal and cultural implications of alternative responses (see Box 25-1). Participatory processes can help balance social preferences with robust scientific information, but their effective use depends on human capital, political commitment and leadership (Blackett *et al*., 2010; Britton, 2010; Gorrdard *et al*., in press; Hobson and Niemeyer, 2011; Leitch and Robinson, in press; Lennox *et al*., 2011; Rouse and Blackett, 2011; Weber *et al*., 2011).

An emerging literature raises questions whether the current generation of adaptation plans and evidence- and standards-based decision-making models indeed provide sufficiently robust frameworks to deal with the uncertainties and dynamic change characteristic of climate change (Kennedy *et al*., 2010; Preston *et al*., 2011).

Alternative decision-making models suggest a greater focus on flexibility and 'real options' (Dobes, 2010; Hertzler, 2007; Howden and Stokes, 2010; Nelson *et al*., 2008) and support more transformative adaptations under higher levels of warming (Linnenluecke *et al*., 2011; Park *et al*., 2012; Stafford-Smith *et al*., 2011). Awareness of limitations of 'mainstreamed' and autonomous adaptation (Dovers and Hezri, 2010) and the potential need for more proactive government interventions and corrections of market failures is emerging (CSIRO, 2011; Productivity Commission, 2012) but has not yet been evaluated, let alone incorporated into policy frameworks.

25.5.3. Limits to Adaptation

AR5 WGII Chapter 16 defines an adaptation limit as a restriction that makes meeting an adaptation objective impossible, noting that some limits depend on socio-economic conditions and societal values and are thus mutable, while others appear less so. Few hard limits to adaptation have been documented in Australasia and those discussed in the literature relate mostly to individual species and ecosystems that occupy climatically constrained ecological niches and/or occur in fragmented habitats or locations where adaptive movement is not possible; e.g. coral reef systems in north-eastern and west Australia and ecosystems in the Australian alpine zone currently covered by seasonal snow (25.6.2, 25.6.3).

Many other limits to adaptation in Australasia appear mutable and represent examples of a transition from incremental adaptation, which aims to preserve current systems and relationships, to transformative change in response to greater levels of warming (Howden *et al*., 2010). Examples from natural systems include the targeted relocation of at-risk species into new habitats, and the deliberate planting of novel plant species to perform key ecosystem services once current native species decline (Steffen *et al*., 2009). Within human systems, examples include managed retreat from eroding coasts (Box 25-2) and the potential transformation of some rural communities and translocation of some industries under higher levels of warming (25.6.5, Box 25-3, Box 25-6; Linnenluecke *et al*., 2011). The extent to which such transformative adaptations are seen as successful or as failure of adaptation depends on the extent to which actors are prepared to accept a change in, or wish to maintain current activities, relationships and management objectives. Different value systems, and different risks and opportunities for individual actors within communities that are being transformed, will influence those views (see Box 25-1).

25.6. Sectoral Assessments of Impacts, Opportunities, and Adaptation Options

25.6.1. Freshwater Resources

Impact of climate change on water resources and river flows is a cross-cutting issue affecting people, agriculture, industries and ecosystems. The challenge of satisfying multiple demands with a limited resource is exacerbated by the high inter-annual and inter-decadal variability of river flows (Chiew and McMahon, 2002; McKerchar *et al*., 2010; Peel *et al*., 2004; Verdon *et al*., 2004) particularly in Australia.

25.6.1.1. Projected Impacts

Figure 25-3 shows projected changes to mean annual runoff across Australia for a 1°C global warming (Chiew and Prosser, 2011; Teng *et al*., 2012). The range of projections arises mainly from uncertainty in projections of precipitation (25.3.3). Current models give *high confidence* that freshwater resources in south-eastern Australia (supporting more than 70% of the population and irrigated agriculture) and the south-west will decline (by 0-40% and 20-70%, respectively, for 2°C warming) due to the reduction in winter half-year precipitation (25.3.3) when most of the runoff in southern Australia occurs. The change in mean annual precipitation in Australia is generally amplified as a 2–3 times larger change in mean annual streamflow (Chiew, 2006; Jones *et al*., 2006). This, however, can change over time, with unprecedented declines in flow in south-eastern Australia in the 1997–2009 drought (25.3.4; Cai and Cowan, 2008b; Chiew *et al*., 2011; Potter and Chiew, 2011; Potter *et al*., 2010). Higher temperatures and associated evaporation (25.3.1), tree re-growth following more frequent bushfires (Cornish and Vertessy, 2001; Kuczera, 1987; Lucas *et al*., 2007; Marcar *et al*., 2006), interception activities like farm dams (Lett *et al*., 2009; Van Dijk *et al*., 2006) and reduced surface-groundwater connectivity in long dry spells (Hughes *et al*., 2012; Petrone *et al*., 2010) can further accentuate declines. In the longer-term, water availability will also be affected by changes in vegetation response and surface-atmosphere feedbacks from a warmer and higher CO_2 environment (Betts *et al*., 2007; Donohue *et al*., 2009; McVicar *et al*., 2010).

[INSERT FIGURE 25-3 HERE
Figure 25-3: Projected changes in mean annual runoff for a 1°C global average warming. Figures show changes in annual run-off (percentage change; top row) and run-off depth (millimetres; bottom row), for median, dry and wet (10th and 90th percentile) range of estimates, based on hydrological modelling using catchment-scale climate data downscaled from AR4 GCMs (Chiew *et al*., 2009; CSIRO, 2009b; Petheram *et al*., 2012; Post *et al*., 2012). Projections for a 2°C global average warming are about twice that shown in the plots (Post *et al*., 2011). Figure adapted from (Chiew and Prosser, 2011; Teng *et al*., 2012).]

For New Zealand, projections of future flows are dependent on the location of the catchment in relation to changes in precipitation amounts and characteristics. River flows in Canterbury with sources in the Southern Alps are projected to increase (median projection of 5–8% by 2050) due to greater alpine precipitation (Bright *et al*., 2008; Poyck *et al*., 2011), whereas flows in the north of the South Island are projected to decrease (median projection of 5-8% by 2050) (*medium confidence*) (Zemansky, 2010; 25.3.3). The change to the phase of precipitation is also important for many New Zealand rivers. For example, most of the projected increase in flow in the Clutha River (up to 20% by 2090) will occur between June and October, when precipitation falls more as rainfall and snow melts earlier (Poyck *et al*., 2011).

Climate change will affect groundwater through changes in recharge rates and the relationship between surface waters and aquifers. Dryland diffuse recharge in most of western, central and southern Australia is projected to decrease because of the decline in precipitation, with increases in the north and some parts of the east because of projected increase in high extreme rainfall intensity (Crosbie *et al*., 2010; Crosbie *et al*., 2012; 25.3.4; McCallum *et al*., 2010) (*medium confidence*). In New Zealand's Canterbury Plains, groundwater recharge from un-irrigated cropland is projected to decrease by about 10% by 2040 (Bright *et al*., 2008) whereas river-based recharge in the Wairoa Plains in the north of the South Island is not expected to change (*low confidence*) (Zemansky, 2010).

25.6.2.2. Adaptation

The recent drought and projected declines in future water resources are already stimulating adaptation in Australia (Box 25-3). In New Zealand, there is little evidence of this. Water in New Zealand is not as scarce generally and water policy reform is driven more by pressure to maintain water quality while expanding agricultural activities, with an increasing focus on collaborative management (Lennox *et al*., 2011; Memon *et al*., 2010; Memon and Skelton, 2007; Weber *et al*., 2011) within national guidelines (Jollands *et al*., 2007; LWF, 2010; MfE, 2011). Impacts of climate change on water supply, demand and infrastructure have been considered by several local authorities and consultancy reports (Jollands *et al*., 2007; Kouvelis *et al*., 2010; Williams *et al*., 2008), but no explicit management changes have yet resulted.

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Box 25-3. Adaptation through Water Resources Policy and Management in Australia

Water policy and management in Australia is strongly focused on allocating an often scarce resource exhibiting seasonal, annual and decadal variability of supply (Chiew and Prosser, 2011; Prosser, 2011). Widespread drought in the 15 years to 2010 and projections of a drier future in south-eastern and far south-west Australia (Bates *et al*., 2010; Chiew *et al*., 2011; CSIRO, 2010; Potter *et al*., 2010) saw extensive policy and management change in both rural and urban water systems to cope with a variable water future (Bates *et al*., 2008; DSE, 2007; Hussey and Dovers, 2007; MDBA, 2011; Melbourne Water, 2010; NWC, 2011; Schofield, 2011). These management changes provide examples of adaptations, building on previous policy reforms dealing with climate variability but less explicitly climate change.

The broad policy framework is set out in the 2004-2014 National Water Initiative and the 2007 Commonwealth Water Act. The establishment of the National Water Commission (2004) and the Murray-Darling Basin Authority (2008) were major institutional reforms. The National Water Initiative explicitly recognises climate change as a constraint on future water allocations. Official assessments (NWC, 2009, 2011) and critiques (Byron, 2011; Connell, 2007; Crase, 2011; Grafton and Hussey, 2007; Pittock and Finlayson, 2011) have discussed progress and shortcomings of the initiative, but these are confounded by other factors such as on-going revisions to allocation plans, time lags to observable impacts, and the paucity of comparable data.

Rural water reform in eastern Australia, focused on the Murray Darling Basin, is still unfolding. The first draft Murray Darling Basin Plan (MDBA, 2011) aims to return 2750 gL of consumptive water (about one fifth of current entitlements) to riverine ecosystems and develop flexible and adaptive water sharing plans to cope with current and future climates. The Plan recommends that more than AUD$10 billion be spent on public buyback of entitlements, upgrading infrastructure, and improving efficiency. Water markets are a key policy instrument, allowing water use patterns to adapt to shifting availability and move toward higher value water (Kirby *et al*., 2012; NWC, 2010). A two-thirds reduction in irrigation water use over the 1997-2009 drought in the Basin, for example, only resulted in 20% reduction in agricultural return, mainly because of a shift in use to more valuable enterprises through water trading plus large price rises in cereals, dairy and meat and to a lesser extent, improvements in irrigation efficiency (Kirby *et al*., 2012). If the extreme dry end of future water projections is realized (25.3.3, 25.6.1), however, there is *high confidence* that agriculture and ecosystems across south-eastern Australia would be threatened even with comprehensive adaptation regimes (see 25.6.2, 25.6.5; Connor *et al*., 2009; Kirby *et al*., in press).

Many capital cities in Australia are reducing their reliance on catchment runoff and groundwater as these sources are most sensitive to climate change and drought, and are diversifying supplies by investing in desalinisation plants, water re-use and integrated water cycle management. Demand is being reduced through water conservation and water sensitive urban design and, during severe shortfalls, through implementation of restrictions. In Melbourne, for example, planning has centred on securing new supplies that are resilient to major climate shocks, increasing use of alternative water sources like sewage recycling and stormwater, programs to reduce demand, and integrated planning that also considers climate change impacts on flood risk and on urban stormwater and wastewater infrastructures (DSE, 2007, 2011; Rhodes *et al*., in press; Skinner, 2010). The water augmentation program in Melbourne includes a desalinisation plant with a 150 gL/year capacity (about one third of the current demand) following the lead of Perth in south-west Australia where a desalinisation plant was established in 2006 in face of declines in inflows since the mid-1970s (Bates and Hughes, 2009). Melbourne's water conservation strategies include water efficiency and rebate programs for business and industry, water smart gardens, dual flush toilets, grey water systems, rainwater tank rebates, free water-efficient showerheads and voluntary residential use targets. These conservation measures, together with water restrictions since the early 2000s, have reduced Melbourne's total per capita use by 40% (Fitzgerald, 2009; Rhodes *et al*., in press). Similar programs in Brisbane to cope with severe water shortages in the late 2000s reduced the city's per capita use by about 50% (Shearer, 2011).

The success of urban water reforms in the face of drought and climate change can be interpreted in different ways. To cope with increasing population and to proof cities against future water shortages, increasing supply through desalinisation plants and water reuse schemes is a positive outcome. Uptake of household-scale adaptation options has been significant in some locations, but their long-term sustainability or reversibility in response to changing drivers and societal attitudes, remains an open question (Troy, 2008). In addition, options like desalinisation plants are energy intensive and the enhancement of supply could be maladaptive if it creates a disincentive for reducing demand or rethinking traditional mass supply (Barnett and O'Neill, 2010).

_____ END BOX 25-3 HERE _____

25.6.2. Terrestrial and Inland Freshwater Ecosystems

Terrestrial and freshwater ecosystems have suffered high rates of species extinctions and extensive degradation since European settlement (Bradshaw *et al*., 2010; Kingsford *et al*., 2009; Lundquist *et al*., 2011; McGlone *et al*., 2010; SoE, 2011). Less than 10% of pre-1750 vegetation remains in the intensive use zones of south east and south west Australia (SoE, 2011). In New Zealand, more than 70% of indigenous vegetation cover has been lost from 57% of land environments, with the largest changes in coastal and lowland environments (DOC and MfE, 2000; Kelly and Sullivan, 2010). Approximately 12% of Australia's terrestrial area (CAPAD, 2008) and 33% of New Zealand (MfE, 2010b) is protected but many reserves are small and isolated, and key ecosystems and species under-represented (MfE, 2010b; Sattler and Taylor, 2008; SoE, 2011; Walker *et al*., 2006). Native vegetation loss continues at nearly 1M ha annually in Australia (SoE, 2011). In New Zealand, clearing also continues, mostly for plantation forestry (Ewers *et al*., 2006; McGlone *et al*., 2010). Freshwater ecosystems in both countries are pressured from abstraction, agriculture and pollution (e.g. (Ling, 2010). Additional stresses include erosion, changes in nutrients and fire regimes, mining, invasive species, grazing and salinity (Kingsford *et al*., 2009; McGlone *et al*., 2010; SoE, 2011).

25.6.2.1. Observed Impacts

In Australian terrestrial systems, there is *medium* to *high confidence* that some recently observed changes in species' distributions, genetics, phenology and vegetation can be attributed to recent climatic and atmospheric trends (see Box 25-4). Uncertainty and debate remains regarding the role of non-climatic drivers, including changes in fire, grazing and land-use. The impacts of on-going drought in freshwater systems in the eastern states and the Murray Darling Basin have also been severe, especially near the Murray mouth where reduction in flows together with over-allocation of water has increased salinity (Pittock and Finlayson, 2011) but in many freshwater systems, direct climate impacts are difficult to detect above the strong signal of over-allocation, pollution, sedimentation, and exotic invasions (Jenkins *et al*., 2011). In New Zealand, few impacts have been directly attributed to climate change rather than variability (McGlone *et al*., 2010; McGlone and Walker, 2011) (Box 25-4). Alpine treelines in New Zealand have remained roughly stable for several hundred years (*high confidence*) despite 0.9ºC average warming (McGlone *et al*., 2010; McGlone and Walker, 2011).

_____ START BOX 25-4 HERE _____

Box 25-4. Evidence of a Changing Climate in Natural and Managed Ecosystems

Observed changes in species, natural and managed ecosystems (25.6.2, 25.6.3, 25.6.4) provide multiple lines of evidence of a changing climate. Examples of observations are summarized in Table 25-1. At present only one study describes a climate-related change[1] in a managed ecosystem. It remains unclear whether this imbalance is due to confounding drivers or due to a lack of research.

[INSERT TABLE 25-1 HERE
Table 25-1: Examples of detected changes in species, natural and managed ecosystems, consistent with a climate change signal, published since the AR4. Confidence in detection is based on length of study, amount of data, and natural variability in the species or system. Confidence in the role of climate change for each individual example is based on the extent to which other confounding or interacting non-climate factors have been considered and ruled out as contributing to the observed change.]

[NOTE: We are considering representing the detection and attribution of observed impacts graphically for inclusion in the SOD, using a template being developed by Chapter 18.]

[FOOTNOTE 1: Note that consistent with the IPCC definition, a change in climate refers to any statistically detectable signal, it does not necessarily imply a human cause. See 25.3.]

_____ END BOX 25-4 HERE _____

25.6.2.2. Projected Future Impacts

Episodic climate events drive ecological structure and function across much of the Australian continent and many species are well-adapted to short-term variability, especially in more arid regions. However, there is *high confidence* that existing environmental stresses will interact with, and in many cases be exacerbated by, shifts in mean climatic conditions and increased frequency or intensity of extreme events, especially fire, drought and floods (Bradstock, 2010; Steffen *et al*., 2009).

Recent drought-related mortality of amphibians in south-east Australia (MacNally *et al*., 2009), savanna trees in north east Australia (Allen *et al*., 2010; Fensham *et al*., 2009), eucalypts in sub-alpine regions in Tasmania (Calder and Kirkpatrick, 2008), and mass die-offs of flying foxes and cockatoos during heatwaves (Saunders *et al*., 2011; Welbergen *et al*., 2008) provide *high confidence* that extreme heat combined with reduced water availability, will be a significant driver of population loss and increasing risk of local species extinctions in the future (e.g. McKechnie and Wolf, 2010).

Species distribution modeling (SDM) using specific GCMs and emission scenarios consistently indicate future contractions for native species even assuming optimistic rates of dispersal (e.g. WA *Banksia* (Fitzpatrick *et al*., 2008), koalas (Adams-Hosking *et al*., 2011), northern macropods (Ritchie and Bolitho, 2008), native rats (Green *et al*., 2008b), greater glider (Kearney *et al*., 2010b) quokkas (Gibson *et al*., 2010) and platypus (Klamt *et al*., 2011). In some studies, complete loss of climatically suitable habitat is projected for some species within a few decades, and therefore increased risk of local, and perhaps global extinction (*medium confidence*). SDM has limitations (e.g. Elith *et al*., 2010; McGlone and Walker, 2011) but is being improved through integration with mechanistic and demographic models (Kearney *et al*., 2010b) and incorporation into broader risk assessments (e.g. Williams *et al*., 2008).

In Australia, assessments of ecosystem vulnerability have been based on observed changes, coupled with projections of future climate in relation to known biological thresholds and assumptions about adaptive capacity. There is *very high confidence* that one of the most vulnerable Australian ecosystems is the alpine zone, from loss of snow cover and subsequent exotic invasions (Pickering *et al*., 2008). There is also *high confidence* that substantial risks will accrue to coastal wetlands such as Kakadu National Park subject to saline intrusion (BMT WBM, 2011), biodiversity-rich regions such as the southwest of Western Australia (Yates *et al*., 2010a; Yates *et al*., 2010b), and rainforest in Queensland (Shoo *et al*., 2011; Stork *et al*., 2007); inland freshwater and groundwater systems subject to drought, over-allocation and altered timing of floods (Jenkins *et al*., 2011; Lake and Bond, 2007; Nielsen and Brock, 2009; Pittock, 2008); and peat-forming wetlands along the east coast (Keith *et al*., 2010).

The very few studies of climate change impacts on biodiversity in New Zealand suggest that ongoing impacts of invasive species (Box 25-5) and habitat loss will likely overwhelm any such signal in the short- to medium-term (McGlone *et al*., 2010) but that atmospheric and climatic change have the potential to exacerbate existing stresses (McGlone and Walker, 2011). There is *limited evidence but high agreement* that the rich biota of the alpine zone is at risk through increasing shrubby growth and loss of herbs, especially if combined with easier establishment of invasive species (McGlone *et al*., 2010; McGlone and Walker, 2011). Some cold water-adapted freshwater fish and invertebrates are vulnerable to warming (August and Hicks, 2008; Hitchings, 2009; McGlone and Walker, 2011; Winterbourn *et al*., 2008) and any increase in spring flooding may increase risks for braided-river bird species (MfE, 2008c). Suitable habitat for some restricted native species may increase with warming (e.g. native frogs; Fouquet *et al*., 2010) although limited dispersal ability will limit range expansion. Tuatara populations are at risk as warming increases the ratio of males to females (Mitchell *et al*., 2010), although the lineage has survived higher temperatures in the geological past (McGlone and Walker, 2011).

25.6.2.3. Adaptation

High levels of endemism in both countries (Lindenmayer, 2007; Lundquist *et al*., 2011) are associated with narrow geographic ranges and associated climatic vulnerability, although there is greater scope for adaptive dispersal to higher elevations in New Zealand. Anticipated rates of climate change, together with fragmentation of remaining habitat and limited migration options in many montane and coastal regions (Morrongiello *et al.*, 2011; Steffen *et al.*, 2009), will limit *in situ* adaptive capacity or potential distributional shifts to more climatically suitable areas for many species (*high confidence*) (Steffen *et al.*, 2009); significant local and global losses of species and ecosystem degradation are anticipated.

Adaptation strategies aimed at ameliorating some impacts and delivering multiple benefits by reducing other environmental stresses, are being explored in Australia. Climate change adaptation plans developed by many levels of government and natural resource management (NRM) bodies have identified priorities that include: identification and protection of climatic refugia (Shoo *et al.*, 2011); restoration of riparian zones to reduce stream temperatures (Davies, 2010; Jenkins *et al.*, 2011); construction of levees to protect wetlands from saltwater intrusion (Jenkins *et al.*, 2011); reduction of non-climatic threats such as invasive species to increase ecosystem resilience (Kingsford *et al.*, 2009); ecologically-appropriate fire regimes (Driscoll *et al.*, 2010); restoration of environmental flows in major rivers (Kingsford and Watson, 2011; Pittock and Finlayson, 2011); and, protecting and restoring habitat connectivity in association with expansion of the protected area network (Dunlop and Brown, 2008; Mackey *et al.*, 2008; Prowse and Brook, 2011; Taylor and Philp, 2010). Initiatives within the Clean Energy Future package, including the A$946 million "Biodiversity Fund", and A$44 million to support regional NRM planning for climate change adaptation (DSEWPC, 2011) are broadly aimed at increasing resilience to climate change. The effectiveness of these measures cannot yet be assessed. Biodiversity research in New Zealand to date has taken little account of climate-related pressures and continues to focus largely on managing pressures from invasive species and predators, freshwater pollution, exotic diseases, and halting the decline in native vegetation, although a number of specific recommendations have been made aimed at improving ecosystem resilience to future climate threats (McGlone *et al.*, 2010; McGlone and Walker, 2011).

Development of more strategic monitoring strategies to detect climate change impacts is underway in many regions e.g. WA biodiversity hotspot (Abbott and Le Maitre, 2010). More controversially, active interventionist strategies such as assisted colonization are receiving greater attention, both as a general principle (McDonald-Madden *et al.*, 2011) and with respect to particular vulnerable species, such as the tuatara (Mitchell *et al.*, 2010; Mitchell *et al.*, 2008). Current translocation policies in both countries will require considerable modification if assisted colonization is to be addressed as an adaptation strategy (Burbidge *et al.*, 2011). Climate change responses in other sectors may have beneficial as well as adverse impacts on biodiversity, but few tools to assess risks from an integrated perspective have been developed (25.7, Box 25-11).

25.6.3. Coastal and Ocean Ecosystems

Australia's 60,000 km coastline spans tropical waters in the north to cool temperate waters off Tasmania and the sub-Antarctic islands with sovereign rights over ~8.1 million km^2 (excluding Australian Antarctic Territory) (Richardson and Poloczanska, 2009). New Zealand has ~18,000 km of coastline, spanning subtropical to sub-Antarctic waters, and the world's fifth largest EEZ at 4.2 million km^2 (Gordon *et al.*, 2010). The marine ecosystems of both are considered hotspots of global marine biodiversity with many rare, endemic and commercially important species (Blanchette *et al.*, 2009; Gillanders *et al.*, 2011; Gordon *et al.*, 2010; Hoegh-Guldberg *et al.*, 2007; Lundquist *et al.*, 2011). About 85% of the Australian and 95% of the New Zealand population lives within 50 km of the coast and these coastal zones are densely populated (DCC, 2009). There is *high confidence* that this population density and associated stressors such as pollution and sedimentation are likely to continue and intensify non-climate stressors in coastal areas (e.g. Russell *et al.*, 2009).

25.6.3.1. Observed Impacts

Climate change is already affecting the oceans around Australia (Lough and Hobday, 2011; Pearce and Feng, 2007; Poloczanska *et al.*, 2007) and New Zealand (Lundquist *et al.*, 2011) (*high confidence;* 25.3.1); average climate zones have shifted more than 200 km south along the northeast Australian coast and about 100 km along the northwest coast (Lough, 2008). The rate of warming is even faster in southeast Australia with the poleward advance of the East Australia Current (EAC) of ~350 km (Ridgway, 2007; Wu *et al*., 2012). Southwest and southeast Australia are recognized as global warming hotspots (Wernberg *et al*., 2011; Wu *et al*., 2012).

Observed impacts on marine species around Australia have been reported from a range of trophic levels and include changes in phytoplankton productivity (Johnson *et al*., 2011; Thompson *et al*., 2009), species abundance of macroalgae (Johnson *et al*., 2011), growth rates of abalone (Johnson *et al*., 2011), southern rock lobster (Johnson *et al*., 2011; Pecl *et al*., 2009), coastal fish (Neuheimer *et al*., 2011) and coral (De'ath *et al*., 2009), life cycles of southern rock lobster (Pecl *et al*., 2009), southern bluefin tuna (Randall *et al*., in review) and seabirds (Chambers *et al*., 2011; Cullen *et al*., 2009) and distribution of subtidal seaweeds (Johnson *et al*., 2011; Wernberg *et al*., 2011), fish (Figueira *et al*., 2009; Figueira and Booth, 2010; Last *et al*., 2011; Madin *et al*., 2012), sea urchin (Ling *et al*., 2009) and intertidal invertebrates (Pitt *et al*., 2010) (Box 25-4).

Habitat-related impacts are more prevalent in northern Australia (Pratchett *et al*., 2011), while distribution changes are reported more often in southern waters (Madin *et al*., 2012), particularly south-east Australia, where warming has been greatest. The 2011 marine heat wave in Western Australia caused bleaching at Ningaloo reef for the first time, as well as reports of southern range extensions of many marine species, and declines in local abundance (Pearce *et al*., 2011a). Many observed ecological changes in Australian waters can be attributed to ocean warming although it remains difficult to separate the impacts of interacting non-climate stresses, including habitat degradation, coastal pollution and fisheries (*high confidence*). Changes in distribution and abundance of marine species in New Zealand are undocumented, in part because ENSO-related variability dominates in many time series (Lundquist *et al*., 2011; McGlone and Walker, 2011). New Zealand fisheries export some $1.4 billion worth of product, but no climate impacts have been reported at this stage.

25.6.3.2. Projected Impacts

There is limited evidence to date of climate impacts on coastal habitats, but *high confidence* that negative impacts will arise in future (Lovelock *et al*., 2009; McGlone and Walker, 2011; Traill *et al*., 2011). Some coastal habitats such as mangroves are projected to expand further landward, driven by sea-level rise and soil subsidence due to reduced rainfall (Traill *et al*., 2011) (*medium confidence)*, although this may be at the expense of saltmarsh and be constrained in many regions by the built environment (DCC, 2009). Estuarine habitats will be affected by changing rainfall or sediment discharges, as well as connectivity to the ocean (Gillanders *et al*., 2011) (*high confidence*). Loss of coastal habitats and declines in iconic species will result in significant costs to coastal settlements and infrastructure from direct impacts such as storm surge, and tourism (*medium confidence*). Coastal habitats have high value for carbon capture and storage, particularly seagrass, saltmarsh and mangroves, and may become increasingly important in mitigation efforts (e.g. Irving *et al*., 2011).

Change in the main climate-change drivers (e.g. temperature, sea level rise and rainfall) are expected to lead to secondary effects, including erosion, landslips, and flooding, affecting coastal habitats and their dependent species (e.g. loss of habitat for nesting birds (Chambers *et al*., 2011) (*high confidence*). Increasing ocean acidification is expected to affect many taxa including corals (Fabricius *et al*., 2011), coralline algae (Anthony *et al*., 2008), calcareous plankton (Hallegraeff, 2010; Richardson *et al*., 2009; Thompson *et al*., 2009), reef fishes (Munday *et al*., 2009; Nilsson *et al*., 2012), and bryozoans and other benthic calcifiers (Fabricius *et al*., 2011) (*medium confidence*).

The AR4 identified the Great Barrier Reef (GBR) as highly vulnerable to warming and acidification (Hennessy *et al*., 2007, Box 11.3). More recent observations of bleaching events and reduced calcification rates in both the GBR and other reef systems (25.6.3.1; Cooper *et al*., 2008; De'ath *et al*., 2009; Redondo-Rodriguez *et al*., 2011), along with ecosystem model studies and experiments (Anthony *et al*., 2008; Hoegh-Guldberg *et al*., 2007; Veron *et al*., 2009) further confirm this vulnerability. There is *high confidence* that the combined impacts of warming and acidification associated with atmospheric CO_2 concentrations in excess of 450-500 ppm will be associated with increased frequency and severity of coral bleaching, disease incidence and mortality, and subsequent dominance of the reef system by macroalgae (Hoegh-Guldberg *et al*., 2007; Veron *et al*., 2009). The frequency of bleaching is expected to become increasingly decoupled from the 4-7 year El Niño cycle (Veron *et al*., 2009). Multiple other stresses, including rising sea levels, increased cyclone intensity, and nutrient-enriched runoff will exacerbate these impacts (*high confidence*) (Hoegh-Guldberg *et al*., 2007; Veron *et al*., 2009). Thermal thresholds and the ability to recover from bleaching events vary geographically and between species (e.g. Diaz-Pulido *et al*., 2009) but there is *robust evidence* and *medium agreement* that the ability of corals to adapt to rising temperatures and acidification is limited and appears insufficient to offset the detrimental effects of warming and acidification on coral reef systems (Hoegh-Guldberg *et al*., 2007; Veron *et al*., 2009).

Under all SRES scenarios and a range of CMIP3 models, pelagic fishes such as sharks, tuna and billfish are projected to move further south on the east and west coasts of Australia (Hobday, 2010) (*high confidence*). These changes depend on sensitivity to water temperature, and may lead to shifts in species-overlap with implications for by-catch management (Hartog *et al*., 2011). Substantial changes in production and profit of both wild fisheries (Norman-Lopez *et al*., 2011) and aquaculture species such as salmon, mussels and oysters (Hobday and Poloczanska, 2010; Hobday *et al*., 2008) are anticipated (*medium confidence).*

25.6.3.3. Adaptation

In Australia, research on marine impacts and adaptation has been guided by the National Adaptation Research Plan (NARP) for Marine Biodiversity and Resources (Mapstone *et al*., 2010). Planned adaptation options include removal of human barriers to landward migration, beach nourishment, translocation of seagrass to southerly locations, management of environmental flows to keep estuaries open and functional (Jenkins *et al*., 2010), habitat provision (Hobday and Poloczanska, 2010), translocation of species such as turtles (e.g. Fuentes *et al*., 2009) and burrow modification for nesting seabirds (Chambers *et al*., 2011). For southern species found on the continental shelf, however, options are more limited because suitable habitat will not be present in future – the next shallow water to the south is Macquarie Island.

Management actions to increase resilience of coral reef systems include reduction in fishing pressure on herbivorous fish, protection of top predators, managing the quality of runoff, and minimizing other human disturbances, especially by increasing marine protected areas (Hughes *et al*., 2007; Veron *et al*., 2009; Wooldridge *et al*., 2012). There is *high confidence* that such actions will slow rather than prevent long-term degradation of reef systems once critical thresholds of ocean temperature and acidity are exceeded.

Adaptation by the fishing industry to shifting distributions of target species is considered possible by most participants (e.g. southern rock lobster fishery; Pecl *et al*., 2009) (*medium confidence).* Translocation to maintain production in the face of declining recruitment may also be possible for some high value species, and has been trialled for the southern rock lobster (Green *et al*., 2010a). A range of options exist for aquaculture, including disease management, alternative site selection, and selective breeding (Battaglene *et al*., 2008), although implementation is only in preliminary stages for both Australia and New Zealand. Marine protected area planning is not explicitly considering climate change in either country, but reserve performance will be affected by the projected environment shifts (Hobday, 2011) and ecosystem management will need to prepare for novel combinations of species, habitats and human pressures (*high confidence*).

25.6.4. Production Forestry

The Australian forestry sector annually contributes around $7 billion to GDP (ABARES, 2011a). Australia has about 149 Mha forests, including 2.02 Mha plantations and 9.4 Mha available for timber production in multiple-use native forests (Gavran and Parsons, 2010). New Zealand's plantation estate comprises about 1.8 Mha (89% Pinus radiata; MAF, 2007) – recently contracted as dairying has become more profitable (MfE, 2008e).

25.6.4.1. Observed and Projected Impacts

Existing climate variability and other confounding factors have made it difficult to detect current climate change impacts on forests, in part because CO_2 fertilisation may have partially compensated for reduced productivity in areas of decreased rainfall such as in Western Australia (medium confidence) (Simioni *et al*., 2009).

Projected impacts are based on modelled ecophysiological responses of species to CO_2, water availability and temperatures (Medlyn *et al*., 2011a). In Australia, potential future changes in water availability will be most important (*very high confidence*). Modelling of future distribution or growth rates indicate that plantations in Western Australia are most at risk due to declining rainfall, and there is *high confidence* that plantation growth will be reduced by temperature increases in hotter regions, especially where species are grown at the upper range of their temperature distribution; in cool regions where water is not limiting, higher temperatures could benefit production (Battaglia *et al*., 2009). There is *limited evidence* and *medium agreement* that for moderate rainfall changes, the effects of reduced rainfall and increased temperature could be offset by increasing CO_2 (Simioni *et al*., 2009).

In New Zealand, temperatures are mostly sub-optimal for forest growth and water relations generally less limiting (Kirschbaum and Watt, 2011). Warming is thus expected to increase *P. radiata* growth in the cooler south (*very high confidence*), while in the north, temperature increases can result in declining productivity, although increasing CO_2 may lead to productivity increases even in warmer regions (*medium confidence*) (Kirschbaum *et al*., 2012).

Modelling studies are limited by their reliance on some key assumptions, such as whether there is no or strong down-regulation of photosynthesis under elevated CO_2 (Battaglia *et al*., 2009), which are difficult to verify experimentally. Further. most studies do not include additional impacts of pests, diseases, weeds, fire and wind damage that may change adversely with climate change. For instance, in Australia, fire poses a significant threat expected to worsen with climate change (see Box 25-7), especially for the winter-rainfall regions in the south where most commercial forestry plantations are situated (Clarke *et al*., 2011; Williams *et al*., 2009).

In New Zealand, changes in biotic factors are particularly important as they already affect plantation productivity. For instance, *Dothistroma* blight is a serious pine disease, but has a distinct temperature optimum that coincides with New Zealand's warmer, but not warmest, pine-growing regions (Watt *et al*., 2011). Under climate change, its severity is, therefore, expected to diminish in the warm central North Island but increase in the cooler South Island (*high confidence*) where it can offset temperature-driven improved plantation growth. There is *medium evidence* and *high agreement* of similar future southward shifts in the distribution of existing plantation weed, insect pest and disease species in Australia (see review in Medlyn *et al*., 2011b).

25.6.4.2. Adaptation

Adaptations to climate change involve changes to species or provenance selection or adopting silvicultural options such as fertiliser management or modified stand stocking (Booth *et al*., 2010; White *et al*., 2009). Depending on the extent of climate changes, and plant responses to increasing CO_2, the above studies (25.6.4.1) provide *limited evidence* but *high agreement* of potential net increased productivity across the region, allowing greater wood productivity and enhanced carbon sequestration, but this will require high nutrition to utilise this opportunity fully (*very high confidence*). However, some sites will be affected negatively, especially where climate change adds to existing stresses where species are at the margins of their productive climate range (*medium evidence, high agreement*).

There is *medium evidence and high agreement* that the greatest barriers to long-term adaptation planning currently are in particular incomplete knowledge of plant responses to CO_2 concentration and uncertainty in regionally-specific climate change scenarios (Medlyn *et al*., 2011b).

25.6.5. Agriculture

Australia produces 93% of its domestic food requirements yet still exports 76% of agricultural production (11.9% of total exports) (DAFF, 2010). New Zealand dairy exports contribute 15% of GDP and 26% of total exports (Schilling *et al*., 2010); 95% of all dairy products are exported (35% of the world trade). Although particularly sensitive to climate (in particular to drought, see Box 25-6; also Buckle *et al*., 2002), many non-climate drivers also affect production; detection and attribution of observed impacts are, accordingly, difficult tasks (see AR5, WGII Chap7.2). Recent research emphasis has been on adaptation and providing information specific to "decision-making events or questions" (Preston and Stafford-Smith, 2009b), as summarized in Table 25-2.

[INSERT TABLE 25-2 HERE
Table 25-2: Decisions in the agricultural sector with the potential to be influenced by global change and the information needed to inform these decisions.]

25.6.5.1. Projected Impacts

Knowledge about national, regional, local and enterprise-specific impacts is essential for a range of decisions. Pastoralism dominates land use by area in the region, with rainfall a key determinant of inter-annual variability in production and profitability (Hsu *et al*., 2012; Radcliffe and Baars, 1987). Reduced stomatal conductance under elevated CO_2 can improve water use efficiency but benefits in production may not be realised (Kamman *et al*., 2005; Newton *et al*., 2006; Stokes and Ash, 2007; Wan *et al*., 2007). Modelling suggests changes in livestock production in Tasmania and Victoria will track changes in rainfall (with low temperatures still limiting growth). Production in other areas will be greater than changes in rainfall though of the same sign (*medium confidence*) (McKeon *et al*., 2008). The net effect of a 3°C temperature increase is expected to be a 4% reduction in gross value of the Australian beef, sheep and wool sector (McKeon *et al*., 2008).

Updated predictions for the 2030s in New Zealand suggest changes in national production of -2.8% to -4.3% in dairy and -6.1% to -8.8% in sheep and beef using downscaled TAR projections and a simple pasture growth model (Wratt *et al*., 2008). Impacts vary regionally from -32% to -56% (Hawke's Bay) to +3 to +26% (Nelson) for dairy, and, for sheep and beef, -33% to -59% (Hawke's Bay) to +4 to +19% (Southland)(*medium confidence*). Changes in seasonal pasture growth to greater spring and lower summer/autumn production and increased variability in annual production and profitability are predicted from the farm-scale study of Lieffering et al (in press)(*medium confidence*). The simulations show these changes could be managed by stocking policies requiring increased flexibility in stock movements within and between farms and regions. Comparison of projections with current pasture production curves show the predicted future conditions for Southland and Waikato may currently occur elsewhere in New Zealand, implying possible adaptation. No New Zealand analogues could be found for future (2090) conditions in Hawke's Bay (Lieffering *et al*., in press).

For wheat, experiments (Fitzgerald *et al*., 2010) and modelling for Australia (Crimp *et al*., 2008; Luo *et al*., 2009; O'Leary *et al*., 2010) and New Zealand (Teixeira *et al*., in press) confirm the AR4 conclusion that adaptation, particularly altering sowing dates and cultivars, can sustain or increase yields except under the most extreme low rainfall scenarios (*high confidence*). Although yields may increase in New Zealand with current management (Teixeira *et al*., in press), in Australia, adaptation will be essential to avoid yield reductions in some regions (Luo *et al*., 2009). In the absence of adaptation, under the more severe climate scenarios, Australia could become a net importer of wheat (Howden *et al*., 2010).

Rice production in Australia is largely dependent on irrigation and water availability will determine the impacts of climate change (Gaydon *et al*., 2010). Sugarcane production is also strongly water dependent (Carr and Knox, 2011); yields may increase where rainfall is unchanged or increased but rising temperatures could increase evapotranspiration and change processing schedules (Park *et al*., 2010) (*medium confidence*).

Observed trends and modelling for wine-grapes suggest that climate change will lead to earlier budburst, ripening and harvest for most regions and scenarios (Grace *et al*., 2009; Petrie and Sadras, 2008; Sadras and Petrie, 2011;

Webb *et al*., 2007; Webb *et al*., 2012) (*high confidence*). Without adaptation, reduction in quality is predicted (Webb *et al*., 2008)(*high confidence*). Change in cultivar suitability in specific regions is expected (Clothier *et al*., in press); the potential exists for development of cooler or more elevated sites within some regions (Hall and Jones, 2009; Tait, 2008) and/or expansion to new regions, with some growers in Australia already relocating (Smart, 2010).

Changes in pests and diseases remains an area of high uncertainty for arable crops (Chakraborty *et al*., 2011). The performance of currently effective resistance mechanisms under elevated CO_2 and temperature is a particularly important issue (Chakraborty *et al*., 2011; Melloy *et al*., 2010).

Future-proofing technologies will be necessary where current technologies are climate-sensitive. The likelihood of altered biocontrol efficacy is supported by modelling (Gerard *et al*., 2010) and performance in other regions (see Box 25-5) but not, to date, by observations. Plant germplasm will be central to effective adaptation of agricultural crops. Variation in maturity date and vernalisation requirements are of particular importance; in some cases the current pool of cultivars may be adequate (Clothier *et al*., in press; Teixeira *et al*., in press) but there is little research to produce new cultivars suitable for future conditions (e.g. increased CO_2 concentration) although the requisite genetic variation has been shown to exist (Newton and Edwards, 2007).

Future water demand from the sector is critical for planning (Box 25-3). Dryland agriculture dominates in Australia (DAFF, 2010) but 50% of water consumption is by agriculture; 70% of this is consumed in the Murray-Darling Basin (Quiggin *et al*., 2008), which generates 30% of the gross value produced by Australian agriculture (Robertson, 2010). The median projection of reduced inflow for under A1FI emissions is predicted to result in losses of A$540 million by 2030 and A$2.15 billion by 2050 (Quiggin *et al*., 2008). Under this median and the ‘dry’ “business as usual” scenarios (Garnaut, 2008), it will be very difficult to continue irrigating while sustaining ecosystems beyond the second half of the 21[st] century (Box 25-3). Water availability also constrains agricultural expansion: 17 M ha in northern Australia could be suitable for cropping but only 1% has water availability to permit this (Webster *et al*., 2009). In New Zealand, the irrigated area has risen by 82% since 1999 to over 1 M ha: 76% is on pasture (Rajanayaka *et al*., 2010). The New Zealand dairy herd doubled between 1980-2009 and moved from high rainfall zones (>2000 mm annual) to drier areas (600-1000 mm annual) where irrigation is essential; further expansion will be into these dryland areas with increasing dependence on irrigation (Robertson, 2010).

25.6.5.2. Adaptation

Much adaptation effort has focused on incremental changes (25.5) relevant to land managers. These adaptations have advantages for managing risk in the current climate (Howden *et al*., 2008; also 25.7.1) and adoption is often high (Hogan *et al*., 2011a; Kenny, 2011).

There are limits to incremental on-farm adaptation (Park *et al*., 2012; Stafford Smith *et al*., 2011) which, in any case, tackles only part of the impact of climate change on agriculture (see Table 25-2). Adaptation through transformational change (25.5.3) carries greater risk yet is already being implemented. New investment in grapes in Tasmania (Smart, 2010) and switching from grazing to cropping in South Australia are among several examples (Howden *et al*., 2010). Some decisions run across scales and include many stakeholders. Comprehensive regional assessments, covering different enterprises and with economic (e.g. Heyhoe *et al*., 2007) and resource outcomes are needed.

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Box 25-5. Biosecurity

Biosecurity is a high priority for Australia and New Zealand, given the importance of biologically-based industries to the economy and the potential threats to endemic species and iconic ecosystems. There is *high confidence* that the potential risk from invasive and pathogenic species will be altered by climate change (see Table 25-3; McGlone and Walker, 2011; Roura-Pascual *et al*., 2011). Little research has been conducted on biosecurity under climate change; for example, only four diseases of field crops have been studied under ‘realistic’ future conditions in field experiments (Chakraborty *et al*., 2011). The impact of serious emerging threats such as myrtle rust are uncertain (Carnegie *et al*., 2010).

[INSERT TABLE 25-3 HERE
Table 25-3: Examples of observed and potential consequences of climate change for invasive and pathogenic species relevant to Australia and New Zealand (categories from Hellman *et al*., (2008)).]

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Box 25-6. Climate Change Vulnerability and Adaptation in Rural Areas

Rural communities in Australasia are distinctive from urban populations; they have higher proportions of older and unemployed people (Mulet-Marquis and Fairweather, 2008) and lower incomes and standards of living (Stehlik *et al*., 2000) than urban populations. Economically they are heavily dependent on the physical environment and hence are highly exposed to climate (averages, variability and extremes). There is *high agreement* and *robust evidence* that the vulnerability differs within and between countries reflecting differences in financial security, environmental awareness, policy and social support, strategic skills and capacity for diversification (Bi and Parton, 2008; Hogan *et al*., 2011b; Kenny, 2011; Marshall, 2009; Nelson *et al*., 2010). Climate change will interact with economic, social and environmental pressures, such as changing terms of trade and government policies (e.g. on drought and emissions trading schemes; Nelson *et al*., 2010; Productivity Commission, 2009).

Climate change will affect rural industries and communities through impacts on natural resource availability and distribution. For example, in areas where water availability is projected to decrease (see 25.3.3) and demand increases in response to climate change, tensions between agricultural, mining, urban and environmental water users will increase (*very high confidence*), requiring greater governance and participatory adaptation processes (see 25.6.2, 25.6.5, 25.6.6, Box 25-1, Box 25-3, Box 25-11). Communities will also be affected through impacts on primary production and extraction activities, operation of critical infrastructure, population health, social and economic development (see 25.6.5, 25.6.6, 25.6.9) and the durability and usability of recreational and culturally significant sites (Kouvelis *et al*., 2010).

Altered production and profitability risk profiles and/or land use will translate into complex and interconnected effects on rural communities, particularly income, employment levels, service provision, and reduced volunteerism (Bevin, 2007; Kerr and Zhang, 2009; Stehlik *et al*., 2000). There is *high agreement* and *robust evidence*, for example, that the prolonged drought in Australia during the early 2000s had many interrelated negative social impacts in rural communities, including farm closures, increased poverty, increased off-farm work and, hence, involuntary separation of families, increased social isolation, rising stress and associated health impacts, including in some cases suicide (especially of male farmers), accelerated rural depopulation and the closure of key services (Alston, 2007, 2010, 2012; Edwards and Gray, 2009; Hanigan *et al*., in press). Positive social change also occurred such as increased interaction with community organisations, which increases levels of social capital (Edwards and Gray, 2009).

The economic impact of droughts on rural communities and the economy as a whole can be significant. For example the 2002-03 drought in Australia significantly reduced farm incomes (by 60% on average) and agricultural employment and subtracted around 1.0 percentage point from GDP growth (equivalent to A$7.4 billion) (ABS, 2004). Horridge *et al*., (2005), suggest the impact may have been as high as 1.6 percentage points when indirect impacts from the drought are included. Further, widespread drought in New Zealand during 2007-2009, affected many regions not traditionally impacted by drought, such as the Waikato, resulting in an estimated reduction of NZ$3.56 billion in direct and off-farm output (Butcher, 2009). Other regional economic impacts included a fall in the total gross output for the New Zealand East Coast economy of 2.3% during the 2005/06-2008/09 period (Bevin, 2007). Drought frequency and severity is many parts of the region are projected to increase in future (see 25.3.5).

The strategic and tactical decisions of rural enterprise managers have significant consequences for rural communities and beyond (Clark and Tait, 2008; Pomeroy, 1996). Managers are already undertaking incremental adaptations in response to existing climate variability to maintain production. There are also examples of transformational changes where industries and individual farmers are relocating part of their operations, e.g. rice (Gaydon *et al*., 2010), wine (Park *et al*., 2012), peanuts (Thorburn *et al*., in press) or changing land use *in situ* in response to recent climate change or perceptions of future change. Such changes can be expected to become more frequent and widespread with a changing climate (*high confidence*) but can have positive or negative implications for communities in origin and destination regions (see also Box 25-11).

Social structures, norms and values dictate how different groups within rural communities will be affected by, and adapt to, the effects of climate change. Despite these differences the groups are bound by similar political, economic and societal parameters (Loechel *et al*., 2010). Consequently, rural community adaptation to climate change will require an approach that devolves decision-making to the level where the knowledge for effective adaptations resides, using open communication, interaction and joint-planning (Nelson *et al*., 2008). Climate change will impact most on communities which are ill-prepared socially, economically and environmentally (Smith *et al*., 2011). However, McManus *et al*., (2012), suggest that robust ongoing engagement between farmers (struggling to cope with change) and the local community provides hope for rural communities as it contributes to a strong sense of community and enhances potential for resilience.

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25.6.6. Mining

Australia is the world's largest exporter of black coal, iron ore and gold (Hodgkinson *et al*., 2010a). Recent events demonstrated significant vulnerability to climate extremes: the 2011 floods reduced coal exports by 25-54 million tonnes, representing about A$5-9bn in lost revenue (ABARES, 2011b; QRC, 2011; RBA, 2011). Impacts were exacerbated by regulatory constraints on discharges, highlighting interconnections with societal expectations of environmental performance (QRC, 2011).

Projected increases in floods and heat waves and reduced water availability (see 25.3) imply increased vulnerability without adaptation (high confidence; Hodgkinson *et al*., 2010a; Hodgkinson *et al*., 2010b). Some companies have considered on- and off-shore climate change impacts (Mills, 2009; Stroud, 2009), but no quantitative risk assessments have been published. Stakeholders perceive the adaptive capacity of the industry to be high (Hodgkinson *et al*., 2010a; Loechel *et al*., 2010; QRC, 2011), but no assessment of adaptation cost and broader benefits is available yet. Many options require cross-industry and community collaboration, and thus may be constrained by increasing competition for energy and water and changing societal preferences regarding post-mining rehabilitation and acceptable mine discharges (Loechel *et al*., 2011; Loechel *et al*., 2010).

25.6.7. Energy Supply, Transmission, and Demand

Primary energy demand is projected to grow by 0.9-1.4% per annum in Australasia over the next few decades (MED, 2010; Syed *et al*., 2010). Australia's predominantly thermal power generation is vulnerable to drought-induced water restrictions (AEMO, 2011; ATSE, 2008; Parsons Brinkerhoff, 2009), which could require dry-cooling where rainfall declines further (Graham *et al*., 2008). Renewable generation in Australia is projected to increase from 7% to 19-50% by 2030 (Hayward, 2008a; Syed *et al*., 2010), but few studies have explored the vulnerability of new energy sources to climate change (Bryan *et al*., 2010; Crook *et al*., 2011; Odeh *et al*., 2011).

New Zealand's predominantly hydroelectric power generation is vulnerable to precipitation variability. Increasing winter precipitation, glacial and seasonal snow melt and shift from snowfall to rainfall will reduce this vulnerability (*high confidence*) as winter/spring inflows to main hydro lakes are projected to increase by between 5 and 10% over the next few decades (McKerchar and Mullan, 2004; Poyck *et al*., 2011). Reductions in seasonal snow and glacial melt as glaciers diminish would eventually reduce this benefit (25.3; Chinn, 2001; Renwick *et al*., 2009; Srinivasan *et al.*, 2011). Increasing wind power generation (MED, 2010) would benefit from projected increases in mean westerly winds but would also face greater risk of damages and shut-down during extreme winds (25.3; Renwick *et al.*, 2009).

Climate warming would reduce annual average peak electricity demands by 2(±1)%/°C in New South Wales, but increase by 1.1(±1.4) and 4.6(±2.7)%/°C in Queensland and South Australia (Thatcher, 2007). Increasing summer daytime peak demand for air conditioning is expected to place additional stress on networks (Howden and Crimp, 2008; Thatcher, 2007; Wang *et al.*, 2010b) (*very high confidence*). For example, electrical losses increased by 53% during the 2009 Victorian heat wave as demand rose by 24% (Nguyen *et al.*, 2010), and successive failures of the overloaded network temporarily left more than 500,000 people without power (QUT, 2010). In New Zealand, there is *limited evidence* but *high agreement* that national winter peak demand would reduce by 1-2% per °C warming, but summer daytime demand would increase in northern regions once average temperatures exceed 19-20°C (Chen and Lie, 2010; Jollands *et al.*, 2007; Stroombergen *et al.*, 2006). A variety of adaptation options to limit increasing urban energy demand exist and some are already being implemented (Box 25-9).

There is *limited evidence* but *high agreement* that distribution networks in Australia will be at high risk in all states except Tasmania and ACT by 2031-2070, mainly due to potential increases in bushfire risk, increased strength of the most severe cyclones and southward shift in tropical regions, and changes in generation mix requiring infrastructure upgrades (Maunsell and CSIRO, 2008; Parsons Brinkerhoff, 2009). Adaptation costs have been estimated at A$2.5 billion to 2015, with more than half to meet increasing demand for air conditioning and the remainder to increase resilience to climate-related hazards (Parsons Brinkerhoff, 2009). Underground cabling would reduce bushfire risk but has large investment costs (not included above) and barriers arising from decentralised ownership of assets (ATSE, 2008; Parsons Brinkerhoff, 2009). In New Zealand, increasing high winds and temperatures are considered the most relevant risks to transmission but have not been quantified (Jollands *et al.*, 2007; Renwick *et al.*, 2009).

25.6.8. Tourism

Tourism contributes between 2.6 and 4% of GDP to the economies of Australia and New Zealand (ABS, 2010d; Stats NZ, 2011a). The net present value of the Great Barrier Reef alone over the next 100 years has been estimated at A$51.4 billion (Oxford Economics, 2009). Most tourism in Australia and New Zealand is exposed to climate variability and change (Becken and Hay, 2007), and some tourist activities and locations have demonstrated high sensitivity to recent extremes. For example, the 2011 floods and Cyclone Yasi cost the Queensland tourism industry approximately A$590 million, mainly due to cancellations and damage to the Great Barrier Reef (PWC, 2011). Drought in the Murray-Darling Basin caused an estimated A$70 million loss in 2008 due to reduced visitor days (TRA, 2010). In New Zealand, stakeholders perceive a negative destination image for Northland resulting from storms and floods in 2007 and 2011 (Becken *et al.*, 2011).

25.6.8.1. Projected Impacts

Future impacts on tourism have been modelled for several Australian destinations. The Great Barrier Reef is expected to degrade under all climate change scenarios (Box 5-3, 25.6.3, 30), reducing its destination attractiveness (Marshall and Johnson, 2007; Wilson and Turton, 2011). Ski tourism is expected to decline in the Australian Alps due to reduced snow cover (25.3) as Australian skiers report they would ski less often (69%), ski overseas (16%) or give up in poor snow years (5%) (Pickering *et al.*, 2010). Higher temperature extremes in the Northern Territory (25.3) are projected with *high confidence* to increase heat stress and air conditioning demands resulting in higher costs (Turton *et al.*, 2009). Sea level rise places pressures on shorelines and long-lived infrastructure but implications for tourist resorts have not been quantified (Buckley, 2008).

Economic modelling suggests that the Australian Alpine region would be most negatively affected in relative terms due to limited alternative economic activities (Pham *et al.*, 2010), whereas some destinations (e.g. Margaret River in Western Australia) stand to benefit from projected higher temperatures and lower rainfall that could augment their competitiveness (Jones *et al.*, 2010; Pham *et al.*, 2010). An analogue-based study suggests that in New Zealand, warmer and drier conditions mostly benefit but wetter conditions and extreme climate events undermine tourism (Becken *et al*., 2010). However, confidence in these findings is *low* due to uncertain future tourist behaviour.

25.6.8.2. Adaptation

Both New Zealand and Australia have developed adaptation strategies for tourism (Becken and Clapcott, 2011; Zeppel and Beaumont, 2011); promoted preparation for extreme events (Tourism Queensland, 2007, 2010; Tourism Victoria, 2010); and are strengthening ecosystem resilience for tourism viability (GBRMPA, 2009). The most prominent current adaptation measure is investment into snowmaking (Bicknell and McManus, 2006) , but its effectiveness depends on climate scenario and time horizon (Hennessy *et al*., 2008b). For New Zealand, snowmaking is expected to buffer increasing risk of poor snow seasons for several decades, as the time suitable for snowmaking is projected to reduce only gradually up to 41-68% for different ski fields by the 2090s (A1FI emissions scenario, worst year in 20) relative to average conditions in the 1990s (Hendrikx and Hreinsson, 2010). Options for Australia's six main resorts are more constrained, where investment into 700 snow guns to maintain skiing conditions until at least 2020 would require A$100 million in capital and 2.5-3.3 gL of water per month (Pickering and Buckley, 2010).

Short investment horizons, high substitutability and a high proportion of human capital compared with built assets give *high confidence* that the adaptive capacity of the tourism industry is high overall, except in locations and for specific activities where climate change is projected to degrade core natural assets and opportunities for diversification are limited (Evans *et al*., 2011; Morrison and Pickering, 2011). Strategic adaptation decisions are currently constrained by uncertainties in climatic changes (Turton *et al*., 2010), limited concern (Bicknell and McManus, 2006; Turton *et al*., 2009), lack of leadership, and limited forward planning (Sanders *et al*., 2008). An integrated assessment of the vulnerability of tourism in Australasia is not yet possible due to potentially significant but poorly understood international flow-on effects (25.7.2).

25.6.9. Human Health

Australasian populations have high average life expectancies, but substantial ethnic and socioeconomic inequalities persist (Anderson *et al*., 2006b). Projected population growth and urbanisation could increase health risks via increased stress on infrastructure including housing, transport, energy and water supplies (*low confidence*); overcrowding of homes would increase communicable disease risks (Baker *et al*., 2012); while the projected ageing of the population and increased obesity will increase susceptibility to extreme events such as heatwaves (Howden-Chapman, 2010) (*high confidence*).

25.6.9.1. Observed Impacts

There is *high agreement and robust evidence* that mortality increases in hot weather (Bi and Parton, 2008; Vaneckova *et al*., 2008) with air pollution exacerbating this association. Exceptional heatwave conditions in Australia have been associated with substantial increases in mortality and hospital admissions in several capital cities (Khalaj *et al*., 2010; Loughnan *et al*., 2010; Tong *et al*., 2010a; Tong *et al*., 2010b) (*high confidence*). For example, during January and February 2009, south-eastern Australia experienced record maximum temperatures and a record number of consecutive days above 40°C in many locations (BOM, 2009). Over this period, there was a 25% increase in total emergency cases and a 46% increase over the three hottest days. A 34-fold increase in cases with direct heat-related health problems was observed with 61% of these being people aged 75 years or older. There were 374 excess deaths, representing a 62% increase in total all-cause mortality (Victorian Government, 2009b). A substantially increased number of deaths in the Brisbane heatwave of 2004, when the temperature ranged from 26°C to 42°C was also observed (Tong *et al*., 2010a). Total mental health admissions increased by 7.3% in metropolitan South Australia during heatwaves (1993-2006), with increases across all age groups (Hansen *et al*., 2008). Mortality attributed to mental and behavioural disorders increased in the 65 to 74-year age group and in persons with schizophrenia, schizotypal, and delusional disorders (Hansen *et al*., 2008).

25.6.9.2. Projected Impacts

There is *high confidence* that projected increases in heatwaves will be associated with an increase in both heat-related deaths and increased hospitalizations, especially amongst the elderly. This may be offset by reduced deaths from cold at least for modest rises in temperature in the southern states of Australia and part so New Zealand (*low confidence)* (Kinney, 2012). In Australia, a recent study accounted for changes in the mean, but not the variability of temperatures (Bambrick *et al*., 2008); net temperature-related (heat and cold) deaths changed little across the country until about 2070. The annual net increase for unmitigated climate change, relative to no climate change, was an additional 1250 deaths in 2070 (+14%), rising to 8628 in 2100 (+100%) (Bambrick *et al*., 2008). In a separate study, which did account for increases in daily temperature variability, a substantial increase in heat-related deaths was estimated for Sydney (Gosling *et al*., 2010). Using the HadCM3 climate model, and assuming no adaptation, the average annual heat-related mortality rate was projected to increase by 6.2 per 100,000 from 1961-1990 to 2070-2099 for the A2 emission scenario, and by 5.5 per 100,000 for the B2 scenario.

The annual number of temperature-related hospital admissions in South Australia under the A1FI scenario is projected to increase 110% by 2100 (Bambrick *et al*., 2008).The number of hot days when outdoor work becomes impossible is also projected to increase substantially in Australia by 2070, leading to high economic costs from lost productivity and also some health impacts including increased hospitalisations and occasional deaths (*high confidence*) (Hanna *et al*., 2011; Maloney and Forbes, 2011).

A growing body of literature since the AR4 has focused on the psychological impacts of climate change, based on impacts of recent climate variability and extremes (Doherty and Clayton, 2011). These studies indicate significant mental health risks associated with climate-related disasters, in particular persistent and severe drought, floods and storms, and that impacts may be especially acute in rural communities where climate change places additional stresses on livelihoods (*high confidence*) (Edwards *et al*., 2011; see also Box 25-6). In New South Wales, a projected decrease in precipitation of 300 mm was estimated to increase the suicide rate by approximately 8% (Nicholls *et al*., 2006).

Water- and food-borne diseases are projected to increase in the future but the complexity of their relationship to climate means there is *low confidence* in the specific projections. For Australia, 205,000-335,000 new cases of bacterial gastroenteritis by 2050, and 239,000-870,000 cases by 2100, were projected under a range of emission scenarios (Bambrick *et al*., 2008; Harley *et al*., 2011). Water borne zoonotic diseases such as cryptosporidiosis have more complex relationships with climate (Lal *et al*., 2012), while water treatment systems help to prevent outbreaks related to heavy rainfall or flooding (Britton *et al*., 2010a, b).

The area climatically suitable for transmission of dengue is projected to expand southwards during this century (Bambrick *et al*., 2008) (*medium confidence*). For Australia, under unmitigated emission scenarios, with other factors being equal, the population at risk of dengue is projected to increase from currently less than 0.5 million to 5-8 million by 2100. Mitigation scenarios led to a marked reduction in population at risk to less than 1 million people (Bambrick *et al*., 2008). These estimates, however, were derived from a global empirical model (Hales *et al*., 2002) which did not account for the maximum historical extent of dengue in Australia and elsewhere (Russell, 2009). Biophysical modelling studies suggest that the installation of domestic water tanks could have an even greater effect on the risk of dengue than climatic change, at least until the 2050s (Kearney *et al*., 2009).

Malaria is considered a low risk to both Australia and New Zealand due to high levels of socioeconomic development and availability of effective treatment for sporadic cases (*medium confidence*). Australia and New Zealand are projected to remain malaria free under a range of climate models using the A1B emission scenario for 2030 and 2050 (Béguin *et al*., 2011). The impacts of climate change on Ross River virus and other arboviruses such as Barmah Forest virus and Chikungunya have not been modelled in this region. Future expansion of the geographic range of these viruses seems probable, however, accounting for the combined effects of climate change, frequent travel within and outside the region, and recent incursions of exotic mosquito species (Derraik and Slaney, 2007; Derraik *et al*., 2010) (*medium confidence*).

25.6.9.3. Adaptation

Adaptation for heat-related health problems involves reshaping government policy, improving healthcare services, developing early warning systems to reach all citizens with a social network back-up for those most at risk, preparing health system/emergency departments, improving maintenance programs for key services, seeking behavioural changes and community awareness to reduce exposure to heat stress, retrofitting old houses with better insulation, and developing emergency response plans (Wang and McAllister, 2011). Charging more for energy during peak times would reduce risk to infrastructure overload, but leave low-income residents more vulnerable to heat waves (Strengers and Maller, 2011). Greening cities is an adaptation option to reduce the heat related health impact of climate change (Bambrick *et al.*, 2011; see Box 25-9).

The Victorian government has developed a heatwave plan to coordinate state-wide response and maintain consistent community-wide understanding of health impacts by a Heat Health alert system, building capacity of councils to support communities most at risk from heat-related impacts, supporting and funding of health services, distribution of public health information, and a Heat Health Intelligence surveillance system (Victorian Government, 2009a). Kiem *et al.,* (2010), identified a failure in communication with no clear public information or warning strategy, no clear thresholds for initiating public information campaigns or incident response resulting in mixed messages to the media and public during the southern Australian heatwave of 2009. Additionally, emergency management response services were found to be underprepared and relied on reactive solutions with an overall lack of surge planning (QUT, 2010). In New Zealand, central Government health policies show no specific measures to adaptat to climate change (Wilson, 2011).

25.6.10. Indigenous Peoples

25.6.10.1. Aboriginal and Torres Strait Islanders

Australia's culturally distinct Indigenous population is small (2.5%), widely dispersed and rapidly growing (ABS 2009). Adaptation planning would benefit from a robust typology (Maru *et al.*, 2011) that accounts for the diversity of Indigenous life experience (McMichael *et al.*, 2009). Increased climate change policy attention since AR4 is evidenced by a national Indigenous research action plan (Langton *et al.*, 2012), three regional risk studies (DoNP 2010; Green *et al.*, 2009; TSRA 2010) and scrutiny from an Indigenous rights perspective (ATSISJC 2009).

High levels of socio-economic disadvantage and poor health (SCRGSP 2011) indicate a disproportionate vulnerability of Indigenous Australians to climate change (McMichael *et al.*, 2009). However, no detailed assessments have been undertaken. In urban and regional areas, where 75% of the Indigenous population lives, assessments have not specifically addressed risks to Indigenous people (eg Guillaume *et al.*, 2010). In other regions, all remote, there is limited evidence from empirical studies. However there is a *high agreement and robust evidence* of future impacts arising from increasing heat stress, extreme events and increased disease (Campbell *et al.*, 2008; Green *et al.*, 2009; Spickett *et al.*, 2008).

There is also *high agreement* but *limited evidence*, that (1) dependence on economic activities based on natural resources (eg Bird *et al.*, 2005; Buultjens *et al.*, 2010; Gray *et al.*, 2005a; Kwan *et al.*, 2006) increases Indigenous exposure and sensitivity to climate change (Green *et al.*, 2009); (2) climate change-induced dislocation, attenuation of cultural attachment to place and loss of agency will affect Indigenous mental health and community identity adversely (Fritze *et al.*, 2008; Hunter, 2009; McIntyre-Tamwoy and Buhrich, 2011); and (3) housing, infrastructure, services and transport, many of which are already inadequate for Indigenous needs (ABS 2010c), will be stressed by temperature increases, rising sea levels, flooding and storms (Taylor and Philp, 2010) and little adaptation is apparent (but see Burroughs, 2010; GETF 2011). There is *high confidence* that Torres Strait islands and livelihoods are vulnerable to major impacts from even small sea level rises (DCC, 2009; Green *et al.*, 2010b; TSRA 2010).

A number of studies (Ellemor, 2005; Langton *et al*., 2012; Petheram *et al*., 2010; Veland *et al*., 2010) identify that institutions external to Indigenous communities can constrain their adaptive capacity. Although empirical evidence is limited to a few places, communicating and designing adaptation strategies with local communities will be challenging because they confront multiple stressors. Indigenous re-engagement with environmental management (eg Hunt *et al*., 2009; Ross *et al*., 2009) can promote health (Burgess *et al*., 2009) and may increase adaptive capacity (Berry *et al*., 2010; Davies *et al*., 2011). There is emerging interest in integrating Indigenous observations of climate change (Green *et al*., 2010c; Petheram *et al*., 2010) and developing inter-cultural communication tools (Prober *et al*., 2011; Woodward *et al*., 2012). Other transformative engagements are mitigating greenhouse gas emissions while generating community benefits (Robinson *et al*., 2011; Whitehead *et al*., 2008).

25.6.10.2. New Zealand Māori

The projected impacts of climate change on Māori society are expected to be highly differentiated reflecting complex economic, social, cultural, environmental and political factors (*high confidence*). Since 2007, studies have been either sector specific in their analyses (e.g. Harmsworth *et al*., 2010; Insley, 2007; Insley and Meade, 2008; King *et al*., 2012) or more general in scope inferring risk and vulnerability based on exploratory engagements with varied stakeholders and existing social-economic-political and ecological conditions (e.g. King *et al*., 2010; MfE, 2007b; Te Aho, 2007).

The Māori economy is firmly invested in climate-sensitive primary industries with a range of vulnerabilities to present and future climate conditions (*high confidence*) (Cottrell *et al*., 2004; Harmsworth *et al*., 2010; King and Penny, 2006; King *et al*., 2010; Nana *et al*., 2011a; NZIER, 2003; Packman *et al*., 2001; Tait *et al*., 2008b; TPK, 2007). Large proportions of Māori owned land (>60%) are steep and hilly and susceptible to damage from high intensity rainstorms and erosion; while low-land plains and terraces are vulnerable to flooding and high sedimentation (Harmsworth and Raynor, 2005; King *et al*., 2010). Much Māori land in the east and north is drought prone, and this risk is likely to increase uncertainties for future agricultural performance, product quality and investment (*medium confidence*) (Cottrell *et al*., 2004; Harmsworth *et al*., 2010; King *et al*., 2010). The fisheries sector faces substantial risks (and uncertainties) from rising sea levels, changes in ocean temperature and chemistry, potential changes in species composition, condition and productivity levels (*medium confidence*) (King *et al*., 2010).

Māori organisations have developed sophisticated business structures, governance (e.g. trusts, incorporations) and networks (e.g. Iwi leadership groups) across the state and private sectors (Harmsworth *et al*., 2010; Nana *et al*., 2011b), which are critical for managing and adapting to future climate change risks and impacts (Harmsworth *et al*., 2010; King *et al*., 2012). Some tribal organisations are developing options through joint-ventures and partnerships in response to the New Zealand Government's Emissions Trading Scheme. Future opportunities will depend upon collaborative and strategic partnerships in business, science, research and government (Harmsworth *et al*., 2010; King *et al*., 2010) (*high confidence*); as well as innovative technologies and new land management practices to better suit future climates (Carswell *et al*., 2002; Funk and Kerr, 2007; Harmsworth, 2003; Insley and Meade, 2008; Penny and King, 2010; Tait *et al*., 2008b).

Māori regularly utilise the natural environment for hunting and fishing, for recreation, the collection of cultural resources, and the maintenance of traditional skills and identity (King *et al*., 2012; King and Penny, 2006). Many of these are already compromised amidst increasing resource-competition, degradation and modification of the environment (King *et al*., 2012; Woodward *et al*., 2001). Climate change driven shifts in natural ecosystems will place further burdens on the capacities of some Māori to cope and adapt (*medium confidence*) (King *et al*., 2012). Māori knowledge of environmental processes and hazards (King *et al*., 2005; King *et al*., 2007) as well as strong social-cultural networks will be vital for adaptation and on-going risk management (King *et al*., 2008); however, choices and actions continue to be constrained by insufficient resourcing, shortages in capacity and expertise, and inequalities in political representation (King *et al*., 2012). Reaffirming traditional ways and knowledge as well as new and untried policies and strategies will be key to the long-term sustainability of climate-sensitive Māori communities, groups and activities (*high confidence*) (Harmsworth *et al*., 2010; King *et al*., 2012).

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Box 25-7. Climate Change and Fire

Fire is a characteristic feature of most Australian terrestrial ecosystems – many plants and animal species have evolved to survive it, and some even require it to reproduce. In humid northern Australia, low intensity fires often burn across large areas and may occur annually (Russell-Smith *et al*., 2009). In the south-east and south-west, hot, dry and windy summers provide conditions for intense bushfires that are more difficult to control (Adams and Attiwill, 2010; Cary *et al*., 2003) and can cause substantial damage to property and lives especially during droughts and heat waves. For example, the 'Black Saturday' bushfires in Victoria in February 2009, which burnt over 4,500 km^2, caused 173 deaths and destroyed over 2,000 buildings (Cameron *et al*., 2009; VBRC, 2010), occurred during a drought that lasted 13 years (CSIRO, 2010) and over the longest consecutive period of days over 40°C on record (Tolhurst, 2009).

Large and devastating rural fires occur relatively less frequently in New Zealand compared with Australia, due to its cooler, maritime climate. Nonetheless, some 3000 wildfires annually burn around 6000 ha of grasslands, shrubland and forests in New Zealand (Anderson *et al*., 2008), resulting in over 40,000 ha of exotic plantation forest valued in excess of NZD$300 million being burnt over the past 70 years (Pearce *et al*., 2008). Fire climate severity varies significantly across the country as a result of topography and prevailing climate patterns (Pearce and Clifford, 2008; Pearce *et al*., 2003; Pearce *et al*., 2011c; Pearce *et al*., 2007a). Parts of New Zealand, particularly in eastern areas, can experience in excess of 30-40 days/year of very high and extreme fire danger (Pearce *et al*., 2011c), which is comparable with south-eastern Australia (Lucas *et al*., 2007; Williams *et al*., 2001).

Climate change is expected to increase the number of days with very high and extreme fire danger (25.3.8), with greater changes where fire is constrained by weather (south-east and south-west Australia; eastern and some northern parts of New Zealand) than in regions where it is constrained by fuel load and ignitions (savannas in northern tropical Australia). The fire season length will extend in many areas already at high risk (*high confidence*) and thus reduce opportunities for controlled burning (Lucas *et al*., 2007). The impact of climate change on fuel loads is complex: higher CO_2 is expected to enhance fuel loads but only in regions where moisture is not limiting (Bradstock, 2010; Donohue *et al*., 2009; Hovenden and Williams, 2010; Williams *et al*., 2009).

Climate change and fire will have complex feedback effects on the structure and composition of vegetation communities and biodiversity, with both negative and positive implications in different regions (Williams *et al*., 2009). The most significant impacts of changed fire regimes on biodiversity in Australia are expected in the sclerophyll forests of the south east and south west (Williams *et al*., 2009) (*medium confidence*). Most New Zealand ecosystems have limited exposure but also limited adaptation to fire (McGlone and Walker, 2011; Ogden *et al*., 1998). There is *high agreement* and *medium evidence* that increased incidence of fires in south-east and south-west Australia will increase risk to people, property and infrastructure such as electricity transmission lines (O'Neill and Handmer, 2012; Parsons Brinkerhoff, 2009) and in parts of New Zealand where urban margins expand into rural areas (Jakes *et al*., 2010; Jakes and Langer, in press), exacerbate some respiratory conditions such as asthma (Beggs and Bennett, 2011; Johnston *et al*., 2002), and increase economic risks to plantation forestry (Pearce *et al*., 2011b; Watt *et al*., 2008). Forest regeneration following wildfires also reduces water yields (Brown *et al*., 2005; MDBC, 2007) while reduced vegetation cover increases erosion risk and material washoff to waterways (Shakesby *et al*., 2007; Wilkinson *et al*., 2009).

There is *high confidence* that in Australia, managing fire regimes will become increasingly challenging under climate change (O'Neill and Handmer, 2012). Initiatives centre on planning and regulations, design of buildings to reduce their flammability, avoidance of development in high fire risk areas, fuel management, early warning systems, and fire detection and suppression (Handmer and Haynes, 2008; O'Neill and Handmer, 2012; Preston *et al*., 2009; VBRC, 2010). Some Australian authorities are taking climate change into account in rethinking approaches to managing fire to restore and rebalance ecosystems while protecting human life and properties (Adams and Attiwill, 2010; Preston *et al*., 2009). Improved understanding of climate-drivers of fire risks is also assisting New Zealand fire management agencies, landowners and communities to improve fire management and mitigation strategies (Pearce *et al*., 2008; Pearce *et al*., 2011b), although changes in management practices to date show little evidence of being driven by climate change.

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Box 25-8. Insurance as Climate Risk Management Tool

Insurance provides a mechanism to reduce impacts from extreme events by sharing the risk across communities and spreading costs over time (AR5 WGII Chap 10). In Australia, insured losses due to natural hazards are dominated by floods and storms, including the 2011 Queensland floods and the 1999 Sydney hailstorm (ICA, 2012) with estimated claims of A$3 billion p.a. (IAA, 2011a). In New Zealand, floods and storms are the second most costly natural hazards after earthquakes (ICNZ, 2012). Damaging insured events since 1980 are showing a significant increase (Schuster, in press).

There is *high confidence* that without adaptive measures, projected increases in extremes (25.3) and uncertainties in these projections will lead to increased insurance premiums, exclusions and non-coverage in some locations (IAG, 2011), which will reshape the distribution of vulnerability, e.g., through unaffordability or unavailability of cover in areas at highest risk (IAA, 2011b, a).

Insurance can positively contribute to risk reduction by providing financial incentives to policy holders to reduce their risk profile (O'Neill and Handmer, 2012), e.g. through implementation of resilience ratings given to buildings (Edge Environment, 2011; IAG, 2011; TGA, 2009). Apart from constituting an autonomous private sector response to extreme events, insurance can also be framed as a form of social policy to manage climate risks, similar to New Zealand's government insurance scheme to manage geological risk (Glavovic *et al*., 2010). However, insurance can also act as a barrier to adaptation where those living in climate-risk prone localities pay discounted or cross-subsidised premiums, or if policies fail to encourage betterment after damaging events by requiring replacement of 'like for like', constituting a missed opportunity for risk reduction (Reisinger *et al*., in press).

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Box 25-9. Adaptation to Climate Change in Urban Spaces

Urban environments, and the people living within them, will be affected by future climate-driven changes in heat and cold extremes, river and coastal flooding and erosion, bushfires, storms and drought (for projected changes, see 25.3). There is *high confidence* that these changes will affect human health (Bambrick *et al*., 2011; Tong *et al*., 2010a), lead to damages to and/or deterioration of the built environment (BRANZ, 2007; O'Connell and Hargreaves, 2004; Stewart and Wang, 2011; Wang *et al*., 2010a; Waters *et al*., 2010), and have the potential to disrupt key urban infrastructure services such as energy (Strengers, 2008; Strengers and Maller, 2011), water (Howe *et al*., 2005; Ibbitt and Williams, 2009; see also Box 25-3), and transport (Gardiner *et al*., 2009a; Gardiner *et al*., 2009b; QUT, 2010). Uniquely, urban spaces are areas where high population density, prevalence of infrastructure and streams of materials (inputs and waste) create multiple pressures that can exacerbate these impacts and potentially constrain adaptation options and create inadvertent trade-offs, but they can also offer innovative adaptation solutions.

Greening cities by increasing ground vegetation, trees, parks and green roofs can reduce urban heat island effects and thus reduce heat-related impacts (*high confidence*) (Coutts *et al*., 2010). Green roofs also reduce the cooling demand of buildings by increasing insulation and evapotranspiration, but barriers to wide adoption remain due to lack of standards, higher cost and limited understanding of their benefits (Williams *et al*., 2010). Building design with appropriate shading, insulation, ventilation and air-conditioning also can considerably improve interior temperature during heat waves (BRANZ, 2007). Many of these measures (except air conditioning) reduce summer peak energy demand and thus reduce the risk of black- or brown-outs (*very high confidence*; see also 25.6.8 and 25.7.1).

Overheating and energy demand of buildings can also be reduced through changes in occupant behavior (Stephenson *et al*., 2010), improved energy management (Karjalainen, 2009; Moon and Han, 2011; Orosa and Oliveira, 2010; Strengers, 2008), the reduction of lighting and equipment loads (BRANZ, 2007), passive design (Peterkin, 2009; Su, 2009), and the use of energy efficient appliances (Thatcher, 2007) and reflective paint (Gurzu *et al*., 2010; TUM, 2011). However, significant energy efficiency improvements would be required to counteract the effects of projected warming on energy demand in most regions of Australia (Ren *et al*., 2011; Wang *et al*., 2010b).

Urban spaces allow innovative and significant augmentation of traditional bulk water supply through water recycling (greywater) and rainwater harvesting (*high confidence*) (Attwater *et al*., 2006; Naji and Lustig, 2006; Radcliffe, 2010). In Adelaide, both measures have been adopted with water-self-sufficiency estimated at around 60% (Barton and Argue, 2009). Water quality is a key factor in the use of rainwater tanks (Abbott *et al*., 2006; Kus *et al*., 2010; Rodrigo *et al*., 2010) and social, cultural, institutional, and economic factors influence sustainable water management in Australia (Brown *et al*., 2009; Brown and Farrelly, 2009; Fletcher *et al*., 2008; Gardner and Vieritz, 2010; Mankad and Tapsuwan, 2011; Rozos *et al*., 2010). Rainwater harvesting also reduces storm-water runoff during short-lived high intensity rainfall events (Zhang *et al*., 2010). Strategies to enhance water-saving behaviour are an effective way to reduce water demand through education, regulation and pricing (Chanan *et al*., 2009), together with initiatives for retrofitting water efficient devices (Lawrence and McManus, 2008). While demand- and supply-side strategies can be complementary, enhancing bulk supply can also reduce community support for demand-side management (Barnett and O'Neill, 2010; Taptiklis, 2011; see also Box 25-3 and 25.7.1).

Most cities in Australia and New Zealand are vulnerable to increased river flood and/or coastal inundation risk (*high confidence*; see Boxes 25-2 and 25-10). Several options exist to reduce the impact of flooding on buildings and infrastructure, including coping measures such as raising floor levels, using strong piled foundations, using water-resistant insulation materials, raising the height of wiring, outlets, hot water cylinders, and meter boards, ensuring weathertightness, and protection measures such as upgrading seawalls, flood protection, drains (O'Connell and Hargreaves, 2004) and storm-water retention systems (Wong *et al*., 2012). In many cases, however, avoidance of exposure to future flooding and coastal inundation is the most cost-effective long-term adaptation response in light of increasing asset values, on-going climate change and increasing risk of extreme events (DCCEE, 2011; Glavovic *et al*., 2010) (*robust evidence and high agreement*). For example, if planning regulations allow no further development in high risk areas in Australia (but with no action to protect existing housing stock), the impact of 2.5m storm tides with an additional 0.2m sea level rise in 2030 could be limited to approximately 40,300 residential buildings instead of 61,500 (Wang *et al*., 2010a).

For residential buildings exposed to cyclones, the most cost-effective adaptation strategy for projected increases in cyclone intensity is to design new buildings to withstand 50% higher wind pressures (Stewart and Wang, 2011) (*medium confidence*). The net present value of the average net benefit to implement this approach in Brisbane is A$38 million by 2030, A$142 million by 2050, A$240 million by 2070 and A$340 million by 2100 assuming a moderate climate change scenario (25% reduction in cyclone frequency, 10% increase in wind speeds). In this example, the benefits are maximised if enhancements are implemented promptly, indicating that waiting for increasing certainty of projections is not necessarily a cost-effective adaptation strategy (Stewart and Wang, 2011). A lifetime inspection and maintenance program for buildings in cyclone regions is also suggested (Mason and Haynes, 2010).

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Box 25-10. Changes in Flood Risk and Management Responses

Floods are the most costly natural disaster in Australia (BTE, 2001) and the second-most costly in New Zealand after earthquakes (ICNZ, 2012). Nonetheless, flood damages across eastern Australia and both main islands of New

Zealand in 2010 and 2011 revealed a significant adaptation deficit to this climate extreme (ICA, 2012; ICNZ, 2012). For example, the Queensland floods in January 2011 resulted in 35 deaths, three quarters of the state including Brisbane declared a disaster zone, and damages in excess of AUD$2 billion (Queensland Government, 2011). These floods were associated with a strong monsoon and the strongest La Niña on record (Cai *et al.*, 2012; CSIRO and BOM, 2012). Floods exhibit strong decadal variability and there is no significant long-term trend to date in their frequency and severity (Kiem *et al.*, 2003; Smart and McKerchar, 2010).

Flood risk is projected to increase in many regions due to more intense rainfall events driven by a warmer and wetter atmosphere (*high confidence*; 25.3.4). High resolution downscaling (Carey-Smith *et al.*, 2009; Griffiths, 2007), and dynamic catchment hydrological and river hydraulic modelling in New Zealand (Ballinger *et al.*, 2011; Duncan and Smart, 2011; Gray *et al.*, 2005b; McMillan *et al.*, submitted; McMillan *et al.*, 2010; MfE, 2010a) indicate that the 50-year and 100-year flood peaks for rivers in many parts of the country will increase by 10-20% by 2050 and more (and greater variation between models and scenarios) by 2100, with a corresponding decrease in return periods for design floods (Ballinger *et al.*, 2011; Carey-Smith *et al.*, 2009; McMillan *et al.*, submitted; MfE, 2008c). Studies for Queensland show similar results (DERM *et al.*, 2010). In Australia, flood risk is expected to increase more in the north (which is driven by convective rainfall systems) than in the south (where mean rainfall is projected to decline), consistent with confidence in heavy rainfall projections (see 25.3.4; Alexander and Arblaster, 2009; Rafter and Abbs, 2009).

Flood risk near river mouths will be exacerbated by higher storm surge and potential change in wind speeds (McInnes *et al.*, 2005; MfE, 2010a; Wang *et al.*, 2010a). Higher rainfall intensity and peak flow will also increase erosion and sediment loads in waterways (Nearing *et al.*, 2004) and exacerbate problems from aging stormwater and wastewater infrastructure in cities (CCC, 2010; Howe *et al.*, 2005; Jollands *et al.*, 2007; WCC, 2010). However, moderate flooding also has benefits through infilling reservoirs, recharging groundwater and replenishing natural environments (Chiew and Prosser, 2011; Hughes, 2003; Oliver and Webster, 2011).

Adaptation to increased flood risks from climate change is already happening (Wilby and Keenan, in press) through updating guidelines for design flood estimation (MfE, 2010a; Westra, 2012), increasing protection (GWRC, 2001), enhancing coping capacity for buildings in flood prone areas (Box 25-9) and in some cases risk avoidance including through managed relocation (LVRC, 2011; Trotman, 2008). Adaptation options in urban areas also include retaining floodplains and floodways and retrofitting existing systems to attenuate flows (Box 25-9; Howe *et al.*, 2005; Skinner, 2010; WCC, 2010). The recent flooding in eastern Australia and the projected increase in future flood risk have also resulted in changes to reservoir operations to mitigate floods (QFCI, 2012; van den Honert and McAneney, 2011) and insurance practice to cover flood damages (NDIR, 2011; Phelan, 2011). However, the magnitude of potential future changes in flood risks and limits to incremental adaptation responses in urban areas suggest that more transformative and structural approaches based on altering land-use may be needed in some locations (*high confidence*), especially if changes in the upper range of projections are realised (DERM *et al.*, 2010; Glavovic *et al.*, 2010; Lawrence and Allan, 2009; Lawrence and Quade, 2011; Wilby and Keenan, in press).

_____ END BOX 25-10 HERE _____

25.7. Interactions between Impacts, Adaptation, and Mitigation Responses

The AR4 found that individual adaptation responses can entail synergies or trade-offs with other adaptation responses and with mitigation, but that integrated assessment tools were lacking in Australasia (Hennessy *et al.*, 2007). Subsequent studies provide more detail on such interactions and can inform a balanced portfolio of climate change responses, but formal evaluation tools remain very limited, especially for local-scale decision-making.

25.7.1. Interactions between Local-Level Impacts, Adaptation, and Mitigation Responses

Adaptation responses can be either synergistic or entail trade-offs with impacts or other adaptation responses within or between sectors. Adapting proactively to projected future climate changes (flooding, drought, storms) often render greater near-term resilience to climate variability and can provide environmental co-benefits. Although this can be a key motivation for adopting adaptation measures, there is *high confidence* that relying exclusively on near-term benefits can result in long-term maladaptation. For example, enhancing protection measures after major flood events, combined with rapid re-building, accumulates fixed assets that become increasingly vulnerable and costly to protect as climate change continues (Glavovic *et al.*, 2010; Reisinger *et al.*, in press; Stafford-Smith *et al.*, 2011). Additional examples can be found in Table 25-4.

[INSERT TABLE 25-4 HERE
Table 25-4: Examples of interactions between adaptation measures in different sectors. In each case, impacts or adaptation responses in one sector have the potential to conflict (cause negative impacts) or be synergistic (have co-benefits) with adaptation responses in another sector, or with another type of response in the same sector.]

Mitigation can contribute to but also counteract local adaptation. For example, reducing energy demand for cooling of buildings reduces the risk of network failure during summer peak demand periods, but urban densification to reduce transport energy demand increases health risks during heat waves and compounds stormwater management problems. Vice versa, adaptations can make mitigation targets easier or harder to achieve. For example, afforestation to reduce erosion risk reduces net greenhouse gas emissions, yet increasing reliance on air conditioning and desalination increases energy demand and emissions. Table 25-5 gives further examples of local-scale interactions between mitigation and adaptation. Increasing efforts in mitigation and adaptation imply increasing complexity of interactions; of 25 specific climate change-associated land-use plans from Australia, 12 exhibited potential for conflict between mitigation and adaptation (Hamin and Gurran, 2009). Box 25-11 explores multiple drivers, benefits and trade-offs in changing land-use to both adapt to and mitigate climate change.

[INSERT TABLE 25-5 HERE
Table 25-5: Examples of interactions between adaptation and mitigation measures (green rows denote synergies where multiple benefits may be realized, orange rows denote potential tradeoffs and conflicts).]

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Box 25-11. Land-based Interactions between Climate, Energy, Water, and Biodiversity

Climate, water, biodiversity, food and energy production are intertwined through complex feedbacks and trade-offs, indicating that alternative uses of natural resources within rural landscapes will become increasingly contested (*high confidence*). However, integrated studies of the implications of both mitigation and adaptation objectives to support decision-making under competing societal values are not yet available.

Various policies in Australasia support increased biofuel production and biological carbon sequestration, e.g. via mandatory renewable energy targets and incentives to increase carbon storage. Impacts of increased biological sequestration activities on biodiversity depend on their implementation. Benefits arise from reduced erosion, additional habitat, and enhanced connectivity of ecosystems, while risks or lost opportunities are associated with large-scale monocultures especially if replacing more diverse systems (Brockerhoff *et al.*, 2008; Giltrap *et al.*, 2009; Kerr *et al.*, 2012; Steffen *et al.*, 2009; Todd *et al.*, 2009).

As photosynthesis transfers water to the atmosphere, increased sequestration is projected to further reduce catchment yields particularly in southern Australia and negatively affect water quality (CSIRO, 2008; Schrobback *et al.*, 2011). Accounting for this in water allocations for sequestration activities increases costs and limits the potential scale of sequestration-driven land-use change (Polglase *et al.*, 2011; Stewart *et al.*, 2011). Large-scale land-cover changes also affect regional climate in complex ways through changing albedo, evapotranspiration and surface roughness, but these feedbacks have rarely been integrated with estimates of direct water demands of carbon sequestration activities (Kirschbaum *et al.*, 2011b; McAlpine *et al.*, 2009).

Biological carbon sequestration in New Zealand is less water-challenged than Australia, except where catchments are projected to become drier and/or are already completely allocated (MfE, 2007a; Rutledge *et al.*, 2011). Carbon sequestration would mostly improve water quality (*high confidence*) through reducing erosion (Giltrap *et al.*, 2009).

In turn, policies to protect water quality by limiting allowable nitrogen discharge from agriculture have reduced pastoral production in the Lake Taupo catchment, lowering agricultural greenhouse gas emissions and supporting biological sequestration activities (Browne *et al.*, 2012).

Trade-offs between energy and food production and environmental services depend strongly on the type of sequestration activity and application of consistent principles to evaluate environmental externalities and benefits of alternative land-uses (PMSIEC, 2010). Changes towards woody biofuels in New Zealand are projected to occur on marginal land, not necessarily where the most intense agriculture occurs (Todd *et al.*, 2009), but first-generation biofuels have been modelled to directly compete with agricultural production in Australia (Bryan *et al.*, 2010). As plants are far less efficient than e.g. solar photovoltaics in converting solar energy into usable fuel (e.g. Reijnders and Huijbregts, 2007), falling solar energy costs will also affect future demand for biofuels, together with the local balance of environmental and social benefits and trade-offs and changing climatic suitability (Bryan *et al.*, 2010; Odeh *et al.*, 2011).

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25.7.2. Intra- and Inter-Regional Flow-On Effects Between Impacts, Adaptation and Mitigation

The AR4 noted that flow-on effects from climate change impacts occurring in other regions can both exacerbate and counteract projected impacts on Australasia but found only very limited studies.

Modelling suggests Australia's terms of trade would deteriorate by about 0.23% in 2050 and 2.95% in 2100 due to climate change impacts in other regions, mainly due to reduced demand for coal and minerals (Harman *et al.*, 2008). As a result, Australian Gross National Product (GNP) is expected to decline more strongly than GDP due to climate change, especially towards the end of the 21st century (Gunasekera *et al.*, 2008). However, reliance on simplified assumptions about global climate change impacts, economic effects and policy responses allows only *medium confidence* in these conclusions.

For New Zealand, there is *limited evidence* but *high agreement* that higher global food prices driven by adverse climate change impacts on global agriculture and some international climate policies would increase commodity prices and hence producer returns in New Zealand. For example, agriculture and forestry producer returns are estimated to increase by 14.6% under the A2 scenario by 2070 (Saunders *et al.*, 2010) and real gross disposable national income to increase by 0.6-2.3% under a range of non-mitigation scenarios (Stroombergen, 2010) relative to baseline projections in the absence of global climate change. Some climate policies such as biofuel targets and agricultural mitigation in other regions also would increase global commodity prices and returns to New Zealand farmers (Reisinger and Stroombergen, 2011; Saunders *et al.*, 2009) and, depending on global implementation, could more than offset projected national average domestic climate change impacts on agriculture (Tait *et al.*, 2008a). By contrast, higher international agricultural commodity prices appear insufficient to compensate for the more severe effects of climate change on agriculture in Australia (Garnaut, 2008; Gunasekera *et al.*, 2007).

International tourism in Australasia is also subject to flow-on effects arising from climate change affecting destination preferences (Kulendran and Dwyer, 2010; Rosselló-Nadal *et al.*, 2011) and broader changes in demand (UNWTO *et al.*, 2008), climate policies (Mayor and Tol, 2007) and oil prices (Becken, 2011; Schiff and Becken, 2011). However, these effects remain to be quantified and integrated with intra-regional and local impacts.

There is no evidence that climate change influences migration from New Zealand to Australia, which is largely economically driven, even though a perceived more attractive climate in Australia plays a reported role (Green *et al.*, 2008a; Poot, 2009). Internal migration, especially from the Torres Straits islands to other islands, is the most plausible climate-induced population shift within the region, but the drivers and triggers have been considered only qualitatively (Green *et al.*, 2010b; Hugo, 2012). Potential climate change impacts on migration and geopolitical stability within the Asia-Pacific region (Hugo, 2010; McAdam, 2010) remain speculative as there is no clear evidence of climate-induced migration or violent conflict within the region to date (Barnett, 2003; Farbotko and Lazrus, 2012; Mortreux and Barnett, 2009; Pearman, 2009; Reuveny, 2007). However, there is *high agreement* and *robust evidence* that increasing climate-driven disasters, disease, and border control will stimulate operations other than war for Australasia's armed forces, and that integration of security considerations into adaptation and development assistance for Pacific island countries can play a key role in moderating potential future influence of climate change on forced migration and conflict (Barnett, 2009; Bergin and Townsend, 2007; Dupont, 2008; Dupont and Pearman, 2006; Rolfe, 2009; Sinclair, 2008).

25.8. Synthesis and Regional Key Risks

25.8.1. Economy-wide Impacts and Damages Avoided by Mitigation

Potential impacts pose formidable challenges to adaptation, particularly at the upper end of projected changes. Global mitigation could reduce or delay damages and make adaptation more feasible beyond about 2050, when projected climates begin to diverge substantially between mitigation and non-mitigation scenarios (see also 19.7). However, literature quantifying these benefits for Australasia remains limited.

Economy-wide net costs for Australia are modelled to be substantially greater in 2100 under unmitigated climate change (GNP loss 7.6%) than under effective global mitigation (GNP loss less than 2% for stabilization at 450 or 550ppm CO_2-eq, including residual impacts of climate and costs of mitigation) (Garnaut, 2008). However, these estimates are highly uncertain and depend strongly on valuation of non-market impacts, treatment of potential catastrophic outcomes, and assumptions about autonomous adaptation, international flow-on effects and effectiveness and implementation of global mitigation efforts (Garnaut, 2008). No integrated estimates of climate change costs across the entire economy exist for New Zealand.

The benefits of mitigation (in terms of avoided impacts) have been quantified for individual sectors in Australia, e.g. for irrigated agriculture in the Murray-Darling Basin (Quiggin *et al*., 2010; Quiggin *et al*., 2008; Scealy *et al*., 2011; Valenzuela and Anderson, 2011) and for net health outcomes (Bambrick *et al*., 2008). Although quantitative estimates from individual studies are highly assumption-dependent, multiple lines of evidence (see 25.6) give *very high confidence* that effective global mitigation would reduce or avoid significant fractions of many potential long-term impacts projected across Australia under non-mitigation scenarios. However, benefits differ between states for some issues, e.g. heat and cold mortality (Bambrick *et al*., 2008). Almost no studies consider mitigation benefits for New Zealand. However, scenario-based studies give *high confidence* that mitigating emissions from a high (A2) to at least a medium-low (B1) scenario would markedly lower the projected increase in flood risks (Ballinger *et al*., 2011; McMillan *et al*., submitted) and reduce risks to livestock production in the most drought prone regions (Clark *et al*., 2011; Tait *et al*., 2008a). Conversely, mitigation would also reduce the projected benefits to production forestry, but amounts depend on the response to CO_2 fertilization (Kirschbaum *et al*., 2011a; 25.6.4).

For sectors with very limited adaptive capacity, such as range- and temperature-limited ecosystems (25.6.2, 25.6.3), effective global mitigation is the main option to reduce or delay damages in the long term (*very high confidence*). For many other sectors and over the next few decades, effective adaptation can play a greater role in managing overall risks, but its benefits are sector dependent, often not well quantified and distributed differently in space and time compared to those of mitigation.

25.8.2. Regional Key Risks as a Function of Mitigation and Adaptation

The AR4 concluded with an assessment of sector-specific aggregated vulnerability as a function of global average temperature. Building on recent additional insights, Table 25-6 shows eight key risks that can be identified with *high confidence* within those sectors based on the multiple lines of evidence presented in the preceding sections.[2]

[INSERT TABLE 25-6 HERE
Table 25-6: Key regional risks from climate change for Australia and New Zealand. Colour bars indicate the degree of risk as a function of increase in global average temperature relative to pre-industrial levels, based on the studies assessed and expert judgement, without (left bar) and with (right bar) effective adaptation[*]. Other relevant climate

drivers and assumptions underpinning this assessment are indicated by symbols, in approximate order of priority**. Where climate projections span a particularly wide range, risks are shown in two pairs, without and with effective adaptation, for the best and worst case projections based on current climate models and emissions scenarios***.]

[FOOTNOTE 2: Entries in Table 25-6 have been selected using the framework for identifying key risks set out in WGII AR5 Chapter 19. This combines consideration of biophysical impacts, their likelihood, timing and persistence, with vulnerability of the system affected, based on the exposure, magnitude of harm, significance of the system and its ability to cope with or adapt to projected biophysical changes.]

These risks differ in the degree to which they can be managed via adaptation and mitigation, and some are more likely to be realized than others, but all warrant particular attention from a risk-management perspective. One set of key risk comprises damages to natural ecosystems (widespread decline of coral reefs and some montane and low-lying ecosystems), which could be delayed by effective global mitigation but now appear very difficult to avoid entirely given narrow coping ranges and limited autonomous adaptive capacity. A second set (increase in wild fire, heat waves, water resources and flood risk) comprises damages that could be severe but can be moderated or delayed by combined global mitigation and a portfolio of adaptation. A third set (coastal damages from accelerated sea level rise, and loss of food production from severe drying in the Murray Darling Basin) comprises impacts where future changes are particularly uncertain and alternative climate scenarios materially affect levels of concern and appropriate adaptation strategies. Even though the worst-case scenarios have low or currently unknown probabilities, the associated impacts would severely challenge adaptive capacity and thus constitute important risks.

By contrast, climate change is also projected to have positive consequences for some sectors and sub-regions of Australasia, at least under scenarios of limited warming associated with effective global mitigation (*high confidence*). Examples include an extended growing season for agriculture and forestry in cooler parts of New Zealand and Tasmania, reduced winter energy demand and illnesses in most of New Zealand and southern states of Australia, and increased winter hydropower potential in New Zealand’s South Island.

The distribution of risks provides *high confidence* that Australia is more vulnerable to climate change than New Zealand due to higher exposure and lower coping thresholds of its ecosystems, water resources and agriculture. However, Australia is making significant investments to better understand its vulnerability and enhance its adaptive capacity, whereas the apparent resilience of New Zealand is based on limited studies in many sectors that have considered neither the full range of future scenarios nor flow-on effects from outside New Zealand. There is high agreement that Australia is the most vulnerable developed country (e.g. Eriksen and Kelly, 2007; Garnaut, 2011; Palutikof, 2010; Seo, 2011), but the quality of evidence for this conclusion remains limited due to limited comparability of country-level vulnerability assessments.

25.8.3. The Role of Adaptation in Managing Key Risks

Two key and related challenges for adaptation are apparent in the region: to identify when and where a departure from incremental to transformative adaptation measures is needed; and, where specific policies to facilitate proactive adaptation are needed to overcome barriers to mainstreamed and autonomous adaptation.

The potential magnitude and rate of change especially under non-mitigation scenarios suggests that incremental and autonomous adaptation will not deliver the full potential of adaptation necessary to address the key risks identified above or to adjust natural and human systems such that they can still function even if some of the key risks are realised (*high confidence*; see also 25.5.2, 25.5.3). Most incremental adaptation measures in natural ecosystems focus on reducing other non-climate stresses (25.6.2, 25.6.3), but even with scaled-up efforts the conservation of the current state and composition of natural ecosystems most at risk appears to be increasingly infeasible. Maintenance of key ecosystem functions and services and individual species would require a radical reassessment of conservation values and practices related to translocation of species and the values placed on “introduced” species (Steffen *et al.*, 2009). Divergent views regarding intrinsic and service values of individual species and ecosystems imply that a proactive discussion of these issues is necessary to enable effective decision-making and resource allocation.

In human systems, incremental adjustment of current planning approaches for floods, fire, drought, water resources and coastal hazards will increase resilience to climate variability and could be sufficient under scenarios of limited climate change associated with strong global mitigation or low climate sensitivity and limited precipitation changes (*medium confidence*). However, this approach creates a path-dependency that becomes increasingly risky and costly to overcome under scenarios of greater change. Transformative adaptation becomes more critical where long life- or lead-times are involved, and where high up-front costs or multiple interdependent actors create barriers that require coordinated and proactive interventions (Productivity Commission, 2012; Stafford-Smith *et al*., 2011). In these situations, deferring adaptation decisions due to limited knowledge about the future will not necessarily minimise costs nor ensure adequate flexibility for future responses (see e.g. 25.5.3, and Boxes 25-3, 8-10). Nonetheless, thresholds and any need for policy support inevitably depend upon social, institutional and cultural values and priorities, including perceptions of the risks associated with change itself.

Further scientific research will offer only limited assistance for identifying thresholds between incremental to transformative adaptation, not only because of persistent uncertainty in impacts projections and incomplete understanding of vulnerability and adaptive capacity, but also because societal values strongly influence whether any particular adaptation route and outcome is considered successful. Nonetheless, there are key areas where lack of scientific knowledge is a key impediment to effective near-term adaptation, and where targeted research offers a realistic chance to reduce this impediment; these areas are now listed in section 25.9.

25.9. Key Uncertainties, Knowledge Gaps, and Research Needs

The wide range of projected rainfall changes (both averages and extremes; 25.3.3, 25.3.4) is a key uncertainty that affects the severity of impacts and scale and urgency of adaptation in agriculture, forestry, water resources, some ecosystems, wildfire risks and flood risks to infrastructure (25.6.1, 25.6.2, 25.6.4, 25.6.5, Boxes 25-7, -9, -10).

While adaptive and real options-based management can help robust near-term decision-making despite uncertainties (25.5.3, Box 25-2), narrowing the range of rainfall projections is critical to support planned adaptation in particular for strategic long-term investments and land-use decisions. For ecosystems, agriculture and forestry, these uncertainties are compounded by limited knowledge of plant physiological responses to elevated CO_2, including for new cultivars and invasive species (25.6.3-5, Box 25-4). Progress in these areas will rely on improving understanding of the differences among climate and plant physiological models, observation systems and experiments, but while uncertainties are large, adaptation decisions should be based on an understanding of the full range of possible futures rather than only median estimates. Deep and persistent uncertainty about the rate and magnitude of long-term sea level rise in different regions (AR5 WGI Chap13) creates similar challenges for coastal adaptation and strategic decisions spanning protection, accommodation and retreat (Box 25-2).

Understanding of ecological and physiological thresholds that, once exceeded, would result in rapid changes in ecosystems and their services, is still limited, with noticeably sparse literature in New Zealand (25.6.2, 25.6.3). In the near term, research to evaluate the role of ecosystems in ameliorating impacts on other systems (e.g. water resources and soil erosion) may be most tractable (generally termed ecosystem-based adaptation), and also offer decision-support for regional integration of adaptation and mitigation responses that can identify and exploit synergies rather than conflicts in various policy goals and community values (25.7, Box 25-11).

Vulnerability of human and managed systems depends critically on future socio-economic characteristics as well as potential impacts on physical and biological systems. Yet research into psychological, social and cultural dimensions of vulnerability and their potential change over time is only emerging and poorly integrated with quantitative bio-physical impacts studies. This limits confidence in our understanding of future vulnerabilities and the feasibility and effectiveness of adaptation strategies (25.4). Similarly, understanding of social, cultural and policy drivers and constraints to adaptation, and the role of policy and regulatory environments and market dynamics for adaptation by different sections of the community, is only beginning to attract concerted research (25.5, Box 25-8), although major research investments in Australia are beginning to address many of these gaps.

A key gap remains in understanding the flow-on effects of international responses to climate change (impacts, adaptation and mitigation) and their interactions with the domestic impacts and adaptation options that are the focus of this assessment. Limited existing studies suggest that the scale of flow-on effects could be at least as large as domestic impacts in some economically important sectors, suggesting an urgent need to integrate scenarios of global change into studies of local impacts and responses.

Frequently Asked Questions

FAQ 25-1: How will climate change in Australasia?

The observed trend of warming in Australasia will continue, with projected increases in land and sea surface temperatures of 2 to more than 5ºC by the end of the 21st century. The amount of warming depends on future greenhouse gas emissions but the wide range also reflects uncertainties in climate model projections. Warming will be greater in inland Australia than the coast, and in the north more than the south, and less in New Zealand because of the moderating influence of the southern ocean. This is expected to result in more hot extremes and fewer cold extremes.

Uncertainty in future rainfall projections is greater than for temperature, and climate models do not always agree on the direction of rainfall change. In eastern and northern Australia, for example, projections of change in future mean annual rainfall range from a decrease of 30% to an increase of 20% by 2070. In southern Australia, however, many climate models project a decline in future mean annual rainfall and cool season rainfall in particular (when most of the runoff occurs) - up to about 30% by 2070. In New Zealand, the majority of climate models project that, on average, the north and east will become drier and the south and west will become wetter.

The future climate in Australasia will continue to exhibit high seasonal, annual and decadal variability but, where mean rainfall is projected to decrease, future droughts are expected to be more frequent, longer and more severe, and fire weather is also projected to increase especially in areas that are already dry. Episodes of heavy rainfall are expected to become more intense and frequent as warmer air can hold more moisture. The strongest tropical cyclones are thought to increase in intensity but the overall number of cyclones making landfall is projected to decrease. Sea level will continue to rise for many centuries, but the rate is still very uncertain and ranges from less than half a metre to potentially more than a metre by 2100, and there may be considerable regional variability.

FAQ 25-2: How will climate change affect Australasia?

Climate change will affect many sectors. Australia is more vulnerable to climate change than New Zealand because many ecosystems, agricultural production and urban infrastructure in Australia are exposed to greater changes and are closer to coping thresholds.

Some impacts are very difficult to avoid entirely, even with stringent global mitigation. These include the collapse of coral reef systems in north-eastern and western Australia (driven by rising sea surface temperature and ocean acidification) and loss of montane ecosystems (driven by rising temperature, loss of seasonal snow cover and increased fire risk). Other impacts have the potential to be severe but can be moderated or delayed by a combination of global mitigation and regional adaptation measures. Some examples of such risks include: increased flood damage to settlements and infrastructures; increased health impacts and infrastructure failure during heat waves; increased damages to ecosystems and risk to human life, properties and infrastructures from wildfires; increased damages to coastal infrastructure and low-lying ecosystems from sea level rise; and decline in water availability in south-eastern and south-west Australia affecting urban water use, food production and ecosystems. Lastly, some impacts may be either moderate or very severe, depending on how the climate system responds to increasing greenhouse gas concentrations: these include damages to coastal infrastructure and low-lying ecosystems if sea level rise is near the upper end currently considered possible (more than 1 m by 2100), and severe reductions in food production particularly in the Murray-Darling Basin if rainfall reductions are at the dry end of the range of projections.

Some sectors in some locations have the potential to benefit from climate change, such as reduced winter illnesses in New Zealand and southern Australia, reduced energy demand for winter heating, increased agricultural production under higher CO_2 and longer growing seasons in cooler parts of New Zealand, and increased winter hydropower potential in New Zealand.

FAQ 25-3: Why are impacts of climate change different across Australasia?

Climate change will affect different sectors and regions differently because (i) the baseline climate is very different and variable across Australasia, (ii) the potential changes in the future climate vary depending on the region, (iii) some ecosystems and species can cope with climate change better than others, and (iv) impacts on human systems will depend on where people live and where infrastructures have been and are being built.

For example, warming will be greater in inland Australia than the coast and in the north than the south, and less in New Zealand because of the moderating influence of the southern ocean. Rainfall projections indicate that southern Australia is likely to be drier in the future but the direction of change elsewhere is uncertain, and New Zealand may be drier in the north and east and wetter in the south and west. Cold is an important limitation on pasture production in southern New Zealand, whereas in many parts of Australia and some parts of New Zealand production is limited more by available rainfall.

The projected decline in water availability in southern Australia will significantly affect urban water use in cities and regional centres, and food production and ecosystems in the Murray-Darling Basin, Victoria, far south-west Australia, and in some parts of New Zealand. The projected increase in flood risk will mainly affect cities and regional centres, the projected increase in the intensity of the strongest cyclones, while uncertain, would affect coastal settlements in north-eastern and northern Australia, sea level rise will affect coastal settlements and infrastructures, and increased wildfire risk will affect people, properties and infrastructures in south-eastern Australia. The higher temperatures will increase health risks from summer heat waves but may also reduce winter illnesses in New Zealand and southern Australia. Likewise, higher temperatures will also benefit some agricultural production in colder regions.

The ability of Australian and New Zealand species to cope with the impacts of climate change will vary, depending on their exposure to change, their particular traits, and their capacity to adapt, either via genetic change, ability to cope in situ, or migration to new, more climatically suitable habitats. Some very negative impacts will be very difficult to avoid entirely, such as the severe degradation of coral reefs systems in north-eastern and western Australia and loss of montane ecosystems in the higher regions of eastern Australia and potentially New Zealand, and some low-lying coastal ecosystems. Human-assisted adaptation options, such as reducing other environmental stresses, and increasing protection and connectivity in landscapes, will improve resilience of natural ecosystems and increase adaptive capacity, but are unlikely to offset completely the expected negative impacts.

FAQ 25-4: How is Australasia adapting to climate change?

Adaptation capacity is generally high in many human systems, but implementation of effective adaptation responses faces many constraints. These include uncertainty in the projected impacts and limited resources to develop and implement adaptation plans, but also lack of coordination and sometimes conflicting goals at different levels of governments, absence of binding guidance on principles and priorities that allow vocal local interests to influence community decisions, and different beliefs concerning climate change, values and attitudes towards risk. Nevertheless, adaptation is becoming more prevalent and embedded in planning processes, albeit mostly at the conceptual rather than the level of implementation.

Adaptation in many sectors is driven by a range of stressors where climate change is only one consideration. For example, the desalinisation plants were built in Perth to cope with the shift in hydrologic regime and in Melbourne to cope with the long persistent drought, and projections of population growth and decline in future water availability. The water reforms in south-eastern Australia are aimed at redressing the balance between irrigation and environmental water use and developing water sharing plans that can, at least in principle, cope with current and future climates. Adaptation to increased flood risks in New Zealand and Australia is happening through updating guidelines for estimating future flood risk, enhancing coping capacity of buildings in flood prone areas and avoiding risk through managed relocation. In some cases these measures respond to an already high risk of flooding even under the current climate. Adaptation of terrestrial and freshwater ecosystems is aimed mainly at delivering multiple benefits through reducing other environmental stressors. Planning for sea level rise is becoming more commonplace, but conflicts often arise as to whether this should be achieved by enhancing protection measures, increasing the ability to cope with occasional inundation, or gradually shifting buildings as shorelines erode. Early warning systems are aiming to help health services and communities prepare for and cope with heat waves, and options to reduce heat stress through altered building and urban design are being considered.

Current adaptation plans and incremental adjustment of management practice will probably allow most sectors to cope with the lower end of projected changes in the near future. However, adaptation which involves major change in practices may be needed where long lead times are involved, particularly if the higher end of future projections are realised. A key challenge for many communities and industries is to decide when and how to make a switch from stepwise to transformative adaptation measures, not least because the risks and benefits of doing so will be viewed very differently by different parts of society depending on their beliefs and value systems.

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Table 25-1: Examples of detected changes in species, natural and managed ecosystems, consistent with a climate change signal, published since the AR4. Confidence in detection is based on length of study, amount of data, and natural variability in the species or system. Confidence in the role of climate change for each individual example is based on the extent to which other confounding or interacting non-climate factors have been considered and ruled out as contributing to the observed change.

Type of change and nature of evidence	Examples	Time scale of observations	Confidence in detection of change	Potential climate change driver/s*	Confidence in role of climate change
Morphology Limited evidence (1 study)	Declining body size of southeast Australian passerine birds, equivalent to ~7° latitudinal shift (Gardner *et al.*, 2009)	~100 years	**Medium** trend significant for 4 out of 8 species	Warming air temperatures ~1.0°C over same period	**Medium** Nutritional cause discounted
Geographic distribution High agreement, robust evidence for many marine species & flying terrestrial species	Southerly range extension of the barrens-forming sea urchin *Centrostephanus rodgersii* from the NSW coast to Tasmania; flow on impacts to marine communities including lobster fishery; shift of 160 km per decade over 30 years (Ling, 2008; Ling *et al.*, 2008), (Banks *et al.*, 2010; Ling *et al.*, 2009)	~30-50 years (first recorded in Tasmania late 1970s)	**High**	Increased sea surface temperature (SST) Ocean warming in in SE Australia, increased southerly penetration of the East Australian Current (EAC), 350 km over 60 years	**High**
	Forty-five fish species, representing 27 families (about 30% of the inshore fish families occurring in the region), exhibited major distributional shifts in Tasmania (Last et al 2011)	distributions from late 1880s, 1980s and present (1995-now)	**High**	Increased SST SE Australia, increased southerly penetration of EAC	**Medium** Changed fishing practices have potentially contributed to trends
	Southward range shift of intertidal species (average minimum distance 116 km) off west coast of Tasmania; 55% species recorded at more southerly sites, only 3% species expanded to more northerly sites (Pitt *et al.*, 2010)	~50 years Sites resampled 2007-2008, compared to 1950s	**Medium**	Increased SST in SE Australia (average 0.22°C per decade), increased southerly penetration of the EAC, 350 km over 60 years	**Medium**

Life cycles Robust evidence, medium agreement; increasing documentation of advances in phenology in some species (mainly migration and reproduction in birds, emergence in butterflies, flowering in plants) but also significant trends towards later life cycle events in some taxa	Significant advance in mean emergence date of 1.5 days per decade (1941-2005) in the Common Brown butterfly *Heteronympha merope* in Australia (Kearney *et al*., 2010a)	65 years	**High** Advance consistent with physiologically based model of temperature influence on development	Increase in local air temperatures of 0.16ºC per decade (1945-2007)	**High**
	Earlier wine-grape ripening at 9 of 10 sites in Australia (Webb et al 2012)	Multiple time periods up to 64 years (average 41 years)	**High**	Increased length of growing season, increased average temperature and reduced soil moisture	**Medium** Changed husbandry techniques, resulting in lower crop yields, may have contributed to trend
	Timing of migration of glass eels, *Anguilla* spp. advanced by several weeks in Waikato River, North island, New Zealand (Jellyman *et al*., 2009)	30 years (2004-2005 compared to 1970s)	**Medium**	Warming water temperatures in spawning grounds	**Low** Changes in discharge discounted as contributing factor
Marine productivity Limited evidence, medium agreement	Otolith ("ear stone") analyses in long-lived Pacific fish indicates significantly increased growth rates for shallow-water species (<250m) (3 of 3 species), reduced growth rates of deep-water (>1000m) species (3 of 3 species); no change observed in the 2 intermediate-depth species (Thresher *et al*., 2007)	Birth years ranged 1861-1993 (fish 2-128 years old)	**High**	Increasing growth rates in species in top 250m associated with warming SST, declining growth rates in species >1000m associated with long-term cooling (as indicated by Mg/Ca ratios and delta^{18}O in deep water corals)	**Medium** Changed fishing pressure may have contributed to trend
	~50% decline in growth rate and biomass of spring phytoplankton bloom in western Tasman Sea (Thompson *et al*., 2009)	60 years (1997-2007)	**High**	Increased SST and extension EAC associated with reduced nutrient availability	**Medium**

Vegetation change Limited agreement & evidence; interacting impacts of changed land practices, altered fire regimes, increasing atmospheric CO_2 concentration and climate trends difficult to disentangle	Expansion of monsoon rainforest at expense of eucalypt savanna and grassland in Northern Territory, Australia (Banfai and Bowman, 2007) (Bowman *et al.*, 2010)	~40 years	**Medium**	Increases in rainfall (25.3.4) and atmospheric CO_2	**Medium** Changes in fire regimes and land management practices may have contributed to trend
	Net increase in mire wetland extent (10.2%) and corresponding contraction of adjacent eucalypt woodland in seven sub-catchments in south east Australia (Keith *et al.*, 2010)	Weather data covers 40 years; vegetation mapping from 1961-1998	**Medium**	Decline in evapo-transpiration	**Low** Resource exploitation, fire history and autogenic mire development discounted
Freshwater communities Limited evidence (1 study)	Decline in families of macroinvertebrates that favour cooler, faster-flowing habitats in NSW streams and increase in families favouring warmer and more lentic conditions (Chessman, 2009)	13 years (1994-2007)	**Medium**	Increasing water temperatures and declining flows	**Low** Variation in sampling, changes in water quality, impacts of impoundment and water extraction may have contributed to trends
Disease Limited evidence, robust agreement	Emergence and increased incidence of coral diseases including white syndrome (since 1998), and black band disease (since 1993-4) (Bruno *et al.*, 2007), (Sato *et al.*, 2009), (Dalton *et al.*, 2010)	1998 onwards	**Medium**	Increasing SST	**High**
Coral reefs Robust evidence & agreement	Nine mass bleaching events since 1979 (see 25.6.3, AR5 WGII Chap30);	1979 onwards	**High**	Increasing SST	**High**
	Calcification of *Porites* on GBR declined 21% (1971-2003) (n=4 reefs); (Cooper *et al.*, 2008), 14.2% (1990-2005) (n=69 reefs) (De'ath *et al.*, 2009)	1971-2003; 1961-2005	**High**	Increasing ocean acidification in combination with increasing SSTs	**High** Changes in water quality discounted

*See Section 25.3 for details of associated climate trends.

Table 25-2: Decisions in the agricultural sector with the potential to be influenced by global change and the information needed to inform these decisions.

Decisions	Decision maker	Impact information required
On-farm management	Land managers	Local and enterprise specific impacts
Land use particularly perennial crops	Land managers	Future performance of crops and cultivars
Investment in technology development	Research funders & providers: Agribusinesses	Future-proofing technologies
Location/capacity of agricultural infrastructure	Agribusinesses	Regional enterprise specific impacts
Investment in regional infrastructure	Central and local government	Regional enterprise specific impacts
Biosecurity priorities	Central and local government: Land managers	Changes in pests and diseases
Water management	Central and local government: Land managers	Future water demand from agricultural sector
Property purchase/sale	Landowners: Banks	Regional enterprise specific impacts
National and international policy setting	Central government	National impacts

Table 25-3: Examples of observed and potential consequences of climate change for invasive and pathogenic species relevant to Australia and New Zealand (categories from Hellman *et al*., (2008)).

Impact	Observed	Projected	Entities at risk	Reference
Altered mechanisms of transport and introduction		Increased risk of introduction of Asiatic psyllid, (*Diaphorina citri*) vector of the Citrus Greening Disease	Australian citrus industry; native citrus and other Rutaceae; endemic psyllid fauna (via increased competition)	(Finlay *et al*., 2009)
Altered distribution of existing invasive & pathogenic species	Increased incidence of *Nassella neesiana* between 1987 and 2005 in Marlborough, NZ.	*N. neesiana* (Chilean needle grass) -increased droughts favour establishment	Managed pasture in NZ	(Bourdôt *et al*., 2010)
		Increased distribution of root pathogen *Phytophthora cinnamomi* in Australia	Native vegetation communities	(Pritchard, 2011)
		Warming and drying could promote the spread of invasives such as *Pheidole megacephala* and provide suitable conditions for other exotic ant species	agricultural and natural ecosystems	(Harris and Barker, 2007).
Altered climatic constraints on invasive & pathogenic species		Expansion of Queensland fruit fly distributions southwards (*Bactrocera tryoni*)	Horticulture	(Sutherst *et al*., 2000)
		Increased vulnerability of frogs to chytridiomycosis by *Batrachochytrium dendrobatadis* under warmer conditions	Native fauna	(Laurance, 2008)
Altered impact of existing invasive & pathogenic species		*Fusarium pseudograminearum* causing crown rot increases under elevated CO_2	Wheat	(Melloy *et al*., 2010)
Altered effectiveness of control strategies		Reduction in control by natural enemies of Light brown apple moth, *Epiphyas postvittana* (Walker) due to asynchrony of life cycles and loss of host species for parasitoids	Australian horticulture	(Thomson *et al*., 2010)
		Reduced effectiveness of bicontrol of the Lucerne weevil, *Sitona discoideus* by the wasp *Microctonus aethiopoides*. Climate in East of NZ is becoming more similar to South Australia where the wasp is ineffective	Lucerne in Eastern regions of NZ	(Goldson, 2007)
		Reduced effectiveness of herbicide (glyphosate) control of some invasive exotic C4 grasses	Crop and pasture in Australia and NZ	(Manea *et al*., 2011)

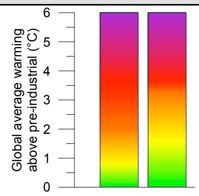
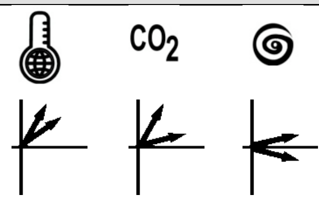
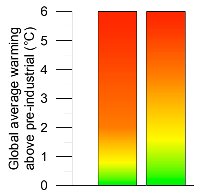
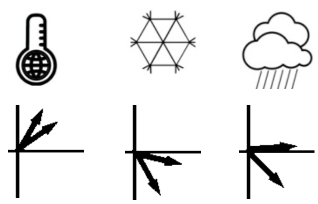
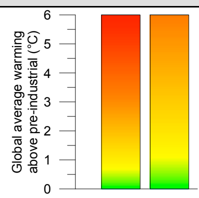
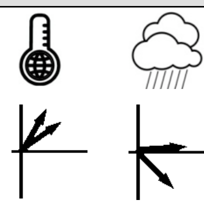
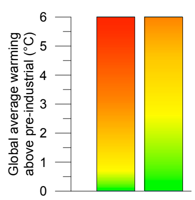
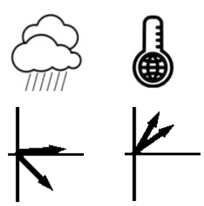
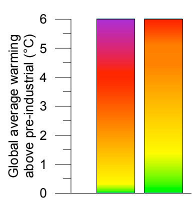
Table 25-4: Examples of interactions between adaptation measures in different sectors. In each case, impacts or adaptation responses in one sector have the potential to conflict (cause negative impacts) or be synergistic (have co-benefits) with adaptation responses in another sector, or with another type of response in the same sector.

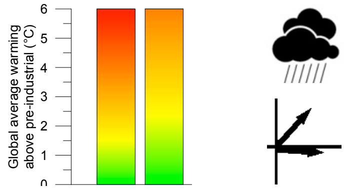
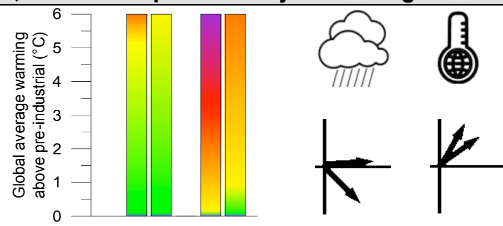
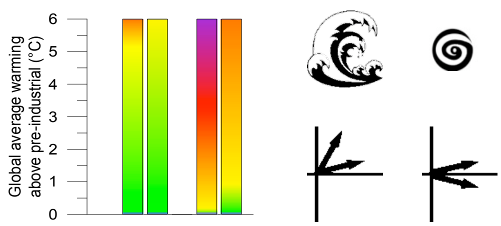
Primary driver	Sector/s affected	Examples
Reduction of bushfire risk	Biodiversity, tourism	Potential for greater conflict between conservation managers and other park users in Kosciuszko National Park if increasing fire incidence causes park closures, either to reduce risk, or to rehabilitate vegetation after fires (Wyborn, 2009). Objectives of the Wildfire Management Overlay (WMO) in Victoria conflict with vegetation conservation (Hughes and Mercer, 2009).
Reduction of bushfire risk and risk of energy transmission interruptions	Energy, biodiversity	Underground cabling would reduce susceptibility of transmission networks to fire but also reduce the risk of fire ignition, with benefits to ecosystems and society; constraints include significant investment cost, ownerships and lack of an overarching national strategy (ATSE, 2008; Linnenluecke *et al*., 2011; Parsons Brinkerhoff, 2009).
Protection of beaches and coastal infrastructure	Biodiversity	Seawalls may provide habitat but these communities have different diversity and structure to those developing on natural substrates (Jackson *et al*., 2008); groynes potentially alter beach fauna diversity and community structure (Walker *et al*., 2008).
Reduction of risk from rising sea level	Indigenous communities	Potential cultural, land rights and economic issues are involved in prospective relocation of Torres Strait islander communities to alternative islands (Green *et al*., 2010b).
Increased water security, water storage	Biodiversity	Australia has highest levels of per capita water storage anywhere in the world (ABS, 2012), buffering urban settlements and agricultural systems against low runoff and high variability in river flow. Altered flow regimes have significant negative impacts on freshwater ecosystems (Bond *et al*., 2008; Kingsford, 2011; Pittock, 2008). Discharge from desalination plants (e.g. in Perth and Sydney) can lead to substantial local increases in salinity and temperature, and the accumulation of metals, hydrocarbons and toxic anti-fouling compounds in receiving waters (Roberts *et al*., 2010).

Table 25-5: Examples of interactions between adaptation and mitigation measures (green rows denote synergies where multiple benefits may be realized, orange rows denote potential tradeoffs and conflicts).

Primary driver	Sector affected	Interaction
Adaptation to decreasing snowfall	Biodiversity, energy use, water use	Artificial snowmaking in the Australian Alps estimated to require large additional energy and water resources by 2020 of 2500-3300 ML of water per month, more than half the average monthly water consumption by Canberra in 2004-05. Increased use of snow manipulation techniques likely to have negative effects on vegetation, soils and hydrology of subalpine-alpine areas (ABS, 2012; Morrison and Pickering, 2011; Pickering and Buckley, 2010).
Increased temperatures	Energy use	Rising temperatures reduce annual average demand and CO_2 emissions from thermal power generation in winter, but increase demand in summer where cooling needs are met by increased air conditioning (Stroombergen *et al*., 2006; Thatcher, 2007; Wang *et al*., 2010b)
Renewable wind energy production	Biodiversity	Wind-farms can have localised negative effects on bats and birds. However, risk assessment of the potential negative impacts of wind turbines on threatened bird species in Australia indicated low to negligible impacts on all species modelled (Smales, 2006).
Urban densification	Biodiversity, water, health	Higher urban density can reduce energy consumption from transport and infrastructure but result in loss of permeable surfaces and tree cover, intensifying flood risks, and exacerbating discomfort and health impacts of hotter summers (Hamin and Gurran, 2009).
Increased temperatures	Energy use	Reducing peak energy demand through passive housing design and other demand management measures could reduce vulnerability of electricity networks to climate extremes and associated adaptation costs (Nguyen *et al*., 2010; Parsons Brinkerhoff, 2009).
Renewable energy from second-generation biofuels	Biodiversity, rural livelihoods, agriculture	New crops such as oil mallees or other eucalypts may provide multiple benefits, especially in marginal areas, displacing fossil fuels or sequestering carbon, generating income for landholders (essential oils, charcoal, bio-char, biofuels), and providing ecosystem services (Cocklin and Dibden, 2009; McHenry, 2009).
Reduction of emissions from fires	Biodiversity indigenous and rural livelihoods	Improved management of savanna fires could reduce emissions by 13 million tonnes CO_2 p.a (90% of current levels) over 2010 – 2050 (Garnaut, 2011). Projects such as the Western Arnhem Land Fire Abatement project applies fire management practices across 28,000 km^2, demonstrating feasibility of reducing extent of late dry season fires. Improved savanna management has biodiversity benefits as well as indigenous employment
Reduction in methane emissions	Biodiversity	Control of exotic vertebrate pests such as camels aimed at reducing methane emissions could have significant biodiversity benefits as these animals cause significant economic and biodiversity damage. Currently over 1 million feral camels in Australia, with the population projected to double over the next decade (NRMMC, 2010). Economic benefits of reduced grazing competition, infrastructure damage and GHGs could outweigh costs of camel reductions (Drucker *et al*., 2010).
Water security	N_2O emissions	Improving efficiency of irrigation systems in response to reduced water availability may also help to reduce emissions of nitrous oxide from soils (Garnaut, 2011).

Table 25-6: Key regional risks from climate change for Australia and New Zealand. Colour bars indicate the degree of risk as a function of increase in global average temperature relative to pre-industrial levels, based on the studies assessed and expert judgement, without (left bar) and with (right bar) effective adaptation*. Other relevant climate drivers and assumptions underpinning this assessment are indicated by symbols, in approximate order of priority**. Where climate projections span a particularly wide range, risks are shown in two pairs, without and with effective adaptation, for the best and worst case projections based on current climate models and emissions scenarios***.

Key Regional Risk	Risk without and with effective adaptation	Key Climate Drivers and Trends	Key characteristics of adaptation options and context for adaptation
Potential impacts that can be delayed but now appear very difficult to avoid entirely, even with combined global mitigation and proactive adaptation			
Collapse of coral reef systems in north-eastern and western Australia *[Box 5.3, 25.6.3, chapter 30]*			Limited to enhancing water quality and limiting other stresses
Loss of montane ecosystems and some endemic species in Australia *[25.6.2]*			Reducing other stresses provides immediate co-benefits; need to consider translocation and migration
Impacts that have the potential to be severe but can be moderated or delayed significantly by combined global mitigation and a portfolio of available adaptation measures			
Increased damages to ecosystems and settlements, economic losses and risks to human life from wildfires [25.3.8, 25.6.7, 25.6.9, Box 25-7]			Part of integrated landscape management; trade-offs exist between different management objectives
Systematic constraints on water resource use in southern Australia [25.3, 25.6.1, Box 25-3]			Water resources already stressed in many locations; need to combine demand and supply mechanisms
Increase in morbidity and infrastructure failure during heat waves in Australia [25.6.9]			Linked to social dynamics and ageing population in cities; transport and power infrastructure already at coping limit in many regions

Increased frequency and intensity of flood damage to settlements and infrastructure [25.3.4, Box 25-2, 25.6.3, Boxes 25-9, -10]		Adaptation deficit in some regions to current flood risk; adaptation needs to consider land-use planning to ensure flexibility
Potential impacts that have a low or currently unknown probability but cannot be ruled out even under mitigation scenarios, and would present major challenges if realized		
Significant reduction in food production particularly in the Murray-Darling Basin if scenarios of severe drying were realised [25.3.3, 25.6.12, 25.6.35, Box 25-6]		Immediate co-benefits to manage over-allocated resource and balance competing demands
Widespread damages to coastal infrastructure and low-lying ecosystems if sea level were to exceed 1m [Box 25-2, 25.3.7, 25.6.2, 25.6.3, 25.6.10]		Adaptation deficit in some regions to current coastal erosion and flood risk; adaptation needs to consider land-use planning to ensure flexibility

* Graphical representation of the degree of risk: *fully realised* *high* *medium* *low*

** Symbols representing key climate drivers: = average temperature; = heat waves; = CO_2 concentration; = precipitation; = extreme precipitation; = damaging cyclone activity; = snow cover; = sea level. Arrows represent the direction and indicative magnitude of change under different climate models and emissions scenarios (CMIP3, CMIP models and RCP emissions/concentration scenarios). Arrows show the direction and indicative magnitudes of change over the 21st century under different scenarios and models.

*** For rainfall, best and worst case is defined based on approximately the 10 and 90 percentile range of current model projections and RCP emissions scenarios. For sea level, the best case is assumed to be a 0.39 m rise by 2100 (mid-range RCP 2.6); the worst case is assumed here to be a 1.5 m rise by 2100 (semi-empirical models, RCP 8.5), and includes consideration of on-going increases in sea level beyond 2100. See AR5 WGI Chap13 for more details.

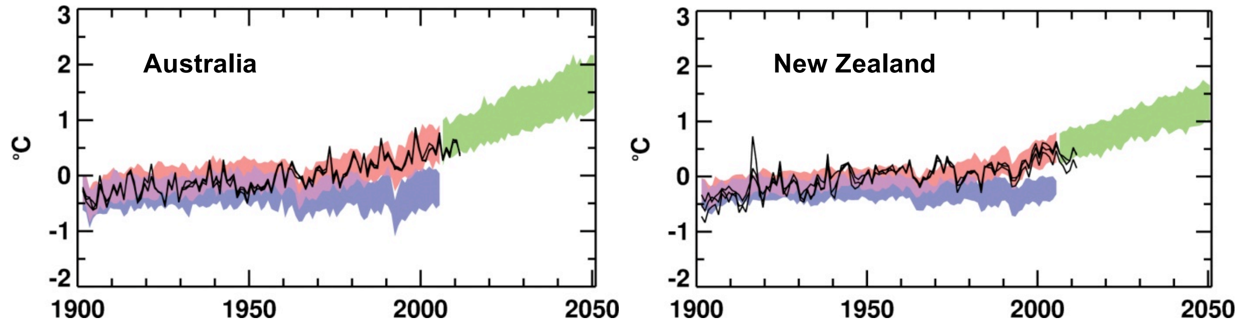


Figure 25-1: Observed and modelled past and projected future annual average temperatures over Australia (left) and New Zealand (right). The areas covered include both land (mainland and Cocos, Christmas, Norfolk, Heard and McDonald Islands for Australia, and Cook Islands, Niue and Tokelau for New Zealand) and exclusive economic zone territory. Black lines show annual average values from observational datasets, namely GISTEMP (Hansen *et al.*, 2010), HadCRUT3 (Brohan *et al.*, 2006), and MLOST (Smith *et al.*, 2008b). The coloured bands show the 10-90th percentile range of annual average values from 32 simulations from 12 climate models from the CMIP3 and CMIP5 projects (Meehl *et al.*, 2007; Taylor *et al.*, 2011a) run under different scenarios of changes in external drivers. The pink band shows simulations driven with observed changes in all known external drivers over the 1901-2005 period; the blue band shows simulations driven with observed changes in natural external drivers only (volcanic eruptions and changes in solar irradiance). The green band shows simulations running over 2006-2050 driven under either the SRES A1B (for CMIP3) or the RCP4.5 (for CMIP5) emissions scenarios. All regional values are plotted as anomalies relative to their 1901-2005 average in the case of observed data, or from the average of the respective simulations driven with past changes in all known observed external drivers. Observed values suffer in some areas from sparse monitoring coverage.

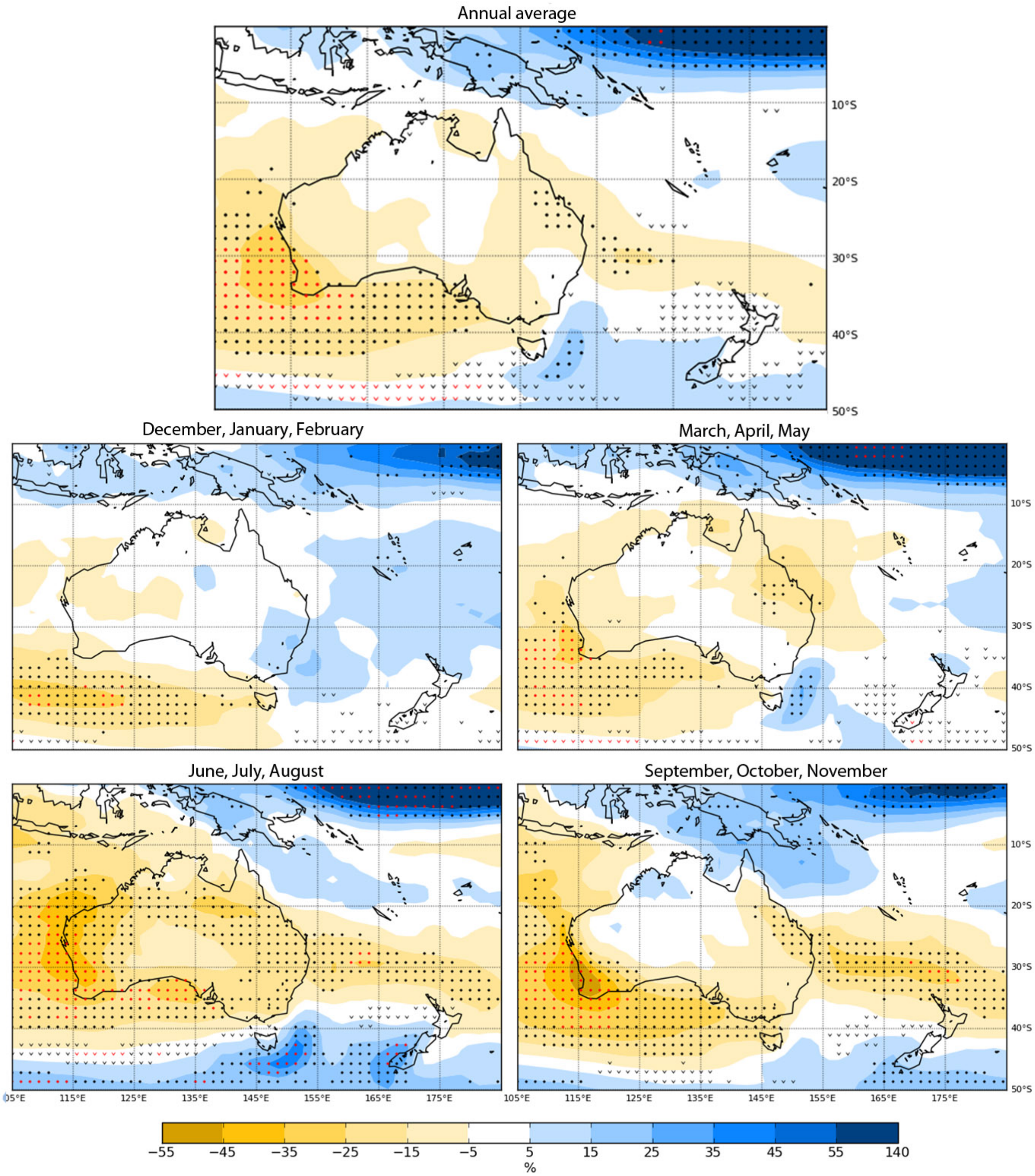


Figure 25-2: Projected multi-model mean change in rainfall for 2080-2099 relative to 1980-1999 for RCP8.5 and 18 CMIP5 models. Dots [carets] indicate where the models agree (>90% red; >67% black) that there will [will not] be a substantial (>10%) change (from Moise *et al.*, 2012).

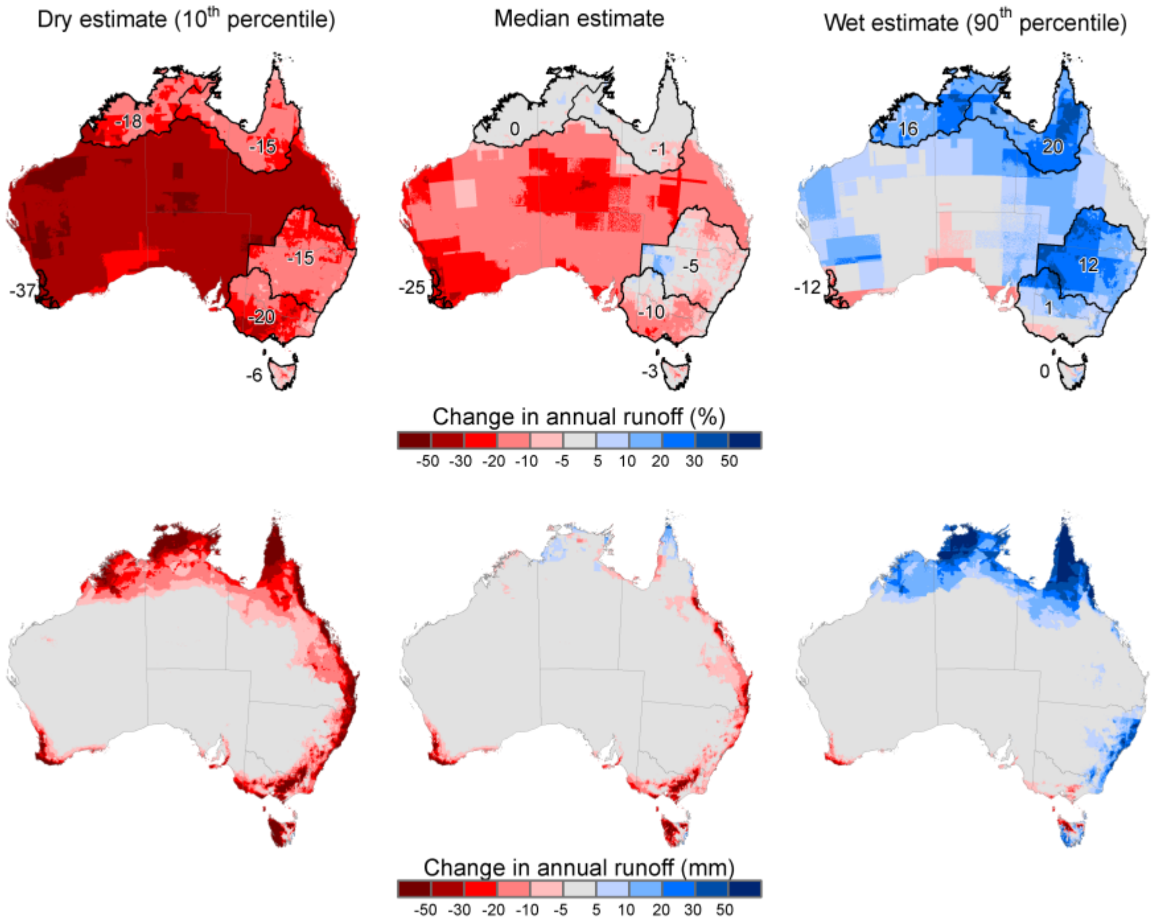


Figure 25-3: Projected changes in mean annual runoff for a 1°C global average warming. Figures show changes in annual run-off (percentage change; top row) and run-off depth (millimetres; bottom row), for median, dry and wet (10th and 90th percentile) range of estimates, based on hydrological modelling using catchment-scale climate data downscaled from AR4 GCMs (Chiew *et al.*, 2009; CSIRO, 2009b; Petheram *et al.*, 2012; Post *et al.*, 2012). Projections for a 2°C global average warming are about twice that shown in the plots (Post *et al.*, 2011). Figure adapted from (Chiew and Prosser, 2011; Teng *et al.*, 2012).