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Australasia

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Frequently Asked Questions

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, increasing greenhouse gas concentrations have contributed to rising average temperature in Australia (*high confidence*) and New Zealand (*medium confidence*) and decreasing rainfall in southwestern Australia (*high confidence*). {25.2; Table 25-1}

Warming is projected to continue through the 21st century (*virtually certain*) along with other changes in climate. Warming is expected to be associated with rising snow lines (*very high confidence*), more frequent hot extremes, less frequent cold extremes (*high confidence*), and increasing extreme rainfall related to flood risk in many locations (*medium confidence*). Annual average rainfall is expected to decrease in southwestern Australia (*high confidence*) and elsewhere in most of far southern Australia and the northeast South Island and northern and eastern North Island of New Zealand (*medium confidence*), and to increase in other parts of New Zealand (*medium confidence*). Tropical cyclones are projected to increase in intensity but remain similar or decrease in numbers (*low confidence*), and fire weather is projected to increase in most of southern Australia (*high confidence*) and many parts of New Zealand (*medium confidence*). Regional sea level rise will *very likely* exceed the historical rate (1971–2010), consistent with global mean trends. {25.2; Table 25-1; Box 25-6; WGI AR5 13.5-6}

Uncertainty in projected rainfall changes remains large for many parts of Australia and New Zealand, which creates significant challenges for adaptation. For example, projections for average annual runoff in far southeastern Australia range from little change to a 40% decline for 2°C global warming above current levels. The dry end of these scenarios would have severe implications for agriculture, rural livelihoods, ecosystems, and urban water supply, and would increase the need for transformational adaptation (*high confidence*). {25.2, 25.5.1, 25.6.1, 25.7.2; Boxes 25-2, 25-5}

Recent extreme climatic events show 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 northeastern Australia (since the late 1970s) and more recently in western Australia. Recent floods in Australia and New Zealand caused severe damage to infrastructure and settlements and 35 deaths in Queensland alone (2011); the Victorian heat wave (2009) increased heat-related morbidity and was associated with more than 300 excess deaths, while intense bushfires destroyed more than 2000 buildings and led to 173 deaths; and widespread drought in southeast Australia (1997–2009) and many parts of New Zealand (2007–2009; 2012–2013) resulted in substantial economic losses (e.g., regional gross domestic product (GDP) in the southern Murray-Darling Basin was below forecast by about 5.7% in 2007–2008, and New Zealand lost about NZ$3.6 billion in direct and off-farm output in 2007–2009). {25.6.2, 25.8.1; Table 25-1; Boxes 25-5, 25-6, 25-8}

Without adaptation, further changes in climate, atmospheric carbon dioxide (CO_2), and ocean acidity are projected to have substantial impacts on water resources, coastal ecosystems, infrastructure, health, agriculture, and biodiversity (*high confidence*). Freshwater resources are projected to decline in far southwest and far southeast mainland Australia (*high confidence*) and for rivers originating in the northeast of the South Island and east and north of the North Island of New Zealand (*medium confidence*). Rising sea levels and increasing heavy rainfall are projected to increase erosion and inundation, with consequent damages to many low-lying ecosystems, infrastructure, and housing; increasing heat waves will increase risks to human health; rainfall changes and rising temperatures will shift agricultural production zones; and many native species will suffer from range contractions and some may face local or even global extinction. {25.5.1, 25.6.1-2, 25.7.2, 25.7.4; Boxes 25-1, 25-5, 25-8}

Some sectors in some locations have the potential to benefit from projected changes in climate and increasing atmospheric CO_2 (*high confidence*). Examples include reduced winter mortality (*low confidence*), reduced energy demand for winter heating in New Zealand and southern parts of Australia, and forest growth in cooler regions except where soil nutrients or rainfall are limiting. Spring pasture growth in cooler regions would also increase and be beneficial for animal production if it can be utilized. {25.7.1-2, 25.7.4, 25.8.1}

Adaptation is already occurring and adaptation planning is becoming embedded in some planning processes, albeit mostly at the conceptual rather than implementation level (*high confidence*). Many solutions for reducing energy and water consumption in urban areas with co-benefits for climate change adaptation (e.g., greening cities and recycling water) are already being implemented. Planning for

reduced water availability in southern Australia and for sea level rise in both countries is becoming adopted widely, although implementation of specific policies remains piecemeal, subject to political changes, and open to legal challenges. {25.4; Boxes 25-1, 25-2, 25-9}

Adaptive capacity is generally high in many human systems, but implementation faces major constraints, especially for transformational responses at local and community levels (*high confidence*). Efforts to understand and enhance adaptive capacity and adaptation processes have increased since the AR4, particularly in Australia. Constraints on implementation arise from: absence of a consistent information base and uncertainty about projected impacts; limited financial and human resources to assess local risks and to develop and implement effective policies and rules; limited integration of different levels of governance; lack of binding guidance on principles and priorities; different attitudes toward the risks associated with climate change; and different values placed on objects and places at risk. {25.4, 25.10.3; Table 25-2; Box 25-1}

Indigenous peoples in both Australia and New Zealand have higher than average exposure to climate change because of a heavy reliance on climate-sensitive primary industries and strong social connections to the natural environment, and face particular constraints to adaptation (*medium confidence*). Social status and representation, health, infrastructure and economic issues, and engagement with natural resource industries 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 communities are vulnerable even to small sea level rises (*high confidence*). {25.3, 25.8.2}

We identify eight regional key risks during the 21st century based on the severity of potential impacts for different levels of warming, uniqueness of the systems affected, and adaptation options (*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 globally effective mitigation and planned adaptation:
  - *Significant change in community composition and structure of coral reef systems in Australia*, driven by increasing sea surface temperatures and ocean acidification; the ability of corals to adapt naturally to rising temperatures and acidification appears limited and insufficient to offset the detrimental effects. {25.6.2, 30.5; Box CC-CR}
  - *Loss of montane ecosystems and some native species in Australia*, driven by rising temperatures and snow lines, increased fire risk, and drying trends; fragmentation of landscapes, limited dispersal, and limited rate of evolutionary change constrain adaptation options. {25.6.1}
- Some impacts have the potential to be severe but can be reduced substantially by globally effective mitigation combined with adaptation, with the need for transformational adaptation increasing with the rate and magnitude of climate change:
  - *Increased frequency and intensity of flood damage to settlements and infrastructure in Australia and New Zealand*, driven by increasing extreme rainfall although the amount of change remains uncertain; in many locations, continued reliance on increased protection alone would become progressively less feasible. {25.4.2, 25.10.3; Table 25-1; Box 25-8}
  - *Constraints on water resources 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 and some are being implemented in areas already facing shortages. {25.2, 25.5.2; Box 25-2}
  - *Increased morbidity, mortality, and infrastructure damages during heat waves in Australia*, resulting from increased frequency and magnitude of extreme high temperatures; vulnerable populations include the elderly and those with existing chronic diseases; population increases and aging trends constrain effectiveness of adaptation responses. {25.8.1}
  - *Increased damages to ecosystems and settlements, economic losses, and risks to human life from wildfires in most of southern Australia and many parts of New Zealand*, driven by rising temperatures and drying trends; local planning mechanisms, building design, early warning systems, and public education can assist with adaptation and are being implemented in regions that have experienced major events. {25.2, 25.6.1, 25.7.1; Table 25-1; Box 25-6}
- For some impacts, severity depends on changes in climate variables that span a particularly large range, even for a given global temperature change. The most severe changes would present major challenges if realized:
  - *Increasing risks to coastal infrastructure and low-lying ecosystems in Australia and New Zealand from continuing sea level rise, with widespread damages toward the upper end of projected sea level rise ranges*; managed retreat is a long-term adaptation strategy for

human systems but options for some natural ecosystems are limited owing to the rapidity of change and lack of suitable space for landward migration. Risks from sea level rise continue to increase beyond 2100 even if temperatures are stabilized. {25.4.2, 25.6.1-2; Table 25-1; Box 25-1; WGI AR5 13.5}

- *Significant reduction in agricultural production in the Murray-Darling Basin and far southeastern and southwestern Australia if scenarios of severe drying are realized*; more efficient water use, allocation, and trading would increase the resilience of systems in the near term but cannot prevent significant reductions in agricultural production and severe consequences for ecosystems and some rural communities at the dry end of the projected changes. {25.2, 25.5.2, 25.7.2; Boxes 25-2, 25-5}

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 an increasing complexity of interactions, particularly at the intersections among water, energy, and biodiversity, 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 within the region, particularly economic impacts on trade-intensive sectors such as agriculture (*medium confidence*) and tourism (*limited evidence*, *high agreement*), but they remain among the least explored issues. {25.7.5, 25.9.1-2; Box 25-10}

Understanding of future vulnerability of human and mixed human-natural systems to climate change remains limited due to incomplete consideration of socioeconomic dimensions (*very high confidence*). Future vulnerability will depend on factors such as wealth and its distribution across society, patterns of aging, access to technology and information, labor force participation, societal values, and mechanisms and institutions to resolve conflicts. These dimensions have received only limited attention and are rarely included in vulnerability assessments, and frameworks to integrate social, psychological, and cultural dimensions of vulnerability with biophysical impacts and economic losses are lacking. In addition, conclusions for New Zealand in many sectors, even for biophysical impacts, are based on limited studies that often use a narrow set of assumptions, models, and data and hence have not explored the full range of potential outcomes. {25.3-4, 25.11}

25.1. Introduction and Major Conclusions from Previous Assessments

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.

Principal findings from the IPCC Fourth Assessment Report (AR4) for the region were (Hennessy et al., 2007):

- Consistent with global trends, Australia and New Zealand had experienced warming of 0.4°C to 0.7°C since 1950 with changed rainfall patterns and sea level rise of about 70 mm across the region; 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 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 the 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, particularly for water security, coastal development, biodiversity, and major infrastructure, but impacts on agriculture and forestry would be variable across the region, including potential benefits in some areas.
- Vulnerability would increase mainly due to an increase in extreme events; human systems were considered to have a higher adaptive capacity than natural systems.
- Hotspots of high vulnerability by 2050 under a medium emissions scenario included:
  - Significant loss of biodiversity in areas such as alpine regions, the Wet Tropics, the Australian southwest, Kakadu wetlands, coral reefs, and sub-Antarctic islands
  - Water security problems in the Murray-Darling basin, southwestern Australia, and eastern New Zealand
  - Potentially large risks to coastal development in southeastern Queensland and in New Zealand from Northland to the Bay of Plenty.

25.2. Observed and Projected Climate Change

Australasia exhibits a wide diversity of climates, such as moist tropical monsoonal, arid, and moist temperate, including alpine conditions. Key climatic processes are the Asian-Australian monsoon and the southeast trade winds over northern Australia, and the subtropical high pressure belt and the mid-latitude storm tracks over southern Australia and New Zealand. Tropical cyclones also affect northern Australia, and, more rarely, ex-tropical cyclones affect some parts of New Zealand. Natural climatic variability is very high in the region, especially for rainfall and over Australia, with the El Niño-Southern Oscillation (ENSO) being the most important driver (McBride and Nicholls, 1983; Power et al., 1998; Risbey et al., 2009). The southern annular mode, Indian Ocean Dipole, and the Inter-decadal Pacific Oscillation are also important regional drivers (Thompson and Wallace, 2000; Salinger et al., 2001; Cai et al., 2009b). This variability poses particular challenges for detecting and projecting anthropogenic climate change and its impacts in the region. For example, changes in ENSO in response to anthropogenic climate change are uncertain (WGI AR5 Chapter 14) but, given current ENSO impacts, any changes would have the potential to significantly influence rainfall and temperature extremes, droughts, tropical cyclones, marine conditions, and glacial mass balance (Mullan, 1995; Chinn et al., 2005; Holbrook et al., 2009; Diamond et al., 2012; Min et al., 2013).

Understanding of observed and projected climate change has received much attention since AR4, particularly in Australia, with a focus on the causes of observed rainfall changes and more systematic analysis of projected changes from different models and approaches. Climatic extremes have also been a research focus. Table 25-1 presents an assessment of this body of research for observed trends and projected changes for a range of climatic variables (including extremes) relevant for regional impacts and adaptation, including examples of the magnitude of projected change, and attribution, where possible. Most studies are based on Coupled Model Intercomparison Project Phase 3 (CMIP3) models and *Special Report on Emission Scenarios* (SRES) scenarios, but CMIP5 model results are considered where available (see also WGI AR5 Chapter 14 and Atlas; Chapter 21).

The region has exhibited warming to the present (*very high confidence*) and is *virtually certain* to continue to do so (Table 25-1). Observed and CMIP5-modeled past and projected future annual average surface temperatures are shown in Figures 25-1 and 25-2. For further details see WGI AR5 Atlas, AI.68–69. Changes in precipitation have been observed with *very high confidence* in some areas over a range of time scales, such as increases in northwestern Australia since the 1950s, the autumn/winter decline since 1970 in southwestern Australia, and, since the 1990s, in southeastern Australia, and over 1950–2004 increases in annual rainfall in the south and west of the South Island and west of the North Island of New Zealand, and decreases in the northeast of the South Island and east and north of the North Island. Based on multiple lines of evidence, annual average rainfall is projected to decrease with *high confidence* in southwestern Australia. For New Zealand, annual average rainfall is projected to decrease in the northeastern South Island and eastern and northern North Island, and increase in other parts of the country (*medium confidence*). The direction and magnitude of rainfall change in eastern and northern Australia remains a key uncertainty (Table 25-1).

This pattern of projected rainfall change is reflected in annual average CMIP5 model results (Figure 25-1), but with important additional dimensions relating to seasonal changes and spread across models (see also WGI AR5 Atlas, AI.70–71). Examples of the magnitude of projected annual change from 1990 to 2090 (percent model mean change +/–

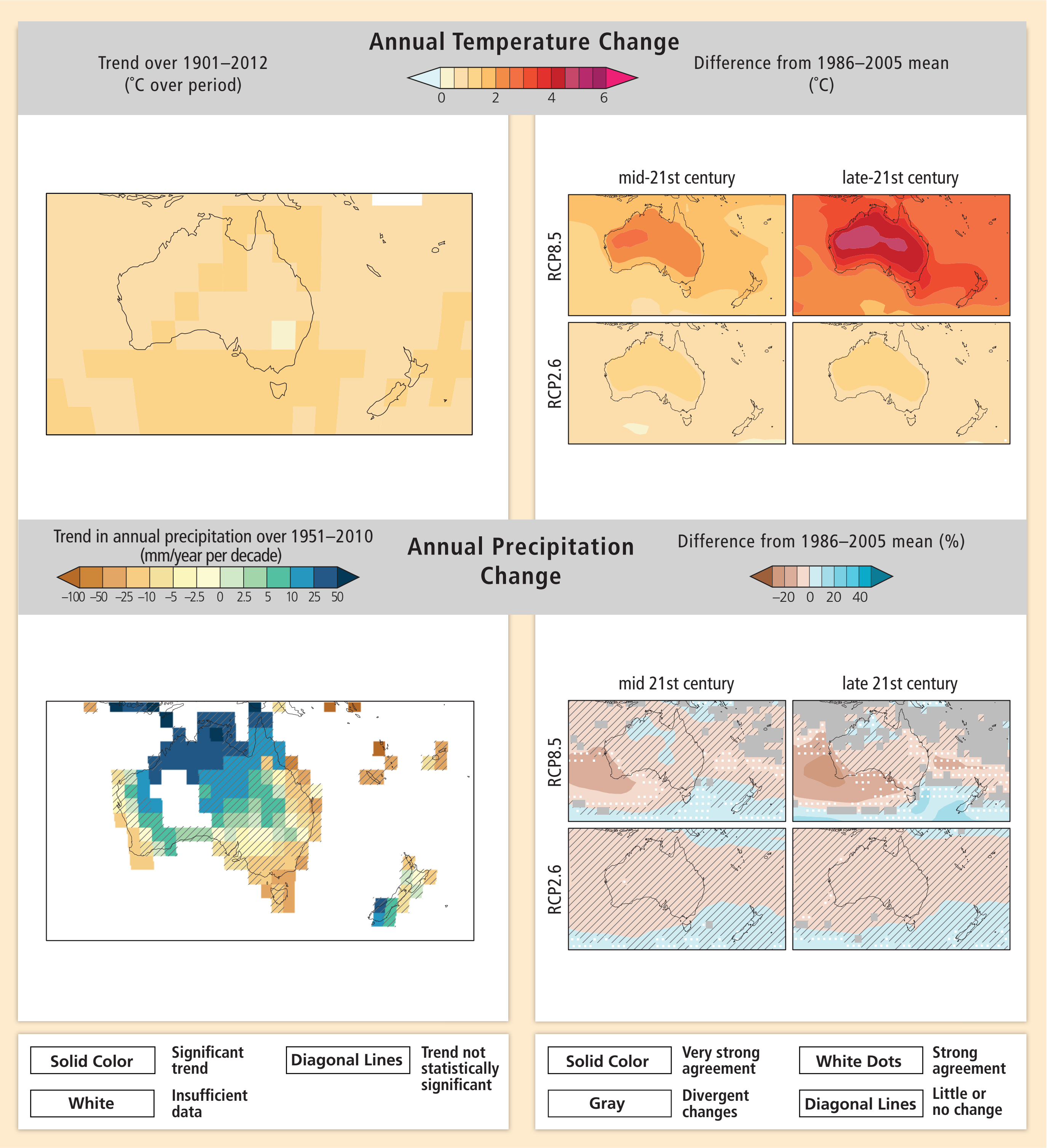

Figure 25-1 | Observed and projected changes in annual average temperature and precipitation. (Top panel, left) Map of observed annual average temperature change from 1901–2012, derived from a linear trend. [WGI AR5 Figures SPM.1 and 2.21] (Bottom panel, left) Map of observed annual precipitation change from 1951–2010, derived from a linear trend. [WGI AR5 Figures SPM.2 and 2.29] For observed temperature and precipitation, trends have been calculated where sufficient data permit a robust estimate (i.e., only for grid boxes with greater than 70% complete records and more than 20% data availability in the first and last 10% of the time period). Other areas are white. Solid colors indicate areas where trends are significant at the 10% level. Diagonal lines indicate areas where trends are not significant. (Top and bottom panel, right) CMIP5 multi-model mean projections of annual average temperature changes and average percent changes in annual mean precipitation for 2046–2065 and 2081–2100 under RCP2.6 and 8.5, relative to 1986–2005. Solid colors indicate areas with very strong agreement, where the multi-model mean change is greater than twice the baseline variability (natural internal variability in 20-yr means) and ≥90% of models agree on sign of change. Colors with white dots indicate areas with strong agreement, where ≥66% of models show change greater than the baseline variability and ≥66% of models agree on sign of change. Gray indicates areas with divergent changes, where ≥66% of models show change greater than the baseline variability, but <66% agree on sign of change. Colors with diagonal lines indicate areas with little or no change, where <66% of models show change greater than the baseline variability, although there may be significant change at shorter timescales such as seasons, months, or days. Analysis uses model data and methods building from WGI AR5 Figure SPM.8. See also Annex I of WGI AR5. [Boxes 21-2 and CC-RC] intermodel standard deviation) under Representative Concentration Pathway (RCP)8.5 from CMIP5 are –20 ± 13% in southwestern Australia, –2 ± 21% in the Murray-Darling Basin, and –5 ± 22% in southeast Queensland (Irving et al., 2012). Projected changes during winter and spring are more pronounced and/or consistent across models than the annual changes, for example, drying in southwestern Australia (–32 ± 11%, June to August), the Murray-Darling Basin (–16 ± 22%, June to August), and southeast Queensland (–15 ± 26%, September to November), whereas there are increases of 15% or more in the west and south of the South Island of New Zealand (Irving et al., 2012). Downscaled CMIP3 model projections for New Zealand indicate a stronger drying pattern in the southeast of the South Island and eastern and northern regions of the North Island in winter and spring (Reisinger et al., 2010) than seen in the raw CMIP5 data; based on similar broader scale changes this pattern is expected to hold once CMIP5 data are also downscaled (Irving et al., 2012).

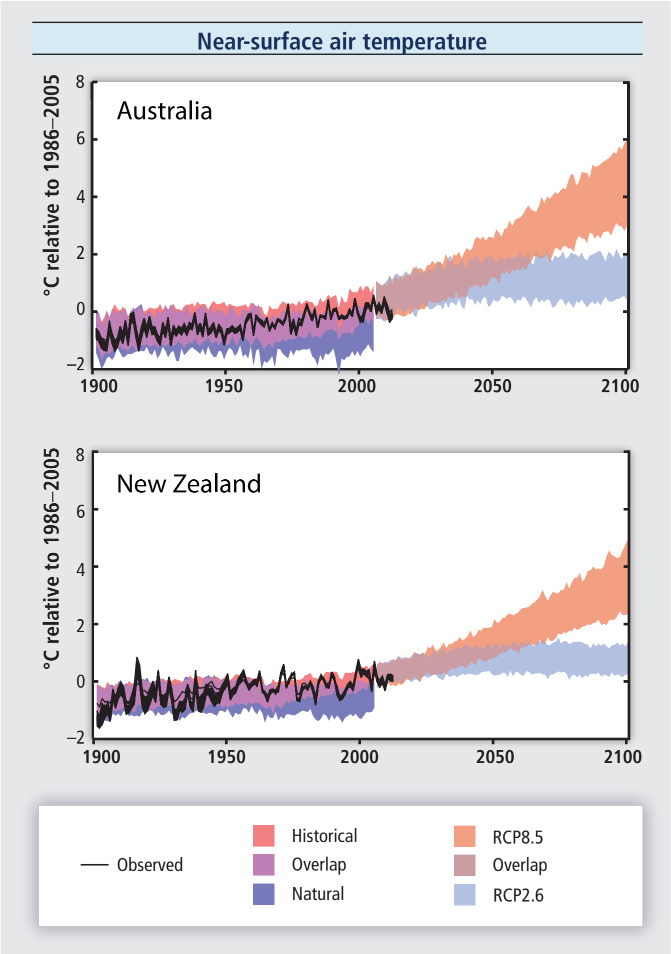

Figure 25-2 | Observed and simulated variations in past and projected future annual average near-surface air temperature over land areas of Australia (top) and New Zealand (bottom). Black lines show various estimates from observational measurements. Shading denotes the 5th to 95th percentile range of climate model simulations driven with "historical" changes in anthropogenic and natural drivers (63 simulations), historical changes in "natural" drivers only (34), the Representative Concentration Pathway (RCP)2.6 emissions scenario (63), and the RCP8.5 (63). Data are anomalies from the 1986–2005 average of the individual observational data (for the observational time series) or of the corresponding historical all-forcing simulations. Further details are given in Box 21-3 and Box CC-RC.

Other projected changes of at least *high confidence* include regional increases in sea surface temperature, the occurrence of hot days, fire weather in southern Australia, mean and extreme sea level, and ocean acidity (see WGI AR5 Section 6.4.4 for projections); and decreases in cold days and snow extent and depth. Although changes to tropical cyclone occurrence and that of other severe storms are potentially important for future vulnerability, regional changes to these phenomena cannot be projected with at least *medium confidence* as yet (Table 25-1).

25.3. Socioeconomic Trends Influencing Vulnerability and Adaptive Capacity

25.3.1. Economic, Demographic, and Social Trends

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 55% (Australia) and 56% and 5% (New Zealand) of the value of total exports in 2010–2011 (ABS, 2012c; SNZ, 2012b). Water abstraction per capita in both countries is in the top half of the Organisation for Economic Co-operation and Development (OECD), decreasing since 1990 in Australia but increasing in New Zealand; more than half is used for irrigation (OECD, 2010, 2013a). Between 1970 and 2011, gross domestic product (GDP) grew by an average of 3.2% per annum in Australia and 2.4% per annum in New Zealand, with annual GDP per capita growth of 1.8% and 1.2%, respectively (SNZ, 2011; ABS, 2012d). GDP is projected to grow on average by 2.5 to 3.5% per annum in Australia and about 1.9% per annum in New Zealand to 2050 (Australian Treasury, 2010; Bell et al., 2010) but subject to significant shorter term fluctuations.

The populations of Australia and New Zealand are projected to grow significantly over at least the next several decades (*very high confidence*; ABS, 2008; SNZ, 2012a): Australia's population from 22.3 million in 2011 to 31 to 43 million by 2056 and 34 to 62 million by 2101 (ABS, 2008, 2013); New Zealand's population from 4.4 million in 2011 to 5.1 to 7.1 million by 2061 (SNZ, 2012a). The number of people aged 65 and over is projected to almost double in the next 2 decades (ABS, 2008; SNZ, 2012a). More than 85% of the Australasian population lives in urban areas and their satellite communities, mostly in coastal areas (DCC, 2009; SNZ, 2010b; UN DESA Population Division, 2012; see Box 25-9). Urban concentration and depletion of remote rural areas is expected to continue (Mendham and Curtis, 2010; SNZ, 2010c; Box 25-5), but some coastal non-urban spaces also face increasing development pressure (Freeman and Cheyne, 2008; Gurran, 2008; Box 25-1). More than 20% of Australasian residents were born overseas (OECD, 2013a).

Poverty rates and income inequality in Australia and New Zealand are in the upper half of OECD countries, and both measures increased significantly in both countries between the mid-1980s and the late 2000s (OECD, 2013a). Measurement of poverty and inequality, however, is highly contested, and it remains difficult to anticipate future changes and their effects on adaptive capacity (Peace, 2001; Scutella et al., 2009; Section 25.3.2). Indigenous peoples constitute about 2.5% and 15% of the Australian and New Zealand populations, respectively, but in

Table 25-1 | Observed and projected changes in key climate variables, and (where assessed) the contribution of human activities to observed changes. For further relevant information see WGI AR5 Chapters 3, 6 (ocean changes, including acidification), 11, 12 (projections), 13 (sea level), and 14 (regional climate phenomena). (*) *medium confidence*, (**) *high confidence*, (***) *very high confidence*, (****) *virtually certain*

Climate variable	Observed change	Direction of projected change	Examples of projected magnitude of change (relative to ~1990, unless otherwise stated)	Additional comments
Mean air temperature	Australia: Increased by 0.09 ± 0.03°C per decade since 1911[1] (***) New Zealand: Increased by 0.09 ± 0.03°C per decade since 1909[2] (***)	Australia and New Zealand: Increase[3–8] (****); greatest over inland Australia and least in coastal areas and New Zealand[5–8] (***)	Australia: 0.6–1.5°C (2030 A1B), 1.0–2.5°C (2070 B1), 2.2–5.0°C (2070 A1FI)[3] New Zealand: 0.3–1.4°C (2040 A1B), 0.7–2.3°C (2090 B1), 1.6–5.1°C (2090 A1FI)[5] Coupled Model Intercomparison Project Phase 5 (CMIP5) Representative Concentration Pathway 4.5 (RCP4.5), relative to ~1995[9]: North Australia: 0.3–1.6°C (2016–2035), 0.7–2.6°C (2046–2065) Southern Australia and New Zealand: 0.1–1.0°C (2016–2035), 0.6–1.7°C (2046–2065)	Australia: A significant contribution to observed change attributed to anthropogenic climate change[10] (**) with some regional variations attributed to atmospheric circulation variations[11,12] New Zealand: Observed change partially attributed to anthropogenic climate change[13] (*)
Sea surface temperature	Australia: Increased by about 0.12°C per decade for northwestern and northeastern Australia and by about 0.2°C per decade for southeastern Australia since 1950[14,15] (***) New Zealand: Increased by about 0.07°C per decade over 1909–2009[2] (***)	Australia and New Zealand: Increase[3,7,8] (***), with greater increase in the Tasman sea region[3,7] (*)	Australia: 0.6–1.0°C (2070 B1) and 1.6–2.0°C (2070 A1FI) for southern coastal and 1.2–1.5°C (2070 B1) and 2.2–2.5°C (2070 A1FI) elsewhere[3] New Zealand: Similar to projected changes in mean air temperature for coastal waters[5]	
Air temperature extremes	Australia and New Zealand: Significant trend since 1950: Cool extremes have become rarer and hot extremes more frequent and intense[16–19] (**). The Australian heat wave of 2012/13 was exceptional in heat, duration, and spatial extent.[20]	Australia and New Zealand: Hot days and nights more frequent and cold days and cold nights less frequent during the 21st century[3,5,21–24] (**)	Australia: Hot days in Melbourne (>35°C max.) increase by 20–40% (2030 A1B), 30–90% (2070 B1), and 70–190% (2070 A1FI)[3] New Zealand: Spring and autumn frost–free land to at least triple by 2080s[24]; up to 60 more hot days (>25°C max.) for northern areas by 2090[5]	Australia: Observed trends partly attributable to anthropogenic climate change (**) as they are consistent with mean warming and historical simulations,[18,19,21,25] although other factors may have contributed to high extremes during droughts[26–28]
Precipitation	Australia: Late autumn/winter decreases in southwestern Australia since the 1970s and in southeastern Australia since the mid–1990s, and annual increases in northwestern Australia since the 1950s[29–31] (***) New Zealand: Mean annual rainfall increased over 1950–2004 in the south and west of the South Island and west of the North Island, and decreased in the northeast of the South Island and east and north of the North Island[32] (***).	Australia: Annual decline in southwestern Australia (**), elsewhere on most of the southern (*) and northeastern (*low confidence*) continental edges, with reductions strongest in the winter half year[3,4,9,33–35] (**). Direction of annual change elsewhere is uncertain[3,35,36] (Figure 25-1) (**). New Zealand: In the South Island, annual increase in the west and south and decrease in northeast. In the North Island, increase in the west and decrease in eastern and northern regions[5,34,37] (Figure 25-1) (*)	Australia: For 2030 A1B, annual changes of –10% to +5% (northern Australia) and –10% to 0% (southern Australia); for 2070 B1, –15% to +7.5% (northern and eastern Australia) and –15% to 0% (southern Australia); and for 2070 A1FI, –30% to +20% (northern and eastern Australia) and –30% to +5% (southern Australia), with larger changes seasonally[3] New Zealand: For 2040 A1B, annual changes of –5% to +15% (southern and western) and –15% to +10% (northern and eastern) and for 2090 A1B, –10% to +25% (southern and western) and –20% to +15% (northern and eastern) based on downscaled projections with larger changes seasonally[5,37]	Australia: Observed decline in southwest is related to atmospheric circulation changes[38–40] (***) and other factors,[41] and partly attributable to anthropogenic climate change[40–43] (**). The recent southeast rainfall decline is also related to circulation changes[31,44–46] (**), with some evidence of an anthropogenic component.[47] New Zealand: Observed trends related to increased westerly winds.[32] Projected annual trends dominated by winter and spring trends related to increased westerlies[5]
Precipitation extremes	Australia: Indices of annual daily extremes (e.g., 95th and 99th percentile rainfalls) show mixed or insignificant trends,[21,48] but significant increase is evident in recent decades for shorter duration (sub-daily) events[49,50] (**). New Zealand: Extreme annual 1-day rainfall decrease in north and east and increase in west since 1930[32] (*)	Australia and New Zealand: Increase in most regions in the intensity of rare daily rainfall extremes (i.e., current 20-year return period events) and in short duration (sub-daily) extremes (*) and an increase in the intensity of 99th percentile daily extremes (*low confidence*)[5,8,21,51–56]	Australia: For 2090 A2, CMIP3 gives increases in the intensity of the 20-year daily extreme of around +200% to –25% depending on region and model.[52] New Zealand: Increases of daily extreme rainfalls of around 8% per degree Celsius are projected but with significant regional variations.[5,56]	Australia and New Zealand: The sign of observed trends mostly reflects trends in mean rainfall (e.g., there is a decrease in mean and daily extremes in southwestern Australia).[21,32,49] Similarly, future increases in intensity of extreme daily rainfall are more likely where mean rainfall is projected to increase.[3,5]
Drought	Australia: Defined using rainfall only, drought occurrence over the period 1900–2007 has not changed significantly[57] (**). New Zealand: Defined using a soil water balance model; there has been no trend in drought occurrence since 1972[58] (*).	Australia and New Zealand: Drought frequency is projected to increase in southern Australia[8,54,57,59,60] (*) and in many regions of New Zealand[58,61] (*).	Australia: Occurrence under 2070 A1B and A2 ranges from a halving to 3 times more frequent in northern Australia and 0–5 times more frequent in southern Australia.[60] New Zealand: Time spent in drought in eastern and northern New Zealand is projected to double or triple by 2040.[61]	Australia: Regional warming may have led to an increase in hydrological drought (*low confidence*).[62,63]

Table 25-1 (continued)

Climate variable	Observed change	Direction of projected change	Examples of projected magnitude of change (relative to ~1990, unless otherwise stated)	Additional comments
Winds	Australia: Significant decline in storminess over southeastern Australia since 1885[64] (*), but inconsistent trends in wind observations since 1975[65,66] New Zealand: Mean westerly flow increased during the late 20th century (1978–1998), associated with the positive phase of the Inter-decadal Pacific Oscillation[67,68]	Australia: Increases in winds in 20–30°S band, with little change to decrease elsewhere, except for winter increases over Tasmania. Decrease to little change in extremes (99th percentile) over most of Australia except Tasmania in winter[69] (*) New Zealand: Mean westerly winds and extreme winds (based on projected changes in circulation patterns) are projected to increase, especially in winter[5,70] (*).	Australia: Magnitude of simulated mean changes may exceed 10% under A1B for 2081–2100 relative to 1981–2000.[69] New Zealand: Mean westerly flow to increase by around 20% in spring and around 70% in winter, and to decrease by around 20% in summer and autumn, by 2090[5]	Australia and New Zealand: Many of past and projected changes in mean wind speed can be related to changes in atmospheric circulation.[43,67,68] New Zealand: Extreme westerlies and southerlies have slightly increased while extreme easterlies have decreased since 1960.[13,71]
Mean sea level	Australia: From 1900 to 2011 the average rate of relative sea level rise (SLR) was 1.4 ± 0.6 mm year^{-1} [72] (***). New Zealand: The average rate of relative SLR was 1.7 ± 0.1 mm year^{-1} over 1900–2009[73] (***).	Australia and New Zealand: Regional sea level rise will *very likely* exceed the 1971–2000 historical rate, consstent with global mean trends.[74] Mean sea level will continue to rise for at least several more centuries[74] (***).	Australia: Offshore regional sea level rise may exceed 10% more than global SLR; see WGI AR5 Figure 13.21.[74] New Zealand: Offshore regional sea level rise may be up to 10% more than global SLR.[75]	Australia and New Zealand: Satellite estimates of regional SLR for 1993–2009 are significantly higher than those for 1920–2000, partly reflecting climatic variability.[72,73,76,77] New Zealand: Allowing for glacial isostatic adjustment, absolute observed SLR is around 2.0 mm year^{-1}. [73,78]
Extreme sea level	Australia and New Zealand: Extreme sea levels have risen at a similar rate to global SLR.[79]	Australia and New Zealand: Projected mean SLR will lead to large increases in the frequency of extreme sea level events (***), with other changes in storm surges playing a lesser role.[80–83]	Australia: An increase of mean sea level by 0.1 m increases the frequency of an extreme sea level event by a factor of between 2 and 10 over southeastern Australia depending on location.[80–82]	
Fire weather	Australia: Increased since 1973 (**), with 24 out of 38 sites showing increases in the 90th percentile of the McArthur Forest Fire Danger Index[84]	Australia: Fire weather is expected to increase in most of southern Australia owing to hotter and drier conditions (**), based on explicit model studies carried out for southeastern Australia,[85–88] and change little or decrease in the northeast[88] (*). New Zealand: Fire danger index is projected to increase in many areas[89] (*).	Australia: Increase in days with very high and extreme fire danger index by 2–30% (2020), 5–100% (2050) (using B1 and A2 and two climate models, and 1973–2007 base)[85] New Zealand: Increase in days with very high and extreme fire danger index from around 0 to 400% (2040) and 0 to 700% (2090) (using A1B, 16 CMIP3 General Circulation Models)[89]	Australia: For the example of Canberra, the projected changes represent the current 17 days per year increasing to 18–23 days in 2020 and 20–33 days in 2050.[85]
Tropical cyclones and other severe storms	Australia: No regional change in the number of tropical cyclones (TCs) or in the proportion of intense TCs over 1981–2007[90] (*), but frequency of severe landfalling TCs in northeastern Australia has declined significantly since the late 19th century[91] and the east–west distribution has changed since 1980.[92] There has been no trend in environments suitable for severe thunderstorms.[93]	Australia: Tropical cyclones are projected to increase in intensity and stay similar or decrease in numbers,[9,94] and occur further south[94] (*low confidence*). New Zealand: Projected increase in the average intensity of cyclones in the south during winter, but a decrease elsewhere[70] (*)	Australia: One modeling study shows a 50% reduction in TC occurrence for 2051–2090 relative to 1971–2000, increases in intensity of the modeled storms, and occurence around 100 km further south.[94] New Zealand: Occurrence of conditions conducive to convective storm development is projected to increase by 3–6% by 2070–2100 (A2), relative to 1970–2000, with the largest increases over the South Island.[70]	Australia: Regional research on convective storms is limited but studies have shown a projected decrease in the frequency of cool-season tornadoes[95] and hail[3] in southern Australia, and increases in the frequency and intensity of hail in the Sydney region.[3,96]
Snow and ice	Australia: Late season significant snow depth decline at three out of four Snowy Mountain sites over 1957–2002[97] (**) New Zealand: Ice volume declined by 36–61% from the mid-late 1800s to the late 1900s[98–100], with glacier volume reducing by 15% between 1976 and 2008[101] (**).	Australia: Both snow depth and area are projected to decline[97] (***). New Zealand: Snowline elevations are projected to rise, and winter snow volume and days with low elevation snow cover are projected to decrease[5,102,103] (***).	Australia: Area with at least 30 days' cover annually is projected to decline by 14–54% (2020) and 30–93% (2050).[97] New Zealand: By 2090, peak snow accumulation is projected to decline by 32–79% at 1000 m and by 6–51% at 2000 m.[103]	New Zealand: Atmospheric circulation variations can enhance or outweigh multi-decadal trends in ice volume over time scales of up to two decades.[104,105]

References: [1]Fawcett et al. (2012); [2]Mullan et al. (2010); [3]CSIRO and BoM (2007); [4]Moise and Hudson (2008); [5]MfE (2008b); [6]AR5 WGI Atlas AI68–69; [7]AR5 WGI Ch11; [8]AR5 WGI Ch12; [9]AR5 WGI Ch14; [10]Karoly and Braganza (2005); [11]Hendon et al. (2007); [12]Nicholls et al. (2010); [13]Dean and Stott (2009); [14]Lough (2008); [15]Lough and Hobday (2011); [16]Chambers and Griffiths (2008); [17]Gallant and Karoly (2010); [18]Nicholls and Collins (2006); [19]Trewin and Vermont (2010); [20]BoM (2013); [21]Alexander and Arblaster (2009); [22]Tryhorn and Risbey (2006); [23]Griffiths et al. (2005); [24]Tait (2008); [25]Alexander et al. (2007); [26]Deo et al. (2009); [27]McAlpine et al. (2007); [28]Cruz et al. (2010); [29]Hope et al. (2010); [30]Jones et al. (2009); [31]Gallant et al. (2012); [32]Griffiths (2007); [33]Timbal and Jones (2008); [34]AR5 WGI Atlas AI70–71; [35]Irving et al. (2012); [36]Watterson (2012); [37]Reisinger et al. (2010); [38]Bates et al. (2008); [39]Frederiksen and Frederiksen (2007); [40]Hope et al. (2006); [41]Timbal et al. (2006); [42]Cai and Cowan (2006); [43]Frederiksen et al. (2011); [44]Cai et al. (2011); [45]Nicholls (2010); [46]Smith and Timbal (2010); [47]Timbal et al. (2010a); [48]Gallant et al. (2007); [49]Westra and Sisson (2011); [50]Jakob et al. (2011); [51]Abbs and Rafter (2009); [52]Rafter and Abbs (2009); [53]Kharin et al. (2013); [54]Ch3 of IPCC (2012); [55]Westra et al. (2013); [56]Carey-Smith et al. (2010); [57]Hennessy et al. (2008a); [58]Mullan et al. (2005); [59]Kirono and Kent (2010); [60]Kirono et al. (2011); [61]Clark et al. (2011); [62]Cai and Cowan (2008); [63]Nicholls (2006); [64]Alexander et al. (2011); [65]McVicar et al. (2008); [66]Troccoli et al. (2012); [67]Parker et al. (2007); [68]Mullan et al. (2001); [69]McInnes et al. (2011a); [70]Mullan et al. (2011); [71]Salinger et al. (2005); [72]Burgette et al. (2013); [73]Hannah and Bell (2012); [74]AR5 WGI Ch13; [75]Ackerley et al. (2013); [76]CSIRO and BoM (2012); [77]Meyssignac and Cazenave (2012); [78]Hannah (2004); [79]Menendez and Woodworth (2010); [80]McInnes et al. (2009); [81]McInnes et al. (2011b); [82]McInnes et al. (2012); [83]Harper et al. (2009); [84]Clarke et al. (2012); [85]Lucas et al. (2007); [86]Hasson et al. (2009); [87]Cai et al. (2009a); [88]Clarke et al. (2011); [89]Pearce et al. (2011); [90]Kuleshov et al. (2010); [91]Callaghan and Power (2011); [92]Hassim and Walsh (2008); [93]Allen and Karoly (2013); [94]Abbs (2012); [95]Timbal et al. (2010b); [96]Leslie et al. (2008); [97]Hennessy et al. (2008b); [98]Hoelzle et al. (2007); [99]Ruddell (1995); [100]Chinn (2001); [101]Chinn et al. (2012); [102]Fitzharris (2004); [103]Hendrikx et al. (2012); [104]Purdie et al. (2011); [105]Willsman et al. (2010).

Australia, their national share is growing and they constitute a much higher percentage of the population in remote and very remote regions (ABS, 2009, 2010b; SNZ, 2010a). Indigenous peoples in both countries have lower than average life expectancy, income, and education, implying that changes in socioeconomic status and social inclusion could strongly influence their future adaptive capacity (see Section 25.8.2).

25.3.2. Use and Relevance of Socioeconomic Scenarios in Adaptive Capacity/Vulnerability Assessments

Demographic, economic, and sociocultural trends influence the vulnerability and adaptive capacity of individuals and communities (see Chapters 2, 11-13, 16, 20). A limited but growing number of studies in Australasia have attempted to incorporate such information, for example, changes in the number of people and percentage of elderly people at risk (Preston et al., 2008; Baum et al., 2009; Preston and Stafford-Smith, 2009; Roiko et al., 2012), the density of urban settlements and exposed infrastructure (Preston and Jones, 2008; Preston et al., 2008; Baynes et al., 2012), population-driven pressures on water demand (Jollands et al., 2007; CSIRO, 2009), and economic and social factors affecting individual coping, planning, and recovery capacity (Dwyer et al., 2004; Khan, 2012; Roiko et al., 2012).

Socioeconomic considerations are used increasingly to understand adaptive capacity of communities (Preston et al., 2008; Smith et al., 2008; Fitzsimons et al., 2010; Soste, 2010; Brunckhorst et al., 2011) and to construct scenarios to help build regional planning capacity (Energy Futures Forum, 2006; Frame et al., 2007; Pride et al., 2010; Pettit et al., 2011; Taylor et al., 2011). Such scenarios, however, are only beginning to be used to quantify vulnerability to climate change (except, e.g., Bohensky et al., 2011; Baynes et al., 2012; Low Choy et al., 2012).

Apart from these emerging efforts, most vulnerability studies from Australasia make no or very limited use of socioeconomic factors, consider only current conditions, and/or rely on postulated correlations between generic socioeconomic indicators and climate change vulnerability. In many cases this limits confidence in conclusions regarding future vulnerability to climate change and adaptive capacity of human and mixed natural-human systems.

25.4. Cross-Sectoral Adaptation: Approaches, Effectiveness, and Constraints

25.4.1. Frameworks, Governance, and Institutional Arrangements

Adaptation responses depend heavily on institutional and governance arrangements (see Chapters 2, 14-16, 20). Responsibility for development and implementation of adaptation policy in Australasia is largely devolved to local governments and, in Australia, to State governments and Natural Resource Management bodies. Federal/central government supports adaptation mostly via provision of information, tools, legislation, policy guidance, and (in Australia) support for pilot projects. A standard risk management paradigm has been promoted to embed adaptation into decision-making practices (AGO, 2006; MfE, 2008b; Standards Australia, 2013), but broader systems and resilience approaches are used increasingly for natural resource management (Clayton et al., 2011; NRC, 2012). The Council of Australian Governments agreed a national adaptation policy framework in 2007 (COAG, 2007). This included establishing the collaborative National Climate Change Adaptation Research Facility (NCCARF) in 2008, which complemented Commonwealth Scientific and Industrial Research Organisation (CSIRO)'s Climate Adaptation Flagship. The federal government supported a first-pass national coastal risk assessment (DCC, 2009; DCCEE, 2011), is developing indicators and criteria for assessing adaptation progress and outcomes (DIICCSRTE, 2013), and commissioned targeted reports addressing impacts and management options for natural and managed landscapes (Campbell, 2008; Steffen et al., 2009; Dunlop et al., 2012), National and World Heritage areas (ANU, 2009; BMT WBM, 2011), and indigenous and urban communities (Green et al., 2009; Norman, 2010). Most State and Territory governments have also developed adaptation plans (e.g., DSE, 2013).

In New Zealand, the central government updated and expanded tools to support impact assessments and adaptation responses consistent with regulatory requirements (MfE, 2008b,c,d, 2010b), and revised key directions for coastal management (Minister of Conservation, 2010). No cross-sectoral adaptation policy framework or national-level risk assessments exist, but some departments commissioned high-level impacts and adaptation assessments after the AR4 (e.g., on agriculture and on biodiversity; Wratt et al., 2008; McGlone and Walker, 2011; Clark et al., 2012).

Public and private sector organizations are potentially important adaptation actors but exhibit large differences in preparedness, linked to knowledge about climate change, economic opportunities, external connections, size, and scope for strategic planning (Gardner et al., 2010; Taylor, B.M. et al., 2012; Johnston et al., 2013; Kuruppu et al., 2013; see also Chapters 10, 16). This creates challenges for achieving holistic societal outcomes (see also Sections 25.7-9).

Several recent policy initiatives in Australia, while responding to broader socioeconomic and environmental pressures, include goals to reduce vulnerability to climate variability and change. These include establishing the Murray-Darling Basin Authority to address over-allocation of water resources (Connell and Grafton, 2011; MDBA, 2011), removal of the interest rate subsidy during exceptional droughts (Productivity Commission, 2009), and management of bush fire and flood risk (VBRC, 2010; QFCI, 2012). These may be seen as examples of mainstreaming adaptation (Dovers, 2009), but they also demonstrate lag times in policy design and implementation, windows of opportunity presented by crises (e.g., the Millennium Drought of 1997–2009, the Victorian bushfires of 2009, and Queensland floods of 2011), and the challenges arising from competing interests in managing finite and changing water resources (Botterill and Dovers, 2013; Pittock, 2013; Box 25-2).

25.4.2. Constraints on Adaptation and Emerging Leading Practice Models

A rapidly growing literature since the AR4 confirms, with *high confidence*, that while the adaptive capacity of society in Australasia is generally high,

Table 25-2 | Constraints and enabling factors for institutional adaptation processes in Australasia.

Constraint	Enabling factors
Uncertainty of projections	• Improved guidance and tools to manage uncertainty and support adaptive management[1–8] • Increased focus on lead and consequence time of decisions and link with current climate variability and related risks[9–13] • Increased communication between practitioners and scientists to identify and provide decision-relevant data and context[2,3,11,13–17]
Availability and cost of data and models	• Central provision of relevant core climate and non-climate data, including regional scenarios of projected changes[4,5,7,9,18,19] • National first-pass risk assessments[4,5,7,8,18,20–24]
Limited financial and human capability and capacity; time lag in developing expertise	• Support for pilot projects[4,8,15,18,24,25] • Building capacity through institutional commitment and learning[3,5,11,17,23,26–28] • Central databases on guidance, tools, methodologies, case studies[4,5,7,18,24] • Regional partnerships and collaborations, knowledge networks[3,4,8,13,15,17,26,28–30]
Unclear problem definition and goals; unclear standards for risk assessment methodologies and decision support tools; limited monitoring and evaluation	• Explicit but iterative framing and scoping of adaptation challenge, to reflect alternative entry points for stakeholders while meeting expectations of project sponsors to ensure long-term support[3,11,17,31–34] • Tailoring decision-making frameworks to specific problems[1,2,6,17,35,36] • Criteria and tools to monitor and evaluate adaptation success[7,18,37–39]
Unclear or contradictory legislative frameworks and responsibilities, unclear liabilities	• Clear and coordinated legislative frameworks[5,8,9,15,24,40–45] • Defined responsibilities for public and private actors, including liabilities from acting and failure to act[8,9,11,24,41,44,46] • Legally binding guidance on the incorporation of climate change in planning mechanisms[5,7,8,15,38,40]
Static planning mechanisms and practice; competing mandates and fragmentation of policies; disciplinary voids or single approaches	• Whole-of-council approach to climate adaptation to break up institutional and professional silos[15,33,47] • Long-term policy commitments and implementation support[5,18,26,33,48] • Increased policy coherence across sectors, regulations, and levels of government[9,26,28,40,42,43,47] • Enabling risk-based flexible land use decisions[4,5,9,49] • Strengthening multi-disciplinarity across professional fields[14,29,48]
Lack of political leadership; short election cycles; limited community support, participation, and awareness for adaptation	• Legally binding guidance and clarification of liabilities and duty of care to reduce dependence on individual leadership[5,7–9,15,24,38,40,46,49] • Consistent but audience-specific communication of current and potential future vulnerability and implications for community values[4,5,7,26,42,43,50] • Comprehensible communication of and access to response options, and their consistency with wider development plans[7,26,28,33,39,42,43] • Clearly identified entry points for public participation[17,34,38,39,42,48,51–53]

Note: The relevance of each constraint varies among organizations, sectors, and locations. Some enabling factors are only beginning to be implemented or have only been suggested in the literature; hence their effectiveness cannot yet be evaluated. Entries for enabling factors exclude generic mechanisms, such as insurance (see Box 25-7); emergency management and early warning systems; and funding for pilot studies, capital infrastructure upgrades, or retreat schemes.

References: [1]Randall et al. (2012); [2]Verdon-Kidd et al. (2012); [3]Webb et al. (2013); [4]Mukheibir et al. (2013); [5]Lawrence et al. (2013b); [6]Nelson et al. (2008); [7]Britton (2010); [8]Gurran et al. (2008); [9]Productivity Commission (2012); [10]Stafford-Smith et al. (2011); [11]Johnston et al. (2013); [12]Park et al. (2012); [13]Power et al. (2005); [14]Reisinger et al. (2011); [15]Smith et al. (2008); [16]Stafford-Smith (2013); [17]Yuen et al. (2012); [18]Webb and Beh (2013); [19]Roiko et al. (2012); [20]DCCEE (2011); [21]DCC (2009); [22]Baynes et al. (2012); [23]Smith et al. (2010); [24]SCCCWEA (2009); [25]DSEWPC (2011); [26]Low Choy et al. (2012); [27]Gardner et al. (2010); [28]Fidelman et al. (2013); [29]Mustelin et al. (2013); [30]Serrao-Neumann et al. (2013); [31]Fünfgeld et al. (2012); [32]Kuruppu et al. (2013); [33]Britton et al. (2011); [34]Alexander et al. (2012); [35]Maru et al. (2011); [36]Preston et al. (2008); [37]Norman et al. (2013); [38]Rouse and Norton (2010); [39]Preston et al. (2011); [40]Rive and Weeks (2011); [41]Abel et al. (2011); [42]Norman (2009); [43]Gurran et al. (2006); [44]McDonald (2013); [45]Minister of Conservation (2010); [46]McDonald (2010); [47]Measham et al. (2011); [48]Rouse and Blackett (2011); [49]McDonald (2011); [50]Hine et al. (2013); [51]Burton and Mustelin (2013); [52]Hobson and Niemeyer (2011); [53]Gardner et al. (2009a).

there are formidable environmental, economic, informational, social, attitudinal, and political constraints, especially for local governments and small or highly fragmented industries. Reviews of public- and private-sector adaptation plans and strategies in Australia demonstrate strong efforts in institutional capacity building, but differences in assessment methods and weaknesses in translating goals into specific policies (White, 2009; Gardner et al., 2010; Measham et al., 2011; Preston et al., 2011; Kay et al., 2013). Similarly, local governments in New Zealand to date have focused mostly on impacts and climate-related hazards; some have developed adaptation plans, but few have committed to specific policies and steps to implementation (e.g., O'Donnell, 2007; Britton, 2010; Fitzharris, 2010; HRC, 2010; KCDC, 2012; Lawrence et al., 2013b).

Table 25-2 summarizes key constraints and corresponding enabling factors for effective institutional adaptation processes identified in Australia and New Zealand. Scientific uncertainty and resource limitations are reported consistently as important constraints, particularly for smaller councils. Ultimately more powerful constraints arise, however, from current governance and legislative arrangements and the lack of consistent tools to deal with dynamic risks and uncertainty or to evaluate the success of adaptation responses (*robust evidence*, *high agreement*; Britton, 2010; Barnett et al., 2013; Lawrence et al., 2013b; Mukheibir et al., 2013; Webb et al., 2013; see also Chapter 16).

Some constraints exacerbate others. There is *high confidence* that the absence of a consistent information base and binding guidelines that clarify governing principles and liabilities is a challenge particularly for small and resource-limited local authorities, which need to balance special interest advocacy with longer term community resilience. This heightens reliance on individual leadership subject to short-term political change and can result in piecemeal and inconsistent risk assessments and responses between levels of government and locations, and over time (Smith et al., 2008; Brown et al., 2009; Norman, 2009; Britton, 2010; Rouse and Norton, 2010; Abel et al., 2011; McDonald, 2011; Rive and Weeks, 2011; Corkhill, 2013; Macintosh et al., 2013). In these situations, planners tend to rely more on single numbers for climate projections that can be argued in court (Reisinger et al., 2011; Lawrence et al., 2013b), which increases the risk of maladaptation given

Box 25-1 | Coastal Adaptation—Planning and Legal Dimensions

Sea level rise is a significant risk for Australia and New Zealand (*very high confidence*) due to intensifying coastal development and the location of population centers and infrastructure (see Section 25.3). Under a high emissions scenario (Representative Concentration Pathway (RCP)8.5), global mean sea level would *likely* rise by 0.53 to 0.97 m by 2100, relative to 1986–2005, whereas with stringent mitigation (RCP2.6), the *likely* rise by 2100 would be 0.28 to 0.6 m (*medium confidence*). Based on current understanding, only instability of the Antarctic ice sheet, if initiated, could lead to a rise substantially above the *likely* range; evidence remains insufficient to evaluate its probability, but there is *medium confidence* that this additional contribution would not exceed several tenths of a meter during the 21st century (WGI AR5 Section 13.5). Local case studies in New Zealand (Fitzharris, 2010; Reisinger et al., 2013) and national reviews in Australia (DCC, 2009; DCCEE, 2011) demonstrate risks to large numbers of residential and commercial assets as well as key services, with widespread damages at the upper end of projected ranges (*high confidence*). In Australia, sea level rise of 1.1 m would affect more than AU$226 billion of assets, including up to 274,000 residential and 8600 commercial buildings (DCCEE, 2011), with additional intangible costs related to stress, health effects, and service disruption (HCCREMS, 2010) and ecosystems (DCC, 2009; BMT WBM, 2011). Under expected future settlement patterns, exposure of the Australian road and rail network will increase significantly once sea level rises above about 0.5 m (Baynes et al., 2012). Even if temperatures peak and decline, sea level is projected to continue to rise beyond 2100 for many centuries, at a rate dependent on future emissions (WGI AR5 Section 13.5).

Responsibility for adapting to sea level rise in Australasia rests principally with local governments through spatial planning instruments. Western Australia, South Australia, and Victoria have mandatory State planning benchmarks for 2100, with local governments determining how they should be implemented. Long-term benchmarks in New South Wales and Queensland have either been suspended or revoked, so local authorities now have broad discretion to develop their own adaptation plans. The New Zealand Coastal Policy Statement (Minister of Conservation, 2010) mandates a minimum 100-year planning horizon for assessing hazard risks, discourages hard protection of existing development, and recommends avoidance of new development in vulnerable areas. Non-binding government guidance recommends a risk-based approach, using a base value of 0.5 m sea level rise by the 2090s and considering the implications of at least 0.8 m and, for longer term planning, an additional 0.1 m per decade (MfE, 2008d).

The incorporation of climate change impacts into local planning has evolved considerably over the past 20 years, but remains piecemeal and shows a diversity of approaches (Gibbs and Hill, 2012; Kay et al., 2013). Governments have invested in high-resolution digital elevation models of coastal and flood prone areas in some regions, but many local governments still lack the resources for hazard mapping and policy design. Political commitment is variable, and legitimacy of approaches and institutions is often strongly contested (Gorddard et al., 2012), including pressure on State governments to modify adaptation policies and on local authorities to compensate developers for restrictions on current or future land uses (LGNZ, 2008; Berry and Vella, 2010; McDonald, 2010; Reisinger et al., 2011). Incremental adaptation responses can entrench existing rights and expectations about ongoing protection and development, which limit options for more transformational responses such as accommodation and retreat (*medium evidence*, *high agreement*; Gorddard et al., 2012; Barnett et al., 2013; Fletcher et al., 2013; McDonald, 2013). Strategic regional-scale planning initiatives in rapidly growing regions, like southeast Queensland, allow climate change adaptation to be addressed in ways not typically achieved by locality- or sector-specific plans, but require effective coordination across different scales of governance (Serrao-Neumann et al., 2013; Smith et al., 2013).

Courts in both countries have played an important role in evaluating planning measures. Results of litigation have varied and, in the absence of clearer legislative guidance, more litigation is expected as rising sea levels affect existing properties and adaptation responses constrain development on coastal land (MfE, 2008d; Kenderdine, 2010; Rive and Weeks, 2011; Verschuuren and McDonald, 2012; Corkhill, 2013; Macintosh, 2013).

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Box 25-1 (continued)

In addition to raising minimum floor levels and creating coastal setbacks to limit further development in areas at risk, several councils in Australia and New Zealand have consulted on or attempted to implement managed retreat policies (ECAN, 2005; BSC, 2010; HDC, 2012; KCDC, 2012). These policies remain largely untested in New Zealand, but experience in Australia has shown high litigation potential and opposing priorities at different levels of government, undermining retreat policies (SCCCWEA, 2009; DCCEE, 2010; Abel et al., 2011). Mandatory disclosure of information about future risks, community engagement, and policy stability are critical to support retreat, but existing-use rights, liability concerns, special interests, community resources, place attachment, and divergent priorities at different levels of government present powerful constraints (*high confidence*; Hayward, 2008b; Berry and Vella, 2010; McDonald, 2010; Abel et al., 2011; Alexander et al., 2012; Leitch and Robinson, 2012; Macintosh et al., 2013; Reisinger et al., 2013).

the uncertain and dynamic nature of climate risk (McDonald, 2010; Stafford-Smith et al., 2011; Gorddard et al., 2012; McDonald, 2013; Reisinger et al., 2013).

Vulnerability assessments that take mid- to late-century impacts as their starting point can inhibit actors from implementing adaptation actions, as distant impacts are easily discounted and difficult to prioritize in competition with near-term non-climate change pressures (Productivity Commission, 2012). Emerging leading practice models in Australia (Balston, 2012; HCCREMS, 2012; SGS, 2012) and New Zealand (MfE, 2008a; Britton et al., 2011) recommend a high-level scan of sectors and locations at risk and emphasize a focus on near-term decisions that influence current and future vulnerability (which could range from early warning systems to strategic and planning responses). More detailed assessment can then focus on this more tractable subset of issues, based on explicit and iterative framing of the adaptation issue (Webb et al., 2013) and taking into account the full lifetime (lead- and consequence time) of the decision/asset in question (Stafford-Smith et al., 2011).

Participatory processes help balance societal preferences with robust scientific information and ensure ownership by affected communities but rely on human capital and political commitment (*high confidence*; Hobson and Niemeyer, 2011; Rouse and Blackett, 2011; Weber et al., 2011; Leitch and Robinson, 2012). Realizing widespread and equitable participation is challenging where policies are complex, debates polarized, legitimacy of institutions contested, and potential transformational changes threaten deeply held values (Gardner et al., 2009a; Gorddard et al., 2012; Burton and Mustelin, 2013; see also Section 25.4.3). Regional approaches that engage diverse stakeholders, government, and science providers, and support the co-production of knowledge can help overcome some of these problems but require long-term institutional and financial commitments (e.g., Britton et al., 2011; DSEWPC, 2011; CSIRO, 2012; IOCI, 2012; Low Choy et al., 2012; Webb and Beh, 2013).

There is active debate about the extent to which incremental adjustments of existing planning instruments, institutions, and decision-making processes can deal adequately with the dynamic and uncertain nature of climate change and support transformational responses (Kennedy et al., 2010; Preston et al., 2011; Park et al., 2012; Dovers, 2013; Lawrence et al., 2013b; McDonald, 2013; Stafford-Smith, 2013). Recent studies suggest a greater focus on flexibility and matching decision-making frameworks to specific problems (Hertzler, 2007; Nelson et al., 2008; Dobes, 2010; Howden and Stokes, 2010; Randall et al., 2012). Limitations of mainstreamed and autonomous adaptation and the case for more proactive government intervention are being explored in Australia (Productivity Commission, 2012; Johnston et al., 2013), but have not yet resulted in new policy frameworks.

25.4.3. Psychological and Sociocultural Factors Influencing Impacts of and Adaptation to Climate Change

Adapting to climate change relies on individuals accepting and understanding changing risks and opportunities, and responding to these changes both psychologically and behaviorally (see Chapters 2, 16). The majority of Australasians accept the reality of climate change and less than 10% fundamentally deny its existence (*high confidence*; ShapeNZ, 2009; Leviston et al., 2011; Lewandowsky, 2011; Milfont, 2012; Reser et al., 2012b). Australians perceive themselves to be at higher risk from climate change than New Zealanders and citizens of many other countries, which may reflect recent experiences of climatic extremes (Gifford et al., 2009; Agho et al., 2010; Ashworth et al., 2011; Milfont et al., 2012; Reser et al., 2012c). However, beliefs about climate change and its risks vary over time, are uneven across society, and reflect media coverage and bias, political preferences, and gender (ShapeNZ, 2009; Bacon, 2011; Leviston et al., 2012; Milfont, 2012), which can influence attitudes to adaptation (Gardner et al., 2010; Gifford, 2011; Reser et al., 2011; Alexander et al., 2012; Raymond and Spoehr, 2013).

Surveys in Australia between 2007 and 2011 show moderate to high levels of climate change concern, distress, frustration, resolve, psychological adaptation, and carbon-reducing behavior (*medium evidence*, *high agreement*; Agho et al., 2010; Reser et al., 2012b,c). About two-thirds of respondents expected global warming to worsen, with about half very or extremely concerned that they or their family would be affected directly. Direct experience with environmental changes or events attributed to climate change, reported by 45% of respondents, was particularly influential, but the extent to which resulting distress and concern translate into support for planned adaptation has not been fully assessed (Reser et al., 2012a,b).

Frequently Asked Questions

FAQ 25.1 | How can we adapt to climate change if projected future changes remain uncertain?

Many existing climate change impact assessments in Australia and New Zealand focus on the distant future (2050 to 2100). When contrasted with more near-term non-climate pressures, the inevitable uncertainty of distant climate impacts can impede effective adaptation. Emerging best practice in Australasia recognizes this challenge and instead focuses on those decisions that can and will be made in the near future in any case, along with the "lifetime" of those decisions, and the risk from climate change during that lifetime. Thus, for example, the choice of next year's annual crop, even though it is greatly affected by climate, only matters for a year or two and can be adjusted relatively quickly. Even land-use change among cropping, grazing, and forestry industries has demonstrated significant flexibility in Australasia over the space of a decade. When the adaptation challenge is reframed as *implications for near-term decisions*, uncertainty about the distant future becomes less problematic and adaptation responses can be better integrated into existing decision-making processes and early warning systems.

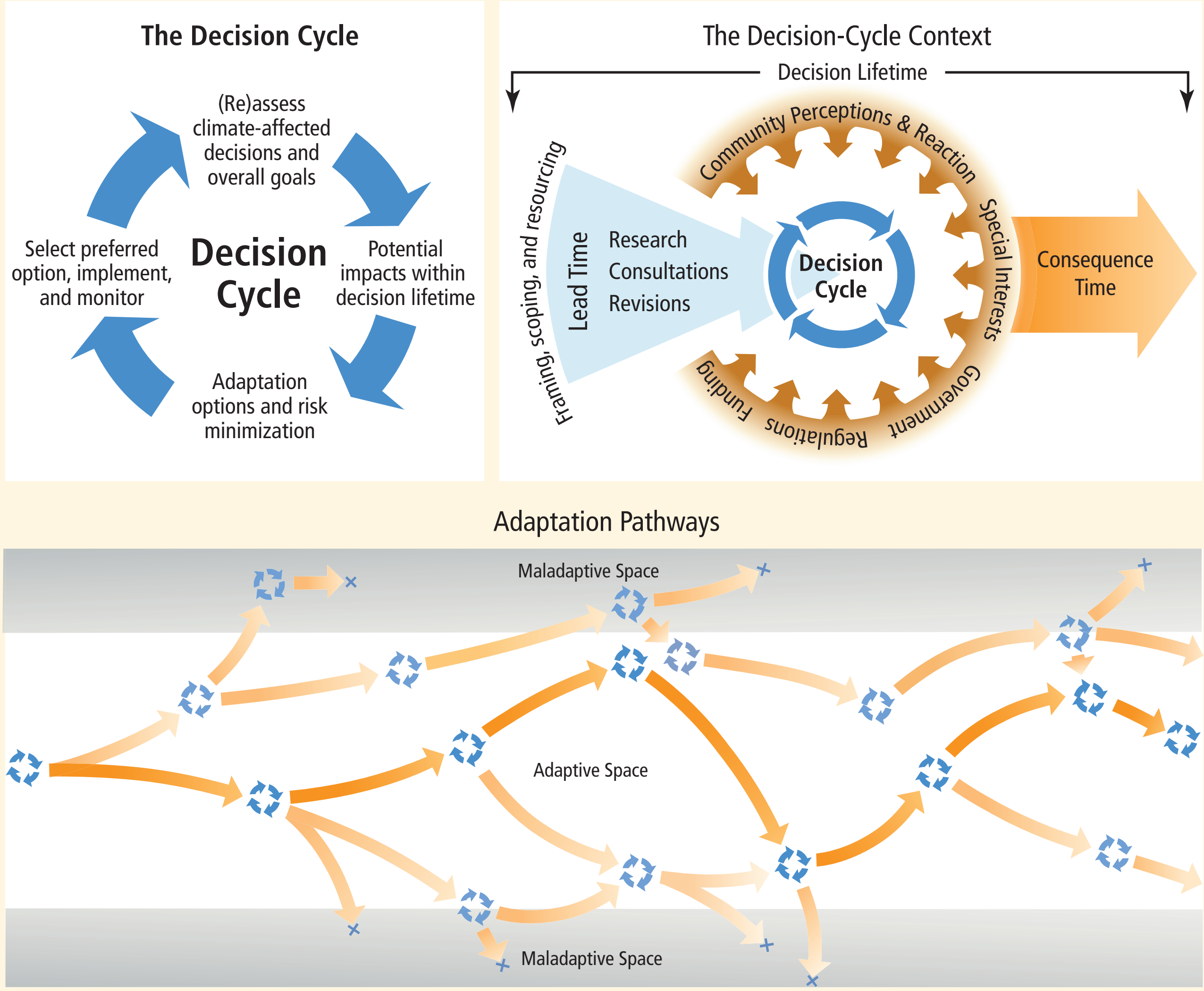

Figure 25-3 | Adaptation as an iterative risk management process. Individual adaptation decisions comprise well known aspects of risk assessment and management (top left panel). Each decision occurs within and exerts its own sphere of influence, determined by the lead and consequence time of the decision, and the broader regulatory and societal influences on the decision (top right panel). A sequence of adaptation decisions creates an adaptation pathway (bottom panel). There is no single "correct" adaptation pathway, although some decisions, and sequences of decisions, are more likely to result in long-term maladaptive outcomes than others, but the judgment of outcomes depends strongly on societal values, expectations, and goals.

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Frequently Asked Questions

FAQ 25.1 (continued)

Some decisions, such as those about long-lived infrastructure and spatial planning and of a public good nature, must take a long-term view and deal with significant uncertainties and trade-offs between short- and long-term goals and values. Even then, widely used techniques can help reduce challenges for decision making—including the "precautionary principle," "real options," "adaptive management," "no regrets strategies," or "risk hedging". These can be matched to the type of uncertainty but depend on a regulatory framework and institutions that can support such approaches, including the capacity of practitioners to implement them robustly.

Adaptation is not a one-off action but will take place along an evolving pathway, in which decisions will be revisited repeatedly as the future unfolds and more information comes to hand (see Figure 25-3). Although this creates learning opportunities, successive short-term decisions need to be monitored to avoid unwittingly creating an adaptation path that is not sustainable as climate change continues, or that would cope only with a limited subset of possible climate futures. This is sometimes referred to as maladaptation. Changing pathways—for example, shifting from ongoing coastal protection to gradual retreat from the most exposed areas—can be challenging and may require new types of interactions among governments, industry, and communities.

Perceived risks and potential losses from climate change depend on values associated by individuals with specific places, activities, and objects. Examples from Australia include the value placed on snow cover in the Snowy Mountains (Gorman-Murray, 2008, 2010), risks to biodiversity and recreational values in coastal South Australia (Raymond and Brown, 2011), conflicts between human uses and environmental priorities in national parks (Wyborn, 2009; Roman et al., 2010), and trade-offs between alternative water supplies and relocation in rural areas (Hurlimann and Dolnicar, 2011). These and additional studies in Australasia confirm that the more individuals identify with particular places and their natural features, the stronger the perceived potential loss but also the greater the motivation to address environmental threats (e.g., Rogan et al., 2005; McCleave et al., 2006; Collins and Kearns, 2010; Gosling and Williams, 2010; Raymond et al., 2011; Russell et al., 2013). This indicates that ecosystem-based climate change adaptation (see Box CC-EA) can provide co-benefits for subjective well-being and mental health, especially for disadvantaged and indigenous communities (Berry et al., 2010; see also Section 25.8.2).

At the same time, social and cultural values and norms can constrain adaptation options for communities by limiting the range of acceptable responses and processes (e.g., place attachment, differing values relating to near- versus long-term, private versus public, and economic versus environmental or social costs and benefits, and perceived legitimacy of institutions). Examples of this are particularly prominent in Australasia in the coastal zone (e.g., Hayward, 2008a; King et al., 2010; Gorddard et al., 2012; Hofmeester et al., 2012) and acceptance of water recycling or pricing (e.g., Pearce et al., 2007; Kouvelis et al., 2010; Mankad and Tapsuwan, 2011).

Overall, these studies give *high confidence* that the experience and threat of climate change and extreme climatic events are having appreciable psychological impacts, resulting in psychological and subsequent behavioral adaptations, reflected in high levels of acceptance and realistic concern; motivational resolve; self-reported changes in thinking, feeling, and understanding of climate change and its implications; and behavioral engagement (Reser and Swim, 2011; Reser et al., 2012a,b,c). However, adequate strategies and systems to monitor trends in psychological and social impacts, adaptation, and vulnerability are lacking, and such perspectives remain poorly integrated with and dominated by biophysical and economic characterizations of climate change impacts.

25.5. Freshwater Resources

25.5.1. Observed Impacts

Climate change impacts on water represent 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 interannual and inter-decadal variability of river flows (Chiew and McMahon, 2002; Peel et al., 2004; Verdon et al., 2004; McKerchar et al., 2010) particularly in Australia. Declining river flows since the mid-1970s in far southwestern Australia have led to changed water management (see Box 11.2 in Hennessy et al., 2007). The unprecedented decline in river flows during the 1997–2009 "Millennium" drought in southeastern Australia resulted in low irrigation water allocations, severe water restrictions in urban centers, suspension of water sharing arrangements, and major environmental impacts (Chiew and Prosser, 2011; Leblanc et al., 2012).

25.5.2. Projected Impacts

Figure 25-4 shows estimated changes to mean annual runoff across Australia for a 1°C global average warming above current levels (Chiew and Prosser, 2011; Teng et al., 2012). The range of estimates arises mainly from uncertainty in projected precipitation (Table 25-1). Hydrological modelling with CMIP3 future climate projections indicates that freshwater resources in far southeastern and far southwest Australia will decline (*high confidence*; by 0 to 40% and 20 to 70%, respectively, for 2°C warming) due to the reduction in winter precipitation (Table 25-1) when most of the runoff in southern Australia occurs. The percent change in mean annual precipitation in Australia is generally amplified as a two to three times larger percent change in mean annual stream flow (Chiew, 2006; Jones et al., 2006).

This can vary, however, with unprecedented declines in flow in far southeastern Australia in the 1997–2009 drought (Cai and Cowan, 2008; Potter and Chiew, 2011; Chiew et al., 2013). Higher temperatures and associated evaporation, tree regrowth following more frequent bushfires (Kuczera, 1987; Cornish and Vertessy, 2001; Marcar et al., 2006; Lucas et al., 2007), interceptions from farm dams (van Dijk et al., 2006; Lett et al., 2009), and reduced surface-groundwater connectivity in long dry spells (Petrone et al., 2010; Hughes et al., 2012) can further accentuate declines. In the longer-term, water availability will also be affected by changes in vegetation and surface-atmosphere feedbacks in a warmer and higher CO_2 environment (Betts et al., 2007; Donohue et al., 2009; McVicar et al., 2010).

In New Zealand, precipitation changes (Table 25-1) are projected to lead to increased runoff in the west and south of the South Island and reduced runoff in the northeast of the South Island, and the east and north of the North Island (*medium confidence*). Annual flows of eastward flowing rivers with headwaters in the Southern Alps (Clutha,

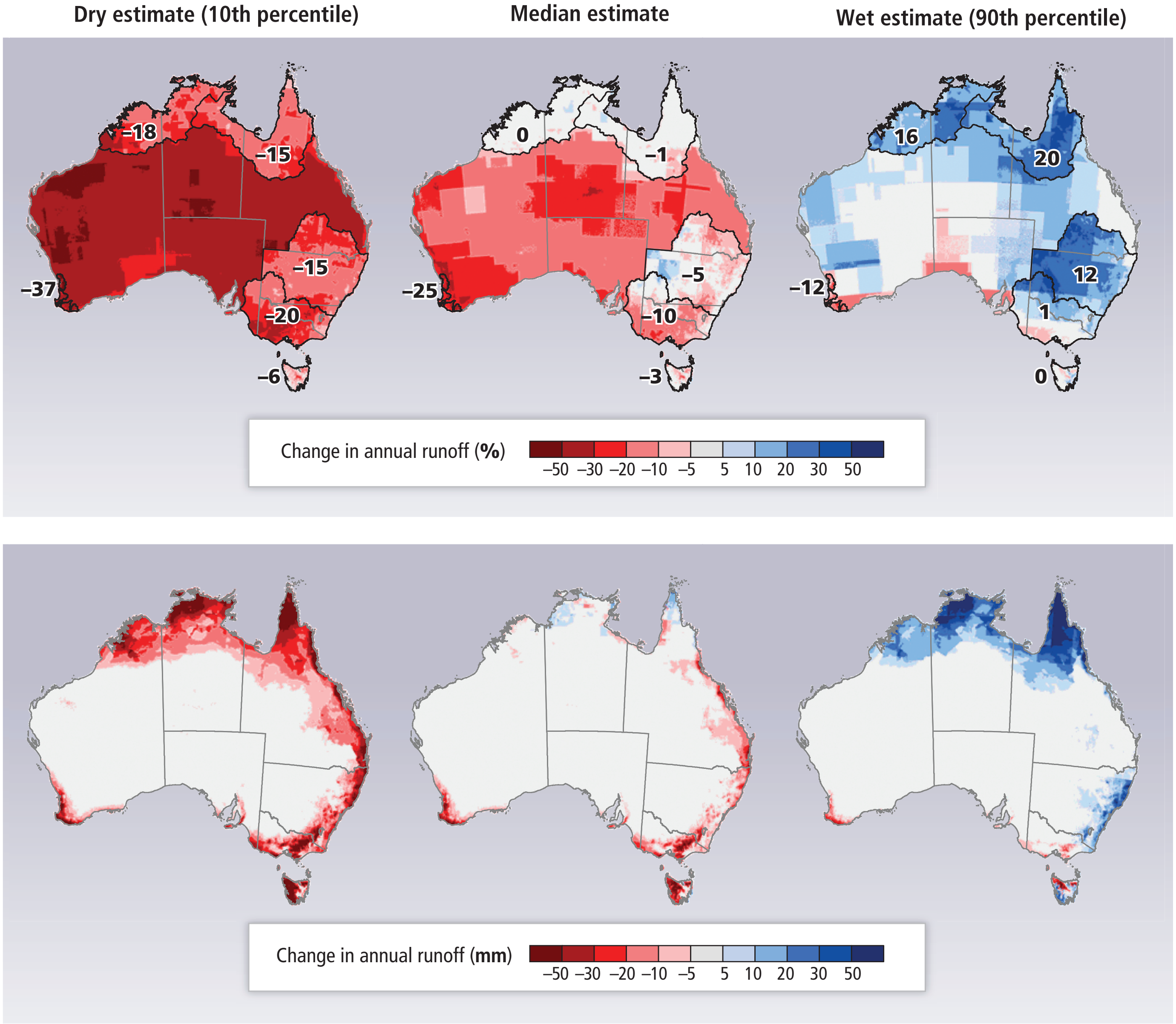

Figure 25-4 | Estimated changes in mean annual runoff for 1°C global average warming above current levels. Maps show changes in annual runoff (percentage change; top row) and runoff depth (millimeters; bottom row), for dry, median, and wet (10th to 90th percentile) range of estimates, based on hydrological modelling using 15 CMIP3 climate projections (Chiew et al., 2009; CSIRO, 2009; Petheram et al., 2012; Post et al., 2012). Projections for 2°C global average warming are about twice that shown in the maps (Post et al., 2011). (Figure adapted from Chiew and Prosser, 2011; Teng et al., 2012).

Waimakariri, Rangitata) are projected to increase by 5 to 10 % (median projection) by 2040 (Bright et al., 2008; Poyck et al., 2011; Zammit and Woods, 2011) in response to higher alpine precipitation. Most of the increases occur in winter and spring, as more precipitation falls as rain and snow melts earlier (Hendrikx et al., 2013). In contrast, the Ashley River, slightly north of this region, is projected to have little change in annual flows, with the increase in winter flows offset by reduced summer flows (Woods et al., 2008). The retreat of glaciers is expected to have only a minor impact on river flows in the first half of the century (Chinn, 2001; Anderson et al., 2008).

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 extreme rainfall intensity (*medium confidence*; Crosbie et al., 2010, 2012; McCallum et al., 2010). In New Zealand, a single study projects groundwater recharge in the Canterbury Plains to decrease by about 10% by 2040 (Bright et al., 2008). Climate change will also degrade water quality, particularly through increased material washoff following bushfires and floods (Boxes 25-6, 25-8).

25.5.3. Adaptation

The 1997–2009 drought in southeastern Australia and projected declines in future water resources in southern Australia are already stimulating adaptation (Box 25-2). In New Zealand, there is little evidence of water resources adaptation specifically to climate change. 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 (Memon and Skelton, 2007; Memon et al., 2010; Lennox et al., 2011; Weber et al., 2011) within national guidelines (LWF, 2010; MfE, 2011). Impacts of climate change on water supply, demand, and infrastructure have been considered by several New Zealand local authorities and consultancy reports (Jollands et al., 2007; Williams et al., 2008; Kouvelis et al., 2010), but no explicit management changes have yet resulted.

Box 25-2 | Adaptation through Water Resources Policy and Management in Australia

Widespread drought and projections of a drier future in southeastern and far southwest Australia (Bates et al., 2010; CSIRO, 2010; Potter et al., 2010; Chiew et al., 2011) saw extensive policy and management change in both rural and urban water systems (Hussey and Dovers, 2007; Bates et al., 2008; Melbourne Water, 2010; DSE, 2011; MDBA, 2011; NWC, 2011; Schofield, 2011). These management changes provide examples of adaptations, building on previous policy reforms (Botterill and Dovers, 2013). The broad policy framework is set out in the 2004 National Water Initiative and 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 recognizes climate change as a constraint on future water allocations. Official assessments (NWC, 2009, 2011) and critiques (Connell, 2007; Grafton and Hussey, 2007; Byron, 2011; Crase, 2011; Pittock and Finlayson, 2011) have discussed progress and shortcomings of the initiative, but assessment of its overall success is made difficult by other factors such as ongoing revisions to allocation plans and time lags to observable impacts.

Rural water reform in southeastern Australia, focused on the Murray-Darling Basin, is currently being implemented. The Murray-Darling Basin Plan (MDBA, 2011, 2012) will return 2750 GL yr^{-1} of consumptive water (about one-fifth of current entitlements) to riverine ecosystems and develop flexible and adaptive water sharing mechanisms to cope with current and future climates. In 2012, the Australian government committed more than AU$12 billion nationally to upgrade water infrastructure, improve water use efficiency, and purchase water entitlements for environmental use. The Basin Plan also includes an environmental watering plan to optimize environmental outcomes for the Basin. Water markets are a key policy instrument, allowing water use patterns to adapt to shifting availability and water to move toward higher value uses (NWC, 2010; Kirby et al., 2012). For example, the two-thirds reduction in irrigation water use over 2000–2009 in the Basin resulted in only 20% reduction in gross agricultural returns, mainly because water use shifted to more valuable enterprises (Kirby et al., 2012). Elsewhere, catchment management authorities and State agencies throughout southeastern Australia develop water management strategies to cope with prolonged droughts and climate change (e.g., DSE, 2011). Nevertheless, if the extreme dry end of future water projections is realized (Section 25.5.2; Figure 25-4), agriculture and ecosystems across southeastern and southwestern Australia would be threatened even with comprehensive adaptation (see Sections 25.6.1, 25.7.1-2; Connor et al., 2009; Kirby et al., 2013).

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Box 25-2 (continued)

Climate change and population growth are the two major factors that influence water planning in Australian capital cities. In Melbourne, for example, planning has centered on securing new supplies that are more resilient to major climate shocks; increasing use of alternative sources such as sewage recycling and stormwater for non-potable water; programs to reduce demand; water-sensitive urban design; and integrated planning that considers climate change impact on water supply, flood risk, and stormwater and wastewater infrastructures (DSE, 2007; Skinner, 2010; DSE, 2011; Rhodes et al., 2012). Melbourne's water augmentation program includes a desalinization plant with a 150 GL yr^{-1} capacity (about one-third of the current demand), following the lead of Perth, where a desalinization plant was established in 2006 because of declining inflows since the mid-1970s (Rhodes et al., 2012). 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 use restrictions since the early 2000s, have reduced Melbourne's total per capita water use by 40% (Fitzgerald, 2009; Rhodes et al., 2012). Similar programs reduced Brisbane's per capita water use by about 50% (Shearer, 2011), while adoption of water recycling and rainwater harvesting resulted in up to 60% water savings in some parts of Adelaide (Barton and Argue, 2009).

The success of urban water reforms in the face of drought and climate change can be variously interpreted. Increasing supply through desalinization plants and water reuse schemes reduces the risk of future water shortages and helps cities cope with increasing population. Uptake of household-scale adaptation options has been locally significant but their long-term sustainability or reversibility in response to changing drivers and societal attitudes needs further research (Troy, 2008; Brown and Farrelly, 2009; Mankad and Tapsuwan, 2011). Desalinization plants can be maladaptive because of their energy demand, and the enhancement of mass supply could create a disincentive for reducing demand or increasing resilience through diversifying supply (Barnett and O'Neill, 2010; Taptiklis, 2011).

25.6. Natural Ecosystems

25.6.1. Inland Freshwater and Terrestrial Ecosystems

Terrestrial and freshwater ecosystems have suffered high rates of habitat loss and species extinctions since European settlement in both Australia and New Zealand (Kingsford et al., 2009; Bradshaw et al., 2010; McGlone et al., 2010; Lundquist et al., 2011; SoE, 2011); many reserves are small and isolated, and some key ecosystems and species under-represented (Sattler and Taylor, 2008; MfE, 2010a; SoE, 2011). Many freshwater ecosystems are pressured from over-allocation and pollution, especially in southern and eastern coastal regions in Australia (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). These increase vulnerability to rapid climate change and provide challenges for both autonomous and managed adaptation (Steffen et al., 2009).

25.6.1.1. Observed Impacts

In Australian terrestrial systems, some recently observed changes in the distribution, genetics, and phenology of individual species, and in the structure and composition of some ecological communities, can be attributed to recent climatic trends (*medium* to *high confidence*; see Box 25-3). Uncertainty remains regarding the role of non-climatic drivers, including changes in atmospheric CO_2, fire management, grazing, and land use. The 1997–2009 drought had severe impacts in freshwater systems in the eastern States and the Murray-Darling Basin (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, exotic invasions, and natural climate variability (Jenkins et al., 2011). In New Zealand, few if any impacts on ecosystems have been directly attributed to climate change rather than variability (Box 25-3; McGlone et al., 2010; McGlone and Walker, 2011). Alpine treelines in New Zealand have remained roughly stable for several hundred years (*high confidence*) despite 0.9°C average warming over the past century (McGlone and Walker, 2011; Harsch et al., 2012).

25.6.1.2. Projected Impacts

Existing environmental stresses will interact with, and in many cases be exacerbated by, shifts in mean climatic conditions and associated change in the frequency or intensity of extreme events, especially fire, drought, and floods (*high confidence*; Steffen et al., 2009; Bradstock, 2010; Murphy et al., 2012). Recent drought-related mortality has been observed for amphibians in southeast Australia (Mac Nally et al., 2009), savannah trees in northeast Australia (Fensham et al., 2009; Allen et al., 2010), Mediterranean-type eucalypt forest in southwest Western

Australia (Matusik et al., 2013), and eucalypts in sub-alpine regions in Tasmania (Calder and Kirkpatrick, 2008). Mass die-offs of flying foxes and cockatoos have been observed during heat waves (Welbergen et al., 2008; Saunders et al., 2011). These examples provide *high confidence* that extreme heat and reduced water availability, either singly or in combination, will be significant drivers of future population losses and will increase the risk of local species extinctions in many areas (e.g., McKechnie and Wolf, 2010; see also Figure 25-5).

Species distribution modeling (SDM) consistently indicates future range contractions for Australia's native species even assuming optimistic rates of dispersal, for example, Western Australian *Banksia* spp. (Fitzpatrick et al., 2008), koalas (Adams-Hosking et al., 2011), northern macropods (Ritchie and Bolitho, 2008), native rats (Green, K. et al., 2008), greater gliders (Kearney et al., 2010b), quokkas (Gibson et al., 2010), platypus (Klamt et al., 2011), birds (Garnett et al., 2013; van der Wal et al., 2013), and fish (Bond 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 physiological (Kearney et al., 2010b) and demographic models (Keith et al., 2008; Harris et al., 2012), genetic estimates of dispersal capacity (Duckett et al., 2013), and incorporation into broader risk assessments (e.g., Williams et al., 2008; Crossman et al., 2012).

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 (e.g., Laurance et al., 2011; Murphy et al., 2012). There is *very high confidence* that one of the most vulnerable Australian ecosystems is the alpine zone because of loss of snow cover, invasions by exotic species, and changed species interactions (reviewed in Pickering et al., 2008). There is also *high confidence* in substantial risks to coastal wetlands such as Kakadu National Park subject to saline intrusion (BMT WBM, 2011); tropical savannahs subject to changed fire regimes (Laurance et al., 2011); inland freshwater and groundwater systems subject to drought, over-allocation, and altered timing of floods (Pittock et al., 2008; Jenkins et al., 2011; Pratchett et al., 2011); peat-forming wetlands along the east coast subject to drying (Keith et al., 2010); and biodiversity-rich regions such as southwest Western Australia (Yates et al., 2010a,b) and tropical and subtropical rain forests in Queensland subject to drying and warming (Stork et al., 2007; Shoo et al., 2011; Murphy et al., 2012; Hagger et al., 2013).

The very few studies of climate change impacts on biodiversity in New Zealand suggest that ongoing impacts of invasive species (Box 25-4) and habitat loss will dominate climate change signals in the short to medium term (McGlone et al., 2010), but that climate change has 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 increased 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; Winterbourn et al., 2008; Hitchings, 2009; McGlone and Walker, 2011) and increased spring flooding may increase risks for braided-river bird species (MfE, 2008b). For some restricted native species, suitable habitat 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 persisted during higher temperatures in the geological past (McGlone and Walker, 2011).

25.6.1.3. 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 than in Australia. Anticipated rates of climate change, together with fragmentation of remaining habitat and limited migration options in many regions (Steffen et al., 2009; Morrongiello et al., 2011), will limit *in situ* adaptive capacity and distributional shifts to more climatically suitable areas for many species (*high confidence*). Significant local and global losses of species, functional diversity, and ecosystem services, and large-scale changes in ecological communities, are anticipated (e.g., Dunlop et al., 2012; Gallagher et al., 2012b; Murphy et al., 2012).

There is increasing recognition in Australia that rapid climate change has fundamental implications for traditional conservation objectives (e.g., Steffen et al., 2009; Prober and Dunlop, 2011; Dunlop et al., 2012; Murphy et al., 2012). Research on impacts and adaptation in terrestrial and freshwater systems has been guided by the National Adaptation Research Plans (Hughes et al., 2010; Bates et al., 2011) and by research undertaken within the CSIRO Climate Adaptation Flagship. Climate change adaptation plans developed by many levels of government and Natural Resource Management (NRM) bodies, supported by substantial Australian government funding, have identified priorities that include identification and protection of climatic refugia (Davis et al., 2013; Reside et al., 2013); 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); protecting and restoring habitat connectivity in association with expansion of the protected area network (Dunlop and Brown, 2008; Mackey et al., 2008; Taylor and Philp, 2010; Prowse and Brook, 2011; Maggini et al., 2013); and active interventionist strategies such as assisted colonization to reduce probability of species extinctions (Burbidge et al., 2011; McIntyre, 2011) or restore ecosystem services (Lunt et al., 2013). Few specific measures have been implemented and thus their effectiveness cannot yet be assessed. Biodiversity research and management in New Zealand to date has taken little account of climate change-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 to improve ecosystem resilience to future climate threats (McGlone et al., 2010; McGlone and Walker, 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 (Section 25.9.1; Box 25-10). Assessments of the impacts of climate change on the provision of ecosystem services (such as pollination and erosion control) via impacts on terrestrial and freshwater ecosystems are generally lacking. Similarly, the concept of Ecosystem-based Adaptation—the role of healthy, well-functioning ecosystems in increasing the resilience of human sectors to the impacts of climate change (see Chapters 4 and 5; Box CC-EA)—is relatively unexplored.

25.6.2. 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 approximately 8.1 million km^2, excluding the Australian Antarctic Territory (Richardson and Poloczanska, 2009). New Zealand has approximately 18,000 km of coastline, spanning subtropical to sub-Antarctic waters, and the world's fifth largest Exclusive Economic Zone at 4.2 million km^2 (Gordon et al., 2010). The marine ecosystems of both countries are considered hotspots of global marine biodiversity with many rare, endemic, and commercially important species (Hoegh-Guldberg et al., 2007; Blanchette et al., 2009; Gordon et al., 2010; Gillanders et al., 2011; Lundquist et al., 2011). The increasing density of coastal populations (see Section 25.3) and stressors such as pollution and sedimentation from settlements and agriculture will intensify non-climate stressors in coastal areas (*high confidence*; e.g., Russell et al., 2009). Coastal habitats provide many ecosystem services including coastal protection (Arkema et al., 2013) and carbon storage, particularly in seagrass, saltmarsh, and mangroves, which could become increasingly important for mitigation (e.g., Irving et al., 2011). Coastal ecosystems occupy less than 1% of the land mass but may account for 39% of Australia's average national annual carbon burial (estimated total: 466 millions tonnes CO_2-eq per year; Lawrence et al., 2012).

25.6.2.1. Observed Impacts

There is *high confidence* that climate change is already affecting the oceans around Australia (Pearce and Feng, 2007; Poloczanska et al., 2007; Lough and Hobday, 2011) and warming the Tasman sea in northern New Zealand (Sutton et al., 2005; Lundquist et al., 2011); average climate zones have shifted south by more than 200 km along the northeast and about 100 km along the northwest Australian coasts since 1950 (Lough, 2008). The rate of warming is even faster in southeast Australia, with a poleward advance of the East Australia Current of approximately 350 km over the past 60 years (Ridgway, 2007). Based on elevated rates of ocean warming, southwest and southeast Australia are recognized as global warming hotspots (Wernberg et al., 2011). It is *virtually certain* that the increased storage of carbon by the ocean will increase acidification in the future, continuing the observed trends of the past decades in Australia as elsewhere (Howard et al., 2012; see also WGI AR5 Sections 3.8, 6.44).

Recently observed changes in marine systems around Australia are consistent with warming oceans (*high confidence*; Box 25-3). Examples include changes in phytoplankton productivity (Thompson et al., 2009; Johnson et al., 2011); species abundance of macroalgae (Johnson et al., 2011); growth rates of abalone (Johnson et al., 2011), southern rock lobster (Pecl et al., 2009; Johnson et al., 2011), coastal fish (Neuheimer et al., 2011), and coral (De'ath et al., 2009); life cycles of southern rock lobster (Pecl et al., 2009) and seabirds (Cullen et al., 2009; Chambers et al., 2011); and distribution of subtidal seaweeds (Johnson et al., 2011; Wernberg et al., 2011; Smale and Wernberg, 2013), plankton (Mcleod et al., 2012), fish (Figueira et al., 2009; Figueira and Booth, 2010; Last et al., 2011; Madin et al., 2012), sea urchins (Ling et al., 2009), and intertidal invertebrates (Pitt et al., 2010).

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 southeast Australia, where warming has been greatest. The 2011 marine heat wave in Western Australia caused the first-ever reported bleaching at Ningaloo reef (Abdo et al., 2012; Feng et al., 2013), resulting in coral mortality (Moore et al., 2012; Depczynski et al., 2013) and changes in community structure and composition (Smale and Wernberg, 2013; Wernberg et al., 2013). About 10% of the observed 50% decline in coral cover on the Great Barrier Reef since 1985 has been attributed to bleaching, the remainder to cyclones and predators (De'ath et al., 2012).

Changes in distribution and abundance of marine species in New Zealand are primarily linked to ENSO-related variability that dominates in many time series (Clucas, 2011; Lundquist et al., 2011; McGlone and Walker, 2011; Schiel, 2011), although water temperature is also important (e.g., Beentjes and Renwick, 2001). New Zealand fisheries exported more than NZ$1.5 billion worth of product in 2012 (SNZ, 2013) and variability in ocean circulation and temperature plays an important role in local fish abundance (e.g., Chiswell and Booth, 2005; Dunn et al., 2009); no climate change impacts have been reported at this stage (Dunn et al., 2009), although this may be due to insufficient monitoring.

25.6.2.2. Projected Impacts

Even though evidence of climate impacts on coastal habitats is limited to date, *confidence* is *high* that negative impacts will arise with continued climate change (Lovelock et al., 2009; McGlone and Walker, 2011; Traill et al., 2011; Chapter 6). Some coastal habitats such as mangroves are projected to expand further landward, driven by sea level rise and exacerbated by soil subsidence if rainfall declines (*medium confidence*; Traill et al., 2011), although this may be at the expense of saltmarsh and constrained in many regions by the built environment (DCC, 2009; Lovelock et al., 2009; Rogers et al., 2012). Estuarine habitats will be affected by changing rainfall or sediment discharges, as well as connectivity to the ocean (*high confidence*; Gillanders et al., 2011). Loss of coastal habitats and declines in iconic species will result in substantial impacts on coastal settlements and infrastructure from direct impacts such as storm surge, and will affect tourism (*medium confidence*; Section 25.7.5).

Changes in temperature and rainfall, and sea level rise, are expected to lead to secondary effects, including erosion, landslips, and flooding, affecting coastal habitats and their dependent species, for example, loss of habitat for nesting birds (*high confidence*; Chambers et al., 2011). Increasing ocean acidification is expected to affect many taxa (*medium confidence*; see also Box CC-OA; Chapters 6, 30) including corals (Fabricius et al., 2011), coralline algae (Anthony et al., 2008), calcareous plankton (Richardson et al., 2009; Thompson et al., 2009; Hallegraeff, 2010), reef fishes (Munday et al., 2009; Nilsson et al., 2012), bryozoans, and other benthic calcifiers (Fabricius et al., 2011). Deep-sea scleractinian corals are also expected to decline with ocean acidification (Miller et al., 2011).

The AR4 identified the Great Barrier Reef as highly vulnerable to both warming and acidification (Hennessy et al., 2007). Recent observations of bleaching (GBRMPA, 2009a) and reduced calcification in both the Great Barrier Reef and other reef systems (Cooper et al., 2008; De'ath et al., 2009; Cooper et al., 2012), along with model and experimental studies (Hoegh-Guldberg et al., 2007; Anthony et al., 2008; Veron et al., 2009) confirm this vulnerability (see also Box CC-CR). The combined impacts of warming and acidification associated with atmospheric CO_2 concentrations in excess of 450 to 500 ppm are projected to be associated with increased frequency and severity of coral bleaching, disease incidence and mortality, in turn leading to changes in community composition and structure including increasing dominance by macroalgae (*high confidence*; Hoegh-Guldberg et al., 2007; Veron et al., 2009). Other stresses, including rising sea levels, increased cyclone intensity, and nutrient-enriched and freshwater runoff, will exacerbate these impacts (*high confidence*; Hoegh-Guldberg et al., 2007; Veron et al., 2009; GBRMPA, 2013). Thermal thresholds and the ability to recover from bleaching events vary geographically and between species (e.g., Diaz-Pulido et al., 2009) but evidence of 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 (*robust evidence*, *medium agreement*; Hoegh-Guldberg, 2012; Howells et al., 2013; Box CC-CR).

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 (*high confidence*; Hobday, 2010). 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). Poleward movements are also projected for coastal fish species in Western Australia (Cheung et al., 2012) and a complex suite of impacts are expected for marine mammals (Schumann et al., 2013). A strengthening East Auckland Current in northern New Zealand is expected to promote establishment of tropical or subtropical species that currently occur as vagrants in warm La Niña years (Willis et al., 2007). Such shifts suggest potentially substantial changes in production and profit of both wild fisheries (Norman-Lopez et al., 2011) and aquaculture species such as salmon, mussels, and oysters (*medium confidence*; Hobday et al., 2008; Hobday and Poloczanska, 2010). Ecosystem models also project changes to habitat and fisheries production (*low confidence*; Fulton, 2011; Watson et al., 2012).

25.6.2.3. Adaptation

In Australia, research on marine impacts and adaptation has been guided by the National Adaptation Research Plan for Marine Biodiversity and Resources (Mapstone et al., 2010), programs within the CSIRO Climate Adaptation Flagship, and the Great Barrier Reef Marine Park Authority (GBRMPA, 2007). Limits to autonomous adaptation are unknown for almost all species, although limited experiments suggests capacity for response on a scale comparable to projected warming for some species (e.g., coral reef fish; Miller et al., 2012) and not others (e.g., Antarctic krill; Kawaguchi et al., 2013). Planned adaptation options include removal of human barriers to landward migration of species, beach nourishment, management of environmental flows to maintain estuaries (Jenkins et al., 2010), habitat provision (Hobday and Poloczanska, 2010), assisted colonization of seagrass and species such as turtles (e.g., Fuentes et al., 2009), and burrow modification for nesting seabirds (Chambers et al., 2011).

For southern species on the continental shelf, options are more limited because suitable habitat will not be present—the next shallow water to the south is Macquarie Island. There is *low confidence* about the adequacy of autonomous rates of adaptation by species, although recent experiments with coral reef fish suggest that some species may adapt to the projected climate changes (Miller et al., 2012).

Management actions to increase coral reef resilience include reducing fishing pressure on herbivorous fish, protecting top predators, managing runoff quality, and minimizing other human disturbances, especially through marine protected areas (Hughes et al., 2007; Veron et al., 2009; Wooldridge et al., 2012). Such actions will slow, but not prevent, long-term degradation of reef systems once critical thresholds of ocean temperature and acidity are exceeded (*high confidence*), and so novel options, including assisted colonization and shading critical reefs, have been proposed but remain untested at scale (Rau et al., 2012). Seasonal forecasting can also prepare managers for bleaching events (Spillman, 2011).

Adaptation by the fishing industry to shifting distributions of target species is considered possible by most stakeholders (e.g., southern rock lobster fishery; Pecl et al., 2009). Assisted colonization to maintain production in the face of declining recruitment may also be possible for some high value species, and has been trialed for the southern rock lobster (Green, B.S. et al., 2010). Options for aquaculture include disease management, alternative site selection, and selective breeding (Battaglene et al., 2008), but implementation is only preliminary. Marine protected area planning is not explicitly considering climate change in either country, but reserve performance will be affected by projected environment shifts and novel combinations of species, habitats, and human pressures (Hobday, 2011).

25.7. Major Industries

25.7.1. Production Forestry

Australia has about 149 Mha of forests, including woodlands. Two Mha are plantations and 9.4 Mha multiple-use native forests, and forestry contributes around AU$7 billion annually to GDP (ABARES, 2012). New Zealand's plantation estate in production forests comprises about 1.7 Mha (90% *Pinus radiata*), with recent contractions due to increased profitability of dairying (FOA and MPI, 2012; MfE, 2013).

Box 25-3 | Impacts of a Changing Climate in Natural and Managed Ecosystems

Observed changes in species, and in natural and managed ecosystems (Sections 25.6.1-2, 25.7.2) provide multiple lines of evidence of the impacts of a changing climate. Examples of observations published since the AR4 are shown in Table 25-3.

Table 25-3 | Examples of detected changes in species, natural and managed ecosystems, consistent with a climate change signal, published since the AR4. Confidence in detection of change is based on the length of study and the type, amount, and quality of data in relation to the natural variability in the particular species or system. Confidence in the role of climate being a major driver of the change is based on the extent to which the detected change is consistent with that expected under climate change, and to which other confounding or interacting non-climate factors have been considered and been found insufficient to explain the observed change. (SST = sea surface temperature; EAC = East Australian Current.)

Type of change and nature of evidence	Examples	Time scale of observations	Confidence in the detection of biological change	Potential climate change driver(s)	Confidence in the role of climate vs other drivers
Morphology *Limited evidence* (one study)	Declining body size of southeast Australian passerine birds, equivalent to ~7° latitudinal shift (Gardner et al., 2009)	About 100 years	*Medium*: Trend significant for 4 out of 8 species; 2 other species show same trend but not statistically significant	Warming air temperatures about 1.0°C over same period	*Medium*: Nutritional cause discounted
Geographic distribution *High agreement*, *robust evidence* for many marine species and mobile terrestrial species	Southerly range extension of the barrens-forming sea urchin *Centrostephanus rodgersii* from the New South Wales 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, 2009; Banks et al., 2010)	About 30–50 years (first recorded in Tasmania in late 1970s)	*High*	Increased SST, ocean warming in southeast Australia, increased southerly penetration of the EAC, 350 km over 60 years	*High*
	45 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 in southeast Australia, increased southerly penetration of the 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).	About 50 years; sites resampled 2007–2008, compared with 1950s	*Medium*	Increased SST in southeast 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 toward later life cycle events in some taxa; see meta-analysis for Southern Hemisphere phenology (Chambers et al., 2013a)	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., 2010)	65 years	*High*	Increase in local air temperatures of 0.16°C per decade (1945–2007)	*High*: Advance consistent with physiologically based model of temperature influence on development
	Advances in spring phenology of migratory birds, and both advances and delays in phenology in other seasons at multiple Australian sites: meta-analysis of 52 species and 145 data sets (Chambers et al., 2013b)	Multiple time periods from 1960s, all included 1990s and 2000s	*High*	Local climate trends (increasing air temperature, decreased rain days) were more important than broad-scale drivers such as the Southern Oscillation Index. Strongest associations were with decreased rain days.	*High*: No other potential confounding factors identified
	Earlier wine-grape ripening at 9 of 10 sites in Australia (Webb, L. B. 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

Continued next page →

Box 25-3 (continued)

Table 25-3 (continued)

Type of change and nature of evidence	Examples	Time scale of observations	Confidence in the detection of biological change	Potential climate change driver(s)	Confidence in the role of climate vs other drivers
Marine productivity *Limited evidence, medium agreement*	Otolith ("ear stone") analyses in long-lived Pacific fish indicates significantly increased growth rates for shallow-water species (<250 m) (3 of 3 species), reduced growth rates of deep-water (>1000 m) 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 250 m associated with warming SST, declining growth rates in species >1000 m associated with long-term cooling (as indicated by Mg/Ca ratios and change in ^{18}O in deep water corals)	*Medium*: Changed fishing pressure may have contributed to trend.
	About a 50% decline in growth rate and biomass of spring phytoplankton bloom in western Tasman Sea (Thompson et al., 2009)	60-year data set; decline recorded over period 1997–2007	*High*	Increased SST and extension of the EAC associated with reduced nutrient availability	*Medium*
Vegetation change *Limited agreement and 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 savannah and grassland in Northern Territory, Australia (Banfai and Bowman, 2007; Bowman et al., 2010)	About 40 years	*Medium*	Increases in rainfall 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 southeast Australia (Keith et al., 2010)	Weather data covers >40 years (depending on parameter); vegetation mapping from 1961 to 1998.	*Medium*	Decline in evapo-transpiration	*Low*: Resource exploitation, fire history, and autogenic mire development discounted
Freshwater communities *Limited evidence* (one study)	Decline in families of macroinvertebrates that favor cooler, faster-flowing habitats in New South Wales streams and increase in families favoring 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 1993–1994) (Bruno et al., 2007; Sato et al., 2009; Dalton et al., 2010)	1998 onwards	*Medium*	Increasing SST	*High*
Coral reefs *Robust evidence, high agreement*	Multiple mass bleaching events since 1979 (see Sections 25.6.2 and 30.5)	1979 onwards	*High*	Increasing SST	*High*
	Calcification of *Porites* on GBR declined 21% (1971–2003, 4 reefs; Cooper et al., 2008); about 11% (1990–2005, 69 reefs; De'ath et al., 2009)	1971–2003; 1990–2005	*High*	Increasing SST	*High*: Changes in water quality discounted

25.7.1.1. Observed and Projected Impacts

Existing climate variability and other confounding factors have so far prevented the detection of climate change impacts on forests. Modeled projections are based on ecophysiological responses of forests to CO_2, water, and temperatures. In Australia, potential changes in water availability will be most important (*very high confidence*; e.g., reviews by Battaglia et al., 2009; Medlyn et al., 2011b). Modeling future distributions or growth rates indicate that plantations in southwest 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 tolerances (Medlyn et al., 2011a). Moderate reductions in rainfall and increased temperature could be offset by fertilization from increasing CO_2 (*limited evidence*, *medium agreement*; Simioni et al., 2009). In cool regions where water is not limiting, higher temperatures could benefit production (Battaglia et al., 2009). In New Zealand, temperatures are mostly sub-optimal for growth of *P. radiata* and water relations are generally less limiting (Kirschbaum and Watt, 2011). Warming is expected to increase *P. radiata* growth in the cooler south (*very high confidence*), whereas in the warmer north, temperature increases can reduce productivity, but CO_2 fertilization may offset this (*medium confidence*; Kirschbaum et al., 2012).

Modeling studies are limited by their reliance on key assumptions which are difficult to verify experimentally, for example, the degree to which photosynthesis remains stimulated under elevated CO_2 (Battaglia et al., 2009). Most studies also exclude impacts of pests, diseases, weeds, fire, and wind damage that may change adversely with climate. Fire, for instance, poses a significant threat in Australia and is expected to worsen with climate change (see Box 25-6), especially for the commercial forestry plantations in the southern winter-rainfall regions (Williams et al., 2009; Clarke et al., 2011). In New Zealand, changes in biotic factors are particularly important as they already affect plantation productivity. *Dothistroma* blight, for instance, is a serious pine disease with a temperature optimum that coincides with New Zealand's warmer, but not warmest, pine-growing regions; under climate change, its severity is, therefore, expected to reduce in the warm central North Island but increase in the cooler South Island (*high confidence*) where it could offset temperature-driven improved plantation growth (Watt et al., 2011a). 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).

25.7.1.2. Adaptation

Depending on the extent of climate changes and plant responses to increasing CO_2, the above studies provide *limited evidence* but *high agreement* of potential net increased productivity in many areas, but only where soil nutrients are not limiting. Adaptation strategies include changes to species or provenance selection toward trees better adapted to warmer conditions, or adopting different silvicultural options to increase resilience to climatic or biotic stresses, such as pest challenges (White et al., 2009; Booth et al., 2010; Singh et al., 2010; Wilson and Turton, 2011a). The greatest barriers to long-term adaptation planning are incomplete knowledge of plant responses to increased CO_2 and uncertainty in regional climate scenarios (*medium evidence*, *high agreement*; Medlyn et al., 2011b). The rotation time of plantation forests of about 30 years or more makes proactive adaptation important but also challenging.

25.7.2. Agriculture

Australia produces 93% of its domestic food requirements and exports 76% of agricultural production (PMSEIC, 2010a). New Zealand agriculture contributes about 56% of total export value and dairy products 27%; 95% of dairy products are exported (SNZ, 2012b). Agricultural production is sensitive to climate (especially drought; Box 25-5) but also to many non-climate factors such as management, which thus far has limited both detection and attribution of climate-related changes (see Chapters 7, 18; Webb, L.B. et al., 2012; Darbyshire et al., 2013). Because the region is a major exporter—providing, for example, more than 40% of the world trade in dairy products—changes in production conditions in the region have a major influence on world supply (OECD, 2011). This implies that climate change impacts could have consequences for food security not just locally but even globally (Qureshi et al., 2013a).

25.7.2.1. Projected Impacts and Adaptation—Livestock Systems

Livestock grazing dominates land use by area in the region. At the Australian national level, the net effect of a 3°C temperature increase (from a 1980–1999 baseline) is expected to be a 4% reduction in gross value of the beef, sheep, and wool sector (McKeon et al., 2008). Dairy productivity is projected to decline in all regions of Australia other than Tasmania under a mid-range (A1B) climate scenario by 2050 (Hanslow et al., 2013). Projected changes in national pasture production for dairy, sheep, and beef pastures in New Zealand range from an average reduction of 4% across climate scenarios for the 2030s (Wratt et al., 2008) to increases of up to 4% for two scenarios in the 2050s (Baisden et al., 2010) when the models included CO_2 fertilization and nitrogen feedbacks.

Studies modeling seasonal changes in fodder supply show greater sensitivity in animal production to climate change and elevated CO_2 than models using annual average production, with some impacts expected even under modest warming (*high confidence*) in both New Zealand (Lieffering et al., 2012) and Australia (Moore and Ghahramani, 2013). Across 25 sites in southern Australia (an area that produces 85% of sheep and 40% of beef production by value) modeled profitability declined at most sites by the 2050s because of a shorter growing season due to changes in both rainfall and temperature (Moore and Ghahramani, 2013). In New Zealand, projected changes in seasonal pasture growth drove changes in animal production at four sites representing the main areas of sheep production (Lieffering et al., 2012). In Hawke's Bay, changes in stock number and the timing of grazing were able to maintain farm income for a period in the face of variable forage supply but not in the longer term. In Southland and Waikato, projected increases in early spring pasture growth posed management problems in maintaining pasture quality, yet, if these were met, animal production could be maintained or increased. The temperature-humidity index (THI), an indicator of potential heat stress for animals, increased from 1960 to 2008 in the Murray Dairy region of Australia and further increases and reductions in milk production are projected (Nidumolu et al., 2011). Shading can substantially reduce, but not avoid, the temperature and humidity effects that produce a high THI (Nidumolu et al., 2011).

Rainfall is a key determinant of interannual variability in production and profitability of pastures and rangelands (Radcliffe and Baars, 1987; Steffen et al., 2011) yet remains the most uncertain change. In northern Australia, incremental adaptation may be adequate to manage risks of climate change to the grazing industry but an increasing frequency of droughts and reduced summer rainfall will potentially drive the requirement for transformational change (Cobon et al., 2009). Rangelands that are currently water-limited are expected to show greater sensitivity to temperature and rainfall changes than nitrogen-limited ones (Webb, N.P. et al., 2012). The "water-sparing" effect of elevated CO_2 (offsetting reduced water availability from reduced rainfall and increased temperatures) is invoked in many impact studies but does not always translate into production benefits (Kamman et al., 2005; Newton et al., 2006; Stokes and Ash, 2007; Wan et al., 2007). The impact of elevated CO_2 on forage production, quality, nutrient cycling, and water availability remains the major uncertainty in modeling system responses (McKeon et al., 2009; Finger et al., 2010); recent findings of grazing impacts on plant species composition (Newton et al., 2013) and nitrogen fixation (Watanabe et al., 2013) under elevated CO_2 have added to this uncertainty. New Zealand agro-ecosystems are subject to erosion processes strongly driven by climate; greater certainty in projections of rainfall, particularly storm frequency, are needed to better understand

Box 25-4 | Biosecurity

Biosecurity is a high priority for Australia and New Zealand given the economic importance of biologically based industries and risks to endemic species and iconic ecosystems. The biology and potential risk from invasive and native pathogenic species will be altered by climate change (*high confidence*; Roura-Pascual et al., 2011), but impacts may be positive or negative depending on the particular system.

Table 25-4 | Examples of potential consequences of climate change for invasive and pathogenic species relevant to Australia and New Zealand, with consequence categories based on Hellman et al. (2008).

Consequence	Projected change	Organism/ecosystem affected
Altered mechanisms of transport and introduction	Increased risk of introduction of Asiatic citrus psyllid (*Diaphorina citri*), vector of the disease huanglongbing[1]	Australian citrus industry and native citrus and other rutaceous species and endemic psyllid fauna
Altered distribution of existing invasive and pathogenic species	*Nassella neesiana* (Chilean needle grass): Increased droughts favor establishment.[2]	Managed pasture in New Zealand
	Warming and drying may encourage the spread of existing invasives such as *Pheidole megacephala* in New Zealand and provide suitable conditions for other exotic ant species if they invade.[3]	Human health and potentially agricultural and natural ecosystems
	Reduced climatic suitability for exotic invasive grasses in Australia (11 species including *Nassella* sp.)[4]	Australian rangeland
	Range of the invasive weed *Lantana camara* (lantana) projected to extend from north Australia to Victoria, southern Australia, and Tasmania[5]	Multiple
	Projected increases in the range of three recently naturalized subtropical plants (*Archontophoenix cunninghamiana*, *Psidium guajava*, *Schefflera actinophylla*)[6]	Native ecosystems in New Zealand
Altered climatic constraints on invasive and pathogenic species	Queensland fruit fly (*Bactrocera tryoni*) moving southwards[7]	Australian horticulture
	Significant association between amphibian declines in upland rainforests of north Queensland and three consecutive years of warm weather suggests future warming could increase the vulnerability of frogs to chytridiomycosis caused by the chytrid fungus *Batrachochytrium dendrobatadis*.[8]	Native frogs
Altered impact of existing invasive and pathogenic species	*Fusarium pseudograminearum* causing crown rot increases under elevated CO_2.[9]	Australian wheat
	Increased abundance of the root-feeding nematode *Longidorus elongatus* under elevated CO_2[10]	New Zealand pasture
	Increased severity of Swiss needle cast disease caused by *Phaeocryptopus gaeumannii*[11]	Douglas fir plantations in New Zealand, impact more severe in North Island
Altered effectiveness of management strategies	Light brown apple moth, *Epiphyas postvittana* (Walker) (*Lepidoptera: Tortricidae*) reduction in natural enemies due to asynchrony and loss of host species[12]	Australian horticulture
	Projected changes in the efficacy of five biological control systems demonstrating a range of potential disruption mechanisms[13]	Pastoral and horticultural systems in New Zealand

References: [1]Finlay et al. (2009); [2]Bourdôt et al. (2012); [3]Harris and Barker (2007); [4]Gallagher et al. (2012a); [5]Taylor, S. et al. (2012); [6]Sheppard (2012); [7]Sutherst et al. (2000); [8]Laurance (2008); [9]Melloy et al. (2010); [10]Yeates and Newton (2009); [11]Watt et al. (2011b); [12]Thomson et al. (2010); [13]Gerard et al. (2012).

climate change impacts on erosion and consequent changes in the ecosystem services provided by soils (Basher et al., 2012).

25.7.2.2. Projected Impacts and Adaptation—Cropping

Experiments with elevated CO_2 at two sites with different temperatures have shown a wide range in the response of current wheat cultivars (Fitzgerald et al., 2010). Modeling suggests there is the potential to increase New Zealand wheat yields under climate change with appropriate choices of cultivars and sowing dates (*high confidence*; Teixeira et al., 2012). In Australia, the selection of appropriate cultivars and sowing times is projected to result in increased wheat yields in high rainfall areas such as southern Victoria under climate change and in maintenance of current yields in some areas expected to be drier (e.g., northwestern Victoria; O'Leary et al., 2010). However, if extreme low rainfall scenarios are realized in areas such as South Australia then changes in cultivars and fertilizer applications are not expected to maintain current yields by 2080 (Luo et al., 2009). Under the more severe climate scenarios and without adaptation, Australia could become a net importer of wheat (Howden et al., 2010). One caveat to modeling studies is that an intercomparison of 27 wheat models found large differences between model outputs for already dry and hot Australian sites in response to increasing CO_2 and temperature (Asseng et al., 2013; Carter, 2013).

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

Box 25-5 | Climate Change Vulnerability and Adaptation in Rural Areas

Rural communities in Australasia have higher proportions of older and unemployed people than urban populations (Mulet-Marquis and Fairweather, 2008). Employment and economic prospects depend heavily on the physical environment and hence are highly exposed to climate (averages, variability, and extremes) as well as changing commodity prices. These interact with other economic, social, and environmental pressures, such as changing government policies (e.g., on drought, carbon pricing; Productivity Commission, 2009; Nelson et al., 2010) and access to water resources. The vulnerability of rural communities 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; Marshall, 2010; Nelson et al., 2010; Hogan et al., 2011b; Kenny, 2011).

Climate change will affect rural industries and communities through impacts on resource availability and distribution, particularly water. Decreased availability and/or increased demand, or price, in response to climate change will increase tensions among agricultural, mining, urban, and environmental water users (*very high confidence*), with implications for governance and participatory adaptation processes to resolve conflicts (see Sections 25.4.2, 25.6.1, 25.7.2-3; Boxes 25-2, 25-10). Communities will also be affected through direct impacts on primary production, extraction activities, critical infrastructure, population health, and recreational and culturally significant sites (Kouvelis et al., 2010; Balston et al., 2012; see Sections 25.7-8).

Altered production and profitability risks and/or land use will translate into complex and interconnected effects on rural communities, particularly income, employment, service provision, and reduced volunteerism (Stehlik et al., 2000; Bevin, 2007; Kerr and Zhang, 2009). The prolonged drought in Australia during the early 2000s, for example, 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 suicide (especially of male farmers), accelerated rural depopulation, and closure of key services (*robust evidence*, *high agreement*; Alston, 2007, 2010, 2012; Edwards and Gray, 2009; Hanigan et al., 2012; see also Box CC-GC). Positive social change also occurred, however, including increased social capital through interaction with community organizations (Edwards and Gray, 2009). While social and cultural changes have the potential to undermine the adaptive capacity of communities (Smith, W. et al., 2011), robust ongoing engagement between farmers and the local community can contribute to a strong sense of community and enhance potential for resilience (McManus et al., 2012; see also Section 25.4.3).

The economic impact of droughts on rural communities and the entire economy can be substantial. The most recent drought in Australia (2006/7–2008/9), for example, is estimated to have reduced national GDP by about 0.75% (RBA, 2006) and regional GDP in the southern Murray-Darling Basin was about 5.7% below forecast in 2007/08, along with the temporary loss of 6000 jobs (Wittwer and Griffith, 2011). Widespread drought in New Zealand during 2007–2009 reduced direct and off-farm output by about NZ$3.6 billion (Butcher, 2009). The 2012–2013 drought in New Zealand is estimated to have reduced national GDP by 0.3 to 0.6% and contributed to a significant rise in global dairy prices, which tempered even greater domestic economic losses (Kamber et al., 2013). Drought frequency and severity are projected to increase in many parts of the region (Table 25-1).

The decisions of rural enterprise managers have significant consequences for and beyond rural communities (Pomeroy, 1996; Clark and Tait, 2008). Many current responses are incremental, responding to existing climate variability (Kenny, 2011). Transformational change has occurred where industries and individuals are relocating part of their operations in response to recent and/or expectations of future climate or policy change (Kenny, 2011; see also Box 25-10), for example, rice (Gaydon et al., 2010), wine grapes (Park et al., 2012), peanuts (Thorburn et al., 2012), or changing and diversifying land use *in situ* (e.g., the recent switch from grazing to cropping in South Australia; Howden et al., 2010). Such transformational changes are expected to become more frequent and widespread with a changing climate (*high confidence*; Section 25.7.2), with positive or negative implications for the wider communities in origin and destination regions (Kiem and Austin, 2012).

Continued next page →

Box 25-5 (continued)

Although stakeholders within rural communities differ in their vulnerabilities and adaptive capacities, they are bound by similar dependence on critical infrastructure and resources, economic conditions, government policy direction, and societal expectations (Loechel et al., 2013). Consequently, 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; Kiem and Austin, 2013).

Observed trends and modeling for wine grapes suggest that climate change will lead to earlier budburst, ripening, and harvest for most regions and scenarios (*high confidence*; Grace et al., 2009; Sadras and Petrie, 2011; Webb, L.B. et al., 2012). Without adaptation, reduced quality is expected in all Australian regions (*high confidence*; Webb et al., 2008). Change in cultivar suitability in specific regions is expected (Clothier et al., 2012), with potential for development of cooler or more elevated sites within some regions (Tait, 2008; Hall and Jones, 2009) and/or expansion to new regions, with some growers in Australia already relocating (e.g., to Tasmania; Smart, 2010).

Climate change and elevated CO_2 impacts on weeds, pests, and diseases are highly uncertain (see Box 25-4). Future performance of currently effective plant resistance mechanisms under temperature and elevated CO_2 is particularly important (Melloy et al., 2010; Chakraborty et al., 2011), as is the future efficacy of widely used biocontrol—that is, the introduction or stimulation of natural enemies to control pests (Gerard et al., 2012). Australia is ranked second and New Zealand fourth in the world in the number of biological control agent introductions (Cock et al., 2010).

25.7.2.3. Integrated Adaptation Perspectives

Future water demand by the sector is critical for planning (Box 25-2). Irrigated agriculture occupies less than 1% of agricultural land in Australia but accounted for 28% of gross agricultural production value in 2010–11; almost half of this was produced within the Murray-Darling Basin, which used 68% of all irrigation water (ABS, 2012b; DAFF, 2012). Reduced inflow under dry climate scenarios is predicted to reduce substantially the value of agricultural production in the Basin (*robust evidence*, *high agreement*; Garnaut, 2008; Quiggin et al., 2010; Qureshi et al., 2013b)—for example, in one study by 12 to 44% to 2030 and 49 to 72% to 2050 (A1F1; Garnaut, 2008).

Water availability also constrains agricultural expansion: 17 Mha in northern Australia could support cropping but only 1% has appropriate water availability (Webster et al., 2009). In New Zealand, the irrigated area has risen by 82% since 1999 to more than 1 Mha; 76% is on pasture (Rajanayaka et al., 2010). The New Zealand dairy herd doubled between 1980–2009 expanding from high rainfall zones (>2000 mm annual) into drier, irrigation-dependent areas (600 to 1000 mm annual); this dependence will increase with further expansion (Robertson, 2010), which is being supported by the Government's Irrigation Acceleration Fund.

Many adaptation options—such as flexible water allocation, irrigation, and seasonal forecasting—support managing risk in the current climate (Howden et al., 2008; Botterill and Dovers, 2013) and adoption is often high (Hogan et al., 2011a; Kenny, 2011).

However, incremental on-farm adaptation has limits (Park et al., 2012) and may hinder transformational change such as diversification of land use or relocation (see Box 25-5) if it encourages persistence where climate change may take current systems beyond their response capacity (Marshall, 2010; Park et al., 2012; Rickards and Howden, 2012). In many cases, transformational change requires a greater level of commitment, access to more resources, and greater integration across all levels of decision making that encompass both on- and off-farm knowledge, processes and values (Marshall, 2010; Rickards and Howden, 2012).

25.7.3. Mining

Australia is the world's largest exporter of coking coal and iron ore and has the world's largest resources of brown coal, nickel, uranium, lead, and zinc (ABS, 2012c). Recent events demonstrated significant vulnerability to climate extremes: the 2011 floods reduced coal exports by 25 to 54 million tonnes and led to AU$5 to 9 billion revenue lost in that year (ABARES, 2011; RBA, 2011), and tropical cyclones regularly disrupted mining operations over the past decade (McBride, 2012; Sharma et al., 2013). Flood impacts were exacerbated by regulatory constraints on mine discharges, highlighting tensions among industry, social, and ecological management objectives (QRC, 2011), and by flooding affecting road and rail transport to major shipping ports (QRC, 2011; Sharma et al., 2013).

Projected changes in climate extremes imply increasing sector vulnerability without adaptation (*high confidence*; Hodgkinson et al., 2010a,b). Stakeholders have conducted initial climate risk assessments (Mills, 2009) and perceive the adaptive capacity of the industry to be high (Hodgkinson et al., 2010a; Loechel et al., 2010; QRC, 2011), but costs and broader benefits are yet to be explored along the value chain and evaluated for community support. Ongoing challenges include competition for energy and water, climate change skepticism, dealing with contrasting extremes, avoiding maladaptation, and mining-community relations regarding response options, acceptable mine discharges, and post-mining rehabilitation (Loechel et al., 2013; Sharma et al., 2013).

Box 25-6 | Climate Change and Fire

Fire during hot, dry, and windy summers in southern Australia can cause loss of life and substantial property damage (Cary et al., 2003; Adams and Attiwill, 2011). The "Black Saturday" bushfires in Victoria in February 2009, for example, burned more than 3500 km^2, caused 173 deaths, destroyed more than 2000 buildings, and caused damages of AU\$4 billion (Cameron et al., 2009; VBRC, 2010). This fire occurred toward the end of a 13-year drought (CSIRO, 2010) and after an extended period of consecutive days over 30°C (Tolhurst, 2009).

Climate change is expected to increase the number of days with very high and extreme fire weather (Table 25-1), with greater changes where fire is weather-constrained (most of southern Australia; many, in particular eastern and northern, parts of New Zealand) than where it is constrained by fuel load and ignitions (tropical savannahs in Australia). Fire season length will be extended in many already high-risk areas (*high confidence*) and so reduce opportunities for controlled burning (Lucas et al., 2007). Higher CO_2 may also enhance fuel loads by increasing vegetation productivity in some regions (Donohue et al., 2009; Williams et al., 2009; Bradstock, 2010; Hovenden and Williams, 2010; King et al., 2011).

Climate change and fire will have complex impacts on vegetation communities and biodiversity (Williams et al., 2009). Greatest impacts in Australia are expected in sclerophyll forests of the southeast and southwest (Williams et al., 2009). Most New Zealand native ecosystems have limited exposure but also limited adaptations to fire (Ogden et al., 1998; McGlone and Walker, 2011). There is *high confidence* that increased fire incidence will increase risk in southern Australia to people, property, and infrastructure such as electricity transmission lines (Parsons Brinkerhoff, 2009; O'Neill and Handmer, 2012; Whittaker et al., 2013) and in parts of New Zealand where urban margins expand into rural areas (Jakes et al., 2010; Jakes and Langer, 2012); exacerbate some respiratory conditions such as asthma (Johnston et al., 2002; Beggs and Bennett, 2011); and increase economic risks to plantation forestry (Watt et al., 2008; Pearce et al., 2011). 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 with implications for water quality (Shakesby et al., 2007; Wilkinson et al., 2009; Smith, H.G. et al., 2011).

In Australia, fire management will become increasingly challenging under climate change, potentially exacerbating conflicting management objectives for biodiversity conservation versus protection of property (*high confidence*; O'Neill and Handmer, 2012; Whittaker et al., 2013). Current initiatives center on planning and regulations, building design to reduce flammability, fuel management, early warning systems, and fire detection and suppression (Handmer and Haynes, 2008; Preston et al., 2009; VBRC, 2010; O'Neill and Handmer, 2012). Some Australian authorities are taking climate change into account when rethinking approaches to managing fire to restore ecosystems while protecting human life and properties (Preston et al., 2009; Adams and Attiwill, 2011). Improved understanding of climate drivers of fire risk is assisting fire management agencies, landowners, and communities in New Zealand (Pearce et al., 2008, 2011), although changes in management to date show little evidence of being driven by climate change.

25.7.4. Energy Supply, Demand, and Transmission

Energy demand is projected to grow by 0.5 to 1.3% per annum in Australasia over the next few decades in the absence of major new policies (MED, 2011; Syed, 2012). Australia's predominantly thermal power generation is vulnerable to drought-induced water restrictions, which could require dry-cooling and increased water use efficiency where rainfall declines (Graham et al., 2008; Smart and Aspinall, 2009). Depending on carbon price and technology costs, renewable electricity generation in Australia is projected to increase from 10% in 2010–11 to approximately 33 to 50% by 2030 (Hayward et al., 2011; Stark et al., 2012; Syed, 2012), but few studies have explored the vulnerability of these 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 and snow melt, and a shift from snowfall to rainfall will reduce this vulnerability (*medium confidence*) as winter/spring inflows to main hydro lakes are projected to increase by 5 to 10% over the next few decades (McKerchar and Mullan, 2004; Poyck et al., 2011). Further reductions in seasonal snow and glacial melt as glaciers diminish, however, would compromise this benefit (Chinn, 2001; Renwick et al., 2009; Srinivasan et al., 2011). Increasing wind power generation (MED, 2011) would benefit from projected increases in mean westerly winds but face increased risk of damages and shutdown during extreme winds (Renwick et al., 2009).

Climate warming would reduce annual average peak electricity demands by 1 to 2% per degree Celsius across New Zealand and 2(±1)% in New South Wales, but increase by 1.1(±1.4)% and 4.6(±2.7)% in Queensland and South Australia due to air conditioning demand (Stroombergen et al., 2006; Jollands et al., 2007; Thatcher, 2007; Nguyen et al., 2010). Increased summer peak demand, particularly in Australia (see also Figure 25-5), will place additional stress on networks and can result in blackouts (*very high confidence*; Jollands et al., 2007; Thatcher, 2007; Howden and Crimp, 2008; Wang et al., 2010a). During the 2009 Victorian heat wave, demand rose by 24% but electrical losses from transmission lines increased by 53% due to higher peak currents (Nguyen et al., 2010), and successive failures of the overloaded network temporarily left more than 500,000 people without power (QUT, 2010). Various adaptation options to limit increasing urban energy demand exist and some are being implemented (see Box 25-9).

There is *limited evidence* but *high agreement* that without additional adaptation, distribution networks in most Australian states will be at high risk of failure by 2031–2070 under non-mitigation scenarios due to increased bushfire risk and potential strengthening and southward shift of severe cyclones in tropical regions (Maunsell and CSIRO, 2008; Parsons Brinkerhoff, 2009). Adaptation costs have been estimated at AU$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; underground cabling would reduce bushfire risk but has large investment costs that are not included (Parsons Brinkerhoff, 2009). Decentralized ownership of assets constitutes a significant adaptation constraint (ATSE, 2008; Parsons Brinkerhoff, 2009). In New Zealand, increasing high winds and temperatures have been identified qualitatively as the most relevant risks to transmission (Jollands et al., 2007; Renwick et al., 2009).

25.7.5. Tourism

Tourism contributes 2.6 to 4% of GDP to the economies of Australia and New Zealand (ABS, 2010a; SNZ, 2011). The net present value of the Great Barrier Reef alone over the next 100 years has been estimated at AU$51.4 billion (Oxford Economics, 2009). Most Australasian tourism is exposed to climate variability and change (see Section 25.2 for projected trends), and some destinations are highly sensitive to extreme events (Hopkins et al., 2012). The 2011 floods and Tropical Cyclone Yasi, for example, cost the Queensland tourism industry about AU$590 million, mainly due to cancellations and damage to the Great Barrier Reef (PwC, 2011); and drought in the Murray-Darling Basin caused an estimated AU$70 million loss in 2008 due to reduced visitor days (TRA, 2010).

25.7.5.1. Projected Impacts

Future impacts on tourism have been modeled for several Australian destinations. The Great Barrier Reef is expected to degrade under all climate change scenarios (Sections 25.6.2, 30.5; Box CC-CR), reducing its attractiveness (Marshall and Johnson, 2007; Bohensky et al., 2011; Wilson and Turton, 2011b). Ski tourism is expected to decline in the Australian Alps due to snow cover reducing more rapidly than in New Zealand (Pickering et al., 2010; Hendrikx et al., 2013) and greater perceived attractiveness of New Zealand (Hopkins et al., 2012). Higher temperature extremes in the Northern Territory are projected with *high confidence* to increase heat stress and incur higher costs for air conditioning (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 modeling suggests that the Australian alpine region would be most negatively affected in relative terms due to limited alternative activities (Pham et al., 2010), whereas the competitiveness of some destinations (e.g., Margaret River in Western Australia) could be enhanced by higher temperatures and lower rainfall (Jones et al., 2010; Pham et al., 2010). An analog-based study suggests that, in New Zealand, warmer and drier conditions mostly benefit but wetter conditions and extreme climate events undermine tourism (Wilson and Becken, 2011). *Confidence* in outcomes is *low*, however, owing to uncertain future tourist behaviour (Scott et al., 2012; see also Section 25.9.2).

25.7.5.2. Adaptation

Both New Zealand and Australia have formalized adaptation strategies for tourism (Becken and Clapcott, 2011; Zeppel and Beaumont, 2011). In Australia, institutions at various levels also promote preparation for extreme events (Tourism Queensland, 2007, 2010; Tourism Victoria, 2010) and strengthening ecosystem resilience to maintain destination attractiveness (GBRMPA, 2009b). Snow-making is already broadly adopted to increase reliability of skiing (Bicknell and McManus, 2006; Hennessy et al., 2008b), but its future effectiveness depends on location. In New Zealand, even though warming will significantly reduce the number of days suitable for snow-making (Hendrikx and Hreinsson, 2012), sufficient snow could be made in all years until the end of the 21st century to maintain current minimum operational skiing conditions. Options for resorts in Australia's Snowy Mountains are far more limited (Hendrikx et al., 2013), where maintaining skiing conditions until at least 2020 would require AU$100 million in capital investment into 700 snow guns and 2.5 to 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 for destinations where climate change is projected to degrade core natural assets and diversification opportunities are limited (Evans et al., 2011; Morrison and Pickering, 2011). Strategic adaptation decisions are constrained by uncertainties in regional climatic changes (Turton et al., 2010), limited concern (Bicknell and McManus, 2006), lack of leadership, and limited coordinated forward planning (Sanders et al., 2008; Turton et al., 2009; Roman et al., 2010; White and Buultjens, 2012). An integrated assessment of tourism vulnerability in Australasia is not yet possible owing to limited understanding of future changes in tourism and community preferences (Scott et al., 2012), including the flow-on effects of changing travel behavior and tourism preferences in other world regions (see Section 25.9.2).

25.8. Human Society

25.8.1. Human Health

25.8.1.1. Observed Impacts

Life expectancy in Australasia is high, but shows substantial ethnic and socioeconomic inequalities (Anderson et al., 2006). Mortality increases in hot weather in Australia (*robust evidence*, *high agreement*; Bi and Parton, 2008; Vaneckova et al., 2008) with air pollution exacerbating this association. The last 4 decades have seen a steady increase in the ratio of summer to winter mortality in Australia, indicating a health effect from climatic warming (Bennett et al., 2013). Exceptional heat wave conditions in Australia have been associated with substantial increases in mortality and hospital admissions in several regional towns and capital cities (*high confidence*; Khalaj et al., 2010; Loughnan et al., 2010; Tong et al., 2010a,b). For example, during the heat wave in January and February 2009 in southeastern Australia (BoM, 2009), total emergency cases increased by 46% over the three hottest days: direct heat-related health problems increased 34-fold, 61% of these being in people aged 75 years or older, and there were an estimated 374 excess deaths, a 62% increase in all-cause mortality (Victorian Government, 2009a). Mental health admissions increased across all age groups by 7.3% in metropolitan South Australia during heat waves (1993–2006; Hansen et al., 2008). Mortality attributed to mental and behavioral disorders increased in the 65- to 74-year age group and in persons with existing mental health problems (Hansen et al., 2008). Experience of extreme events also strongly affects psychological well-being (see Section 25.4.3).

25.8.1.2. Projected Impacts

Projected increases in heat waves (Figure 25-5) will increase heat-related deaths and hospitalizations, especially among the elderly, compounded by population growth and aging (*high confidence*; Bambrick et al., 2008;

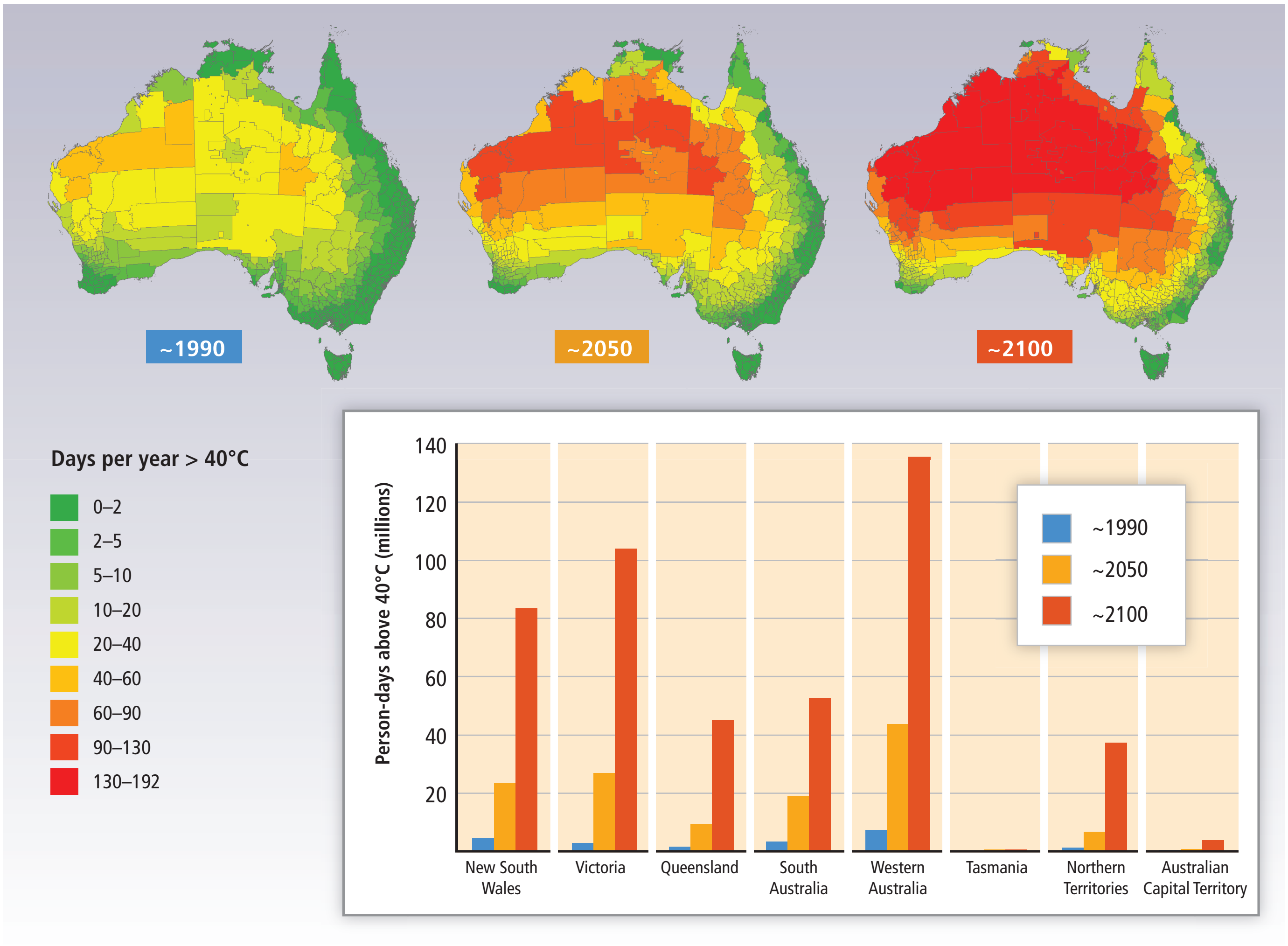

Figure 25-5 | Projected changes in exposure to heat under a high emissions scenario (A1FI). Maps show the average number of days with peak temperatures >40°C, for approximately 1990 (based on available meteorological station data for the period 1975–2004), approximately 2050, and approximately 2100. Bar charts show the change in population heat exposure, expressed as person-days exposed to peak temperatures >40°C, aggregated by State/Territory and including projected population growth for a default scenario. Future temperatures are based on simulations by the Geophysical Fluid Dynamics Laboratory Coupled Model version 2 (GFDL-CM2) global climate model (Meehl et al., 2007), re-scaled to the A1FI scenario; simulations based on other climate models could give higher or lower results. Data from Baynes et al. (2012).

Box 25-7 | Insurance as a Climate Risk Management Tool

Insurance helps spread the risk from extreme events across communities and over time and therefore enhances the resilience of society to disasters (see Section 10.7). In Australia, insured losses are dominated by meteorological hazards, including the 2011 Queensland floods and the 1999 Sydney hailstorm (ICA, 2012) with estimated claims of AU$3 billion per annum (IAA, 2011b). In New Zealand, floods and storms are the second most costly natural hazards after earthquakes (ICNZ, 2013). The number of damaging insured events (up to a certain loss value) has increased significantly in the Oceania region since 1980 (Schuster, 2013). Normalized losses in Australia show no significant trend from at least 1967 to 2006 (Crompton and McAneney, 2008; Crompton et al., 2010; Table 10-4), consistent with the global conclusion (IPCC, 2012) that increasing exposure of people and economic assets has been the major cause of long-term increases in economic losses from weather- and climate-related disasters. Issues relating to data quality and methodological choices prevent definitive conclusions regarding the role of climate change in loss trends (Crompton et al., 2011; Nicholls, 2011; IPCC, 2012).

There is *high confidence* that, without adaptive measures, projected increases in extremes (Table 25-1) 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, for example, through unaffordability or unavailability of cover in areas at highest risk (IAA, 2011a,b; NDIR, 2011; Booth and Williams, 2012). Restriction of cover occurred in some locations following the 2011 flood events in Queensland (Suncorp, 2013).

Insurance can contribute positively to risk reduction by providing incentives to policy holders to reduce their risk profile (O'Neill and Handmer, 2012), for example, through resilience ratings given to buildings (TGA, 2009; Edge Environment, 2011; IAG, 2011). 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 (Glavovic et al., 2010); government measures to reduce or avoid risks also interact with insurance companies' willingness to provide cover (Booth and Williams, 2012). Yet insurance can also act as a constraint on adaptation, if those living in climate-risk prone localities pay discounted or cross-subsidized premiums or policies fail to encourage betterment after damaging events by requiring replacement of "like for like," constituting a missed opportunity for risk reduction (NDIR, 2011; QFCI, 2012; Reisinger et al., 2013; see also Section 10.7). The effectiveness of insurance thus depends on the extent to which it is linked to a broader national resilience approach to disaster mitigation and response (Mortimer et al., 2011).

Gosling et al., 2009; Huang et al., 2012). In the southern states of Australia and parts of New Zealand, this may be partly offset by reduced deaths from cold at least for modest rises in temperature (*low confidence*; Bambrick et al., 2008; Kinney, 2012). With strong mitigation, climate change is projected to result in 11% fewer temperature-related deaths in both 2050 and 2100 in Australia, but 14% and 100% more deaths in 2050 and 2100, respectively, without mitigation under a hot, dry A1FI scenario (Bambrick et al., 2008; see Chapter 11 for detail on temperature-related health trade-offs). Net results were driven almost entirely by increased mortality in the north, especially Queensland, consistent with Huang et al. (2012). In a separate study that accounted for increased daily temperature variability, a threefold increase in heat-related deaths is projected for Sydney by 2100 for the A2 scenario, assuming no adaptation (Gosling et al., 2009). The number of hot days when physical labor in the sun becomes dangerous is also projected to increase substantially in Australia by 2070, leading to economic costs from lost productivity, increased hospitalizations, and occasional deaths (*medium confidence*; Hanna et al., 2011; Maloney and Forbes, 2011).

Water- and food-borne diseases are projected to increase, but the complexity of their relationship to climate and non-climate drivers means there is *low confidence* in specific projections. For Australia, 205,000 to 335,000 new cases of bacterial gastroenteritis by 2050, and 239,000 to 870,000 cases by 2100, are projected under a range of emission scenarios (Bambrick et al., 2008; Harley et al., 2011). Based on their observed positive relationship with temperature, notifications of salmonellosis notifications are projected to increase 15% for every 1°C increase in average monthly temperatures (Britton et al., 2010a). Water-borne zoonotic diseases such as cryptosporidiosis and giardiasis have more complex relationships with climate and are amenable to various adaptations, making future projections more difficult (Britton et al., 2010b; Lal et al., 2012).

Understanding the combined effects of climate change and socioeconomic development on the distribution of vector-borne diseases has improved since the AR4. Australasia is projected to remain malaria free under the A1B emission scenario until at least 2050 (Béguin et al., 2011) and

Box 25-8 | Changes in Flood Risk and Management Responses

Flood damages across eastern Australia and both main islands of New Zealand in 2010 and 2011 revealed a significant adaptation deficit (ICA, 2012; ICNZ, 2013). 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 to public infrastructure of AU$5 to 6 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; Evans and Boyer-Souchet, 2012). Flood frequency and severity exhibit strong decadal variability with no significant long-term trend in Australasia to date (Kiem et al., 2003; Smart and McKerchar, 2010; Ishak et al., 2013).

Flood risk is projected to increase in many regions due to more intense extreme rainfall events driven by a warmer and wetter atmosphere (*medium confidence*; Table 25-1). High-resolution downscaling (Carey-Smith et al., 2010), and dynamic catchment hydrological and river hydraulic modeling in New Zealand (Gray, W. et al., 2005; McMillan et al., 2010; MfE, 2010b; Ballinger et al., 2011; Duncan and Smart, 2011; McMillan et al., 2012) indicate that the 50-year and 100-year flood peaks for rivers in many parts of the country will increase by 5 to 10% by 2050 and more by 2100 (with large variation between models and emissions scenarios), with a corresponding decrease in return periods for specific flood levels. Studies for Queensland show similar results (DERM et al., 2010). In Australia, flood risk is expected to increase more in the north (driven by convective rainfall systems) than in the south (where more intense extreme rainfall may be compensated by drier antecedent moisture conditions), consistent with confidence in heavy rainfall projections (Table 25-1; Alexander and Arblaster, 2009; Rafter and Abbs, 2009).

Flood risk near river mouths will be exacerbated by storm surge associated with higher sea level and potential change in wind speeds (McInnes et al., 2005; MfE, 2010b; Wang et al., 2010b). Higher rainfall intensity and peak flow will also increase erosion and sediment loads in waterways (Prosser et al., 2001; Nearing et al., 2004) and exacerbate problems from aging stormwater and wastewater infrastructure in cities (Howe et al., 2005; Jollands et al., 2007; CCC, 2010; WCC, 2010; see also Box 25-9). However, moderate flooding also has benefits through filling reservoirs, recharging groundwater, and replenishing natural environments (Hughes, 2003; Chiew and Prosser, 2011; Oliver and Webster, 2011).

Adaptation to increased flood risk from climate change is starting to happen (Wilby and Keenan, 2012) through updating guidelines for design flood estimation (MfE, 2010b; Westra, 2012), improving flood risk management (O'Connell and Hargreaves, 2004; NFRAG, 2008; Queensland Government, 2011), accommodating risk in flood prone areas (options include raising floor levels, using strong piled foundations, using water-resistant insulation materials, and ensuring weather tightness), and risk reduction and avoidance through spatial planning and managed relocation (Trotman, 2008; Glavovic et al., 2010; LVRC, 2012; QFCI, 2012). Adaptation options in urban areas also include ecosystem-based approaches such as retaining floodplains and floodways, restoring wetlands, and retrofitting existing systems to attenuate flows (Howe et al., 2005; Skinner, 2010; WCC, 2010; see also Box 25-9).

The recent flooding in eastern Australia and the projected increase in future flood risk have resulted in changes to reservoir operations to mitigate floods (van den Honert and McAneney, 2011; QFCI, 2012) and insurance practice to cover flood damages (NDIR, 2011; Phelan, 2011; see also Box 25-7). However, the magnitude of potential future changes in flood risk and limits to incremental adaptation responses in urban areas suggest that more transformative approaches based on altering land use and avoidance of exposure to future flooding may be needed in some locations, especially if changes in the upper range of projections are realized (*high confidence*; Lawrence and Allan, 2009; DERM et al., 2010; Glavovic et al., 2010; Wilby and Keenan, 2012; Lawrence et al., 2013a).

sporadic cases could be treated effectively. The area climatically suitable for transmission of dengue will expand in Australasia (*high confidence*; Bambrick et al., 2008; Åström et al., 2012), but changes in socioeconomic factors, especially domestic water storage, may have a more important influence on disease incidence than climate (Beebe et al., 2009; Kearney et al., 2009). Impacts of climate change on Barmah Forest Virus in Queensland depend on complex interactions between rainfall and temperature changes, together with tidal and socioeconomic factors, and thus will vary substantially among different coastal regions (Naish et al., 2013). The effects of climate change combined with frequent travel within and outside the region, and recent incursions of exotic mosquito species, could expand the geographic range of other important arboviruses such as Ross River Virus (*medium confidence*; Derraik and Slaney, 2007; Derraik et al., 2010).

A growing 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; see also Section 25.4.3). These studies indicate significant mental health risks associated with climate-related disasters, in particular persistent and severe drought, floods, and storms; climate 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 25-5).

Projected population growth and urbanization could further increase health risks indirectly via climate-related stress on housing, transport and energy infrastructure, and water supplies (*low confidence*; Howden-Chapman, 2010; see also Box 25-9).

25.8.1.3. Adaptation

Research since the AR4 has mainly focused on climate change impacts, although some adaptation strategies have received attention in Australia. These include improving health care services, social support for those most at risk, improving community awareness to reduce adverse exposures, developing early warning and emergency response plans (Wang and McAllister, 2011), and understanding perceptions of climatic risks to health as they affect adaptive behaviors (Akompad et al., 2013). In New Zealand, central Government health policies do not identify specific measures to adapt to climate change (Wilson, 2011). In both countries, policies to reduce risks from extreme events such as floods and fires will have co-benefits for health (see Boxes 25-6, 25-8).

A review of the southern Australian heat wave of 2009 identified a range of issues including communication failures with no clear public information or warning strategy, and no clear thresholds for initiating public information campaigns (Kiem et al., 2010). Emergency services were underprepared and relied on reactive solutions (QUT, 2010). The Victorian government has since developed a heat wave plan to coordinate a state-wide response, maintain consistent community-wide understanding through a Heat Health alert system, build capacity of councils to support communities most at risk, support a Heat Health Intelligence surveillance system, and distribute public health information (Victorian Government, 2009b).

25.8.2. Indigenous Peoples

25.8.2.1. Aboriginal and Torres Strait Islanders

Work since the AR4 includes a national Indigenous adaptation research action plan (Langton et al., 2012), regional risk studies (Green et al., 2009; DNP, 2010; TSRA, 2010; Nursey-Bray et al., 2013) and scrutiny from an Indigenous rights perspective (ATSISJC, 2009). Socioeconomic disadvantage and poor health (SCRGSP, 2011) indicate a disproportionate climate change vulnerability of Indigenous Australians (McMichael et al., 2009) although there are no detailed assessments. In urban and regional areas, where 75% of the Indigenous population lives (ABS, 2010b), assessments have not specifically addressed risks to Indigenous people (e.g., Guillaume et al., 2010). In other regions, all remote, there is limited empirical evidence of vulnerability (Maru et al., 2012). However, there is *medium evidence* and *high agreement* for significant future impacts from increasing heat stress, extreme events, and increased disease (Campbell et al., 2008; Spickett et al., 2008; Green et al., 2009).

The Indigenous estate comprises more than 25% of the Australian land area (Altman et al., 2007; NNTR, 2013). There is *high agreement* but *limited evidence* that natural resource dependence (e.g., Bird et al., 2005; Gray, M.C. et al., 2005; Kwan et al., 2006; Buultjens et al., 2010) increases Indigenous exposure and sensitivity to climate change (Green et al., 2009); climate change-induced dislocation, attenuation of cultural attachment to place, and loss of agency will disadvantage Indigenous mental health and community identity (Fritze et al., 2008; Hunter, 2009; McIntyre-Tamwoy and Buhrich, 2011); and, housing, infrastructure, services, and transport, often already inadequate for Indigenous needs especially in remote Australia (ABS, 2010c), will be further stressed (Taylor and Philp, 2010). Torres Strait island communities and livelihoods are vulnerable to major impacts from even small sea level rises (*high confidence*; DCC, 2009; Green, D. et al., 2010a; TSRA 2010).

Little adaptation of Indigenous communities to climate change is apparent to date (cf. Burroughs, 2010; GETF 2011; Nursey-Bray et al., 2013; Zander et al., 2013). Plans and policies that are imposed on Indigenous communities can constrain their adaptive capacity (Ellemor, 2005; Petheram et al., 2010; Veland et al., 2010; Langton et al., 2012) but participatory development of adaptation strategies is challenged by multiple stressors and uncertainty about causes of observed changes (Leonard, S. et al., 2010; Nursey-Bray et al., 2013). Adaptation planning would benefit from a robust typology (Maru et al., 2011) across the diversity of Indigenous life experience (McMichael et al., 2009). Indigenous re-engagement with environmental management (e.g., 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, D. et al., 2010b; Petheram et al., 2010) and developing inter-cultural communication tools (Leonard, S. et al., 2010; Woodward et al., 2012). Extensive land ownership in northern and inland Australia and land management traditions mean that Indigenous people are well situated to provide greenhouse gas abatement and carbon sequestration services that may also support their livelihood aspirations (Whitehead et al., 2009; Heckbert et al., 2012).

25.8.2.2. 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 the AR4, studies have been either sector-specific (e.g., Insley, 2007; Insley and Meade, 2008; Harmsworth et al., 2010; King et al., 2012) or more general, inferring risk and vulnerability based on exploratory engagements with varied stakeholders and existing social, economic, political, and ecological conditions (e.g., MfE, 2007b; Te Aho, 2007; King et al., 2010).

The Māori economy depends on climate-sensitive primary industries with vulnerabilities to climate conditions (*high confidence*; Packman et al., 2001; NZIER, 2003; Cottrell et al., 2004; TPK, 2007; Tait et al., 2008b; Harmsworth et al., 2010; King et al., 2010; Nana et al., 2011a). Much of Māori-owned land is steep (>60%) and susceptible to damage from high intensity rainstorms, while many lowland areas are vulnerable to flooding and sedimentation (Harmsworth and Raynor, 2005; King et al., 2010). Land in the east and north is also drought prone, and this increases 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 and aquaculture sector faces substantial risks (and uncertainties) from changes in ocean temperature and chemistry, potential changes in species composition, condition, and productivity levels (*medium confidence*; King et al., 2010; see also Section 25.6.2). At the community and individual level, Māori regularly utilize the natural environment for hunting and fishing, recreation, the maintenance of traditional skills and identity, and collection of cultural resources (King and Penny, 2006; King et al., 2012). Many of these activities are already compromised due to resource competition, degradation, and modification (Woodward et al., 2001; King et al., 2012). Climate change driven shifts in natural ecosystems will further challenge the capacities of some Māori to cope and adapt (*medium confidence*; King et al., 2012).

Māori organizations have 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; Insley, 2010; Nana et al., 2011b), critical for managing and adapting to climate change risks (Harmsworth et al., 2010; King et al., 2012). Future opportunities will depend on partnerships in business, science, research, and government (*high confidence*; Harmsworth et al., 2010; King et al., 2010) as well as innovative technologies and new land management practices to better suit future climates and use opportunities from climate policy, especially in forestry (Carswell et al., 2002; Harmsworth, 2003; Funk and Kerr, 2007; Insley and Meade, 2008; Tait et al., 2008b; Penny and King, 2010).

Māori knowledge of environmental processes and hazards (King et al., 2005, 2007) as well as strong social-cultural networks are vital for adaptation and ongoing risk management (King et al., 2008); however, choices and actions continue to be constrained by insufficient resourcing, shortages in social capital, and competing values (King et al., 2012). Combining traditional ways and knowledge with 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).

25.9. Interactions among 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 detail on such interactions and can inform a balanced portfolio of climate change responses, but evaluation tools remain limited, especially for local decision making (Park et al., 2011). A review of 25 specific climate change-associated land use plans from Australia, for example, found that 14 exhibited potential for conflict between mitigation and adaptation (Hamin and Gurran, 2009).

25.9.1. Interactions among Local-Level Impacts, Adaptation, and Mitigation Responses

Table 25-6 shows examples of adaptation responses that are either synergistic or entail trade-offs with other impacts and/or adaptation responses and goals. Adapting proactively to projected climate changes, particularly extremes such as floods or drought, can increase near-term resilience to climate variability and be a motivation for adopting adaptation measures (Productivity Commission, 2012). However, exclusive reliance on near-term benefits can increase trade-offs and

Box 25-9 | Opportunities, Constraints, and Challenges to Adaptation in Urban Areas

Considerable opportunities exist for Australasian cities and towns to reduce climate change impacts and, in some regions, benefit from projected changes such as warmer winters and more secure water supply (Fitzharris, 2010; Australian Government, 2012). Many tools and practices developed for sustainable resource management or disaster risk reduction in urban areas are co-beneficial for climate change adaptation, and vice versa, and can be integrated with mitigation objectives (Hamin and Gurran, 2009). Despite the abundance of potential adaptation options, however, social, cultural, institutional, and economic factors frequently constrain their implementation (*high confidence*; see also Section 25.4.2). The form and longevity of cities and towns, with their concentration of hard and critical infrastructure such as housing, transport, energy, stormwater and wastewater systems, telecommunications, and public facilities provide additional challenges (see also Chapters 8, 10; Sections 25.7.4, 25.8.1; Boxes 25-1, 25-2, 25-8). Transport infrastructure is vulnerable to extreme heat and flooding (QUT, 2010; Taylor and Philp, 2010) but quantification of future risks remains limited (Gardiner et al., 2009; Balston et al., 2012; Baynes et al., 2012). Table 25-5 summarizes some adaptation options, co-benefits, and constraints on their adoption in Australasia.

Continued next page →

Box 25-9 (continued)

Table 25-5 | Examples of co-beneficial climate change adaptation options for urban areas and barriers to their adoption. Options in italics are already widely implemented in Australia and New Zealand urban areas.

Climate impact	Adaptation options	Co-benefits	Barriers to adoption
Hot days and heat waves[1–8]	Greening cities/roofs; *more green spaces; well-designed energy efficient buildings*; occupant behavioral change; standards for new and retrofitting of existing infrastructure and assets; new methods and material for transport infrastructure to withstand higher extreme temperature	Energy efficiency; reduced risk of blackouts; fewer health impacts; resilient infrastructure and assets; resilient community	Lack of standards; high installation costs; limited understanding of benefits; high individual discount rate; split of private costs and public benefits
Decreased water supply and drought (see Box 25-2 for more)	Supply augmentation (*water recycling, rainwater harvesting, increased storage*, desalinization); *demand management; infrastructure upgrades; integrated water-sensitive urban design*	Water self-sufficiency for current and future demand/population; less pipe/storage leakage; reduced environmental impacts from abstraction	Potential health impacts of recycled water; lower than expected uptake of demand options and relaxation after crises; trade-offs between supply and demand management; cost and environmental impacts of some augmentation options
River and local flooding, coastal erosion and inundation (see Boxes 25-1 and 25-8 for more)	New standards and improvements to *building, water infrastructure (e.g., drainage and sewerage)* and transport infrastructure; *upgrades of protection systems; retaining floodplains/floodways*; restoring wetlands; buffers from hazard-prone areas; *raising minimum floor levels*; rezoning/relocation	Reduced damages to homes and infrastructure and loss of life; decreased insurance premiums; habitat protection	High implementation cost especially if retrospective on existing stock; rezoning/relocation can affect property prices and are highly contested.
Severe storms and tropical cyclones[9–12]	New building design to withstand higher wind pressures; rezoning/relocation	Reduced damages to homes and infrastructure and loss of life; decreased insurance premiums	High implementation cost; rezoning/relocation can affect property prices and are highly contested.
Corrosion from increased atmospheric CO_2 levels[13,14]	Improved standards for construction using concrete; application of coatings for existing building stock	Reduced rates of carbonation-induced corrosion of concrete	Effectiveness of coatings varies with age and condition of concrete.

References: [1]BRANZ (2007); [2]Coutts et al. (2010); [3]Moon and Han (2011); [4]Stephenson et al. (2010); [5]Williams et al. (2010); [6]CSIRO et al. (2007); [7]Taylor and Philp (2010); [8]QUT (2010); [9]Mason and Haynes (2010); [10]Wang et al. (2010b); [11]Stewart and Wang (2011); [12]Mason et al. (2013); [13]Stewart et al. (2012); [14]Wang et al. (2012).

Overall, the implementation of climate change adaptation policy for urban settlements in Australia and New Zealand has been mixed. The Australian National Urban Policy encourages adaptation, and many urban plans include significant adaptation policies (e.g., City of Melbourne, 2009; City of Port Phillip, 2010; ACT Government, 2012; City of Adelaide, 2012). New Zealand also promotes urban adaptation through strategies, plans, and guidance documents (MfE, 2008b; CCC, 2010; WCC, 2010; Auckland Council, 2012; NIWA et al., 2012). Many examples of incremental urban adaptation exist (Box 25-2; Table 25-5), particularly where these include co-benefits and respond to other stressors, like prolonged drought in southern Australia and recurrent floods. Experience is much scarcer with more flexible land uses, managed relocation, and ecosystem-based adaptation that could transform existing settlement patterns and development trends, and where maintaining flexibility to address long-term climate risks can run against near-term development pressures (see Boxes 25-1, 25-2, 25-8, CC-EA). Decision-making models that support such adaptive and transformative changes (Section 25.4.2; Box 25-1) have not yet been implemented widely in urban contexts; increased coordination among different levels of government may be required to spread costs and balance public and private, near- and long-term, and local and regional benefits (Norman, 2009, 2010; Britton, 2010;Abel et al., 2011; Lawrence et al., 2013a; McDonald, 2013; Palutikof et al., 2013; Reisinger et al., 2013).

result in long-term maladaptation (*high confidence*). For example, enhancing protection measures after major flood events, combined with rapid re-building, accumulates fixed assets that can become increasingly costly to protect as climate change continues, with attendant loss of amenity and environmental values (Glavovic et al., 2010; Gorddard et al., 2012; McDonald, 2013). Similarly, deferring adoption of increased design wind speeds in cyclone-prone areas delays near-term investment costs but also reduces the long-term benefit/cost ratio of the strategy (Stewart and Wang, 2011).

Mitigation actions can contribute to but also counteract local adaptation goals. Energy-efficient buildings, for example, reduce network and health risks during heat waves, but urban densification to reduce transport energy demand intensifies urban heat islands and, hence, heat-related health risks (Sections 25.7.4, 25.8.1). Specific adaptations can also make achievement of mitigation targets harder or easier. Increased use of air conditioning, for example, increases energy demand, but energy efficiency and building design can reduce heat exposure as well as energy demand (Section 25.7.4, Box 25-9). Table 25-7 gives further

Table 25-6 | Examples of interactions between impacts and adaptation measures in different sectors. In each case, impacts or responses in one sector have the potential to conflict (cause negative impacts) or be synergistic (have co-benefits) with impacts or responses in another sector, or with another type of response in the same sector.

Primary goal	Sector(s) affected	Examples of interactions between impacts and adaptation responses
Reduction of bushfire risk in natural landscapes	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), e.g., objectives of the Wildfire Management Overlay (WMO) in Victoria conflict with vegetation conservation (Hughes and Mercer, 2009).
Reduction of risk to energy transmission from bushfires	Biodiversity, energy	Underground cabling would reduce both the susceptibility of transmission networks to fire and ignition sources for wild fires, thus reducing risks to ecosystems and settlements; constraints include significant investment cost, diverse ownership of assets, and lack of an overarching national strategy (ATSE, 2008; Parsons Brinkerhoff, 2009; Linnenluecke et al., 2011).
Protection of coastal infrastructure	Biodiversity, tourism	Seawalls may provide habitat but these communities have different diversity and structure from those developing on natural substrates (Jackson et al., 2008); groynes potentially alter beach fauna diversity and community structure (Walker et al., 2008); continuing hard protection against sea level rise results in long-term loss of coastal amenities (Gorddard et al., 2012).
Avoidance of risks from sea level rise via relocation	Indigenous communities	Relocation can avoid increasing local pressures on communities from sea level rise but raises complex cultural, land rights, legal, and economic issues, e.g., potential relocation of Torres Strait islander communities (Green, D. et al., 2010a; McNamara et al., 2011).
Allocating scarce water resources via market instruments	Rural areas, agriculture, mining	Market based instruments such as water trading help allocation of scarce water resources to the highest value uses. The negative implications of this include potential loss of access to lower value users, which in some areas includes agriculture and drinking water supplies, with potentially significant social, environmental, and wider economic consequences (Kiem and Austin, 2012).
Increased water security via augmentation of supply for urban and agricultural systems	Biodiversity, water demand management	Water storage can buffer urban settlements and agricultural systems against high variability in river flows, but altered flow regimes can have significant negative impacts on freshwater ecosystems (Bond et al., 2008; Pittock et al., 2008; Kingsford, 2011). 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); increasing supply can reduce the effectiveness of demand-side measures (Barnett and O'Neill, 2010; Taptiklis, 2011; Box 25-2).

examples, and Box 25-10 explores the multiple and complex benefits and trade-offs in changing land use to simultaneously adapt to and mitigate climate change.

25.9.2. Intra- and Inter-regional Flow-on Effects among Impacts, Adaptation, and Mitigation

Recent studies strengthen conclusions from the AR4 (Hennessy et al., 2007) that flow-on effects from climate change impacts occurring in other world regions can exacerbate or counteract projected impacts in Australasia. Modeling suggests Australia's terms of trade would deteriorate by about 0.23% in 2050 and 2.95% in 2100 as climate change impacts without mitigation reduce economic activity and demand for coal, minerals, and agricultural products in other world regions (A1FI scenario; Harman et al., 2008). As a result, Australian Gross National Product (GNP) is expected to decline more strongly than GDP because of climate change, especially toward the end of the 21st century (Gunasekera et al., 2008). These conclusions, however, merit only *medium confidence*, because they rely on simplified assumptions

Table 25-7 | Examples of interactions between adaptation and mitigation measures (green rows denote synergies where multiple benefits may be realized; yellow rows denote potential trade-offs and conflicts; blue row gives an example of complex, mixed interactions). The primary goal may be adaptation or mitigation.

Primary goal	Sector(s) affected	Examples of interactions between adaptation and mitigation responses
Adaptation to decreasing snowfall	Biodiversity, energy use, water use	Snowmaking in the Australian Alps would 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 2004–2005. Increased snowmaking negatively affects vegetation, soils, and hydrology of subalpine–alpine areas (Pickering and Buckley, 2010; Morrison and Pickering, 2011; ABS, 2012a).
Air conditioning for heat stress	Health, energy use	Rising temperatures degrade building energy efficiency (Wang et al., 2010a) and increase energy demand and associated CO_2 emissions if summer cooling needs are met by increased air conditioning (Stroombergen et al., 2006; Thatcher, 2007; Wang et al., 2010a).
Renewable wind energy production	Biodiversity	Wind-farms can have localized 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 modeled (Smales, 2006).
Urban densification	Biodiversity, water, health	Higher urban density to reduce energy consumption from transport and infrastructure can result in loss of permeable surfaces and tree cover, intensify flood risks, and exacerbate discomfort and health impacts of hotter summers (Hamin and Gurran, 2009).
Water supply from desalination	Energy demand	Meeting increasing urban water demand via desalination plants increases energy demand and CO_2 emissions if this demand is met by increased fossil fuel energy generation (Barnett and O'Neill, 2010; Stamatov and Stamatov, 2010).
Secure food production in a warming climate	Nitrous oxide and methane emissions	Net greenhouse gas emissions intensity from dairy systems in southern Australia have been estimated to increase in future in several locations due to a changing climate and management responses (Cullen and Eckard, 2011; Eckard and Cullen, 2011). A shift toward perennial C4 grasses would increase methane emissions from grazing ruminants due to lower feed quality, but studies in southwest Australia suggest this could be more than offset by increased soil carbon storage (Thomas et al., 2012; Bradshaw et al., 2013).
Housing design to reduce peak energy demand	Energy use, infrastructure, health	Reducing peak energy demand through building design and demand management reduces vulnerability of electricity networks and transmission losses during heat waves (Parsons Brinkerhoff, 2009; Nguyen et al., 2010), reduces heat stress during summer, and provides health benefits during winter (Strengers, 2008; Howden-Chapman, 2010; Strengers and Maller, 2011; Ren et al., 2012).
Energy from second-generation biofuels	Biodiversity, rural areas, 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 including reducing erosion (Cocklin and Dibden, 2009; Giltrap et al., 2009; McHenry, 2009).
Reduced emissions from fires	Biodiversity, livelihoods	Improved management of savannah fires to reduce the extent of high-intensity late season fires could substantially reduce emissions as well as having significant benefits for biodiversity and indigenous employment (Russell-Smith et al., 2009; Bradshaw et al., 2013).
Reduce methane emissions from feral camels	Biodiversity, agriculture	Feral camels in Australia are projected to double from 1 to 2 million by 2020. Controlling their numbers to reduce methane emissions could have significant biodiversity benefits (NRMMC, 2010; Bradshaw et al., 2013). Economic benefits of reduced grazing competition, infrastructure damage, and greenhouse gases could outweigh costs of camel reductions (Drucker et al., 2010).

Box 25-10 | Land-based Interactions among Climate, Energy, Water, and Biodiversity

Climate, water, biodiversity, food, and energy production and use are intertwined through complex feedbacks and trade-offs (see also Box CC-WE). This could make alternative uses of natural resources within rural landscapes increasingly contested, yet decision support tools to manage competing objectives are limited (PMSEIC, 2010b).

Various policies in Australasia support increased biofuel production and biological carbon sequestration via, for example, 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 ecosystem connectivity, while risks or lost opportunities are associated with large-scale monocultures especially if replacing more diverse landscapes (Brockerhoff et al., 2008; Giltrap et al., 2009; Steffen et al., 2009; Todd et al., 2009; Bradshaw et al., 2013).

Photosynthesis transfers water to the atmosphere, so increased sequestration is projected to reduce catchment yields particularly in southern Australia and affect water quality negatively (CSIRO, 2008; Schrobback et al., 2011; Bradshaw et al., 2013). Accounting for this water use in water allocations for sequestration activities would increase their cost and limit the potential of sequestration-driven land use change (Polglase et al., 2011; Stewart et al., 2011). Large-scale land-cover changes also affect local and regional climates and soil moisture through changing albedo, evaporation, plant transpiration, and surface roughness (McAlpine et al., 2009; Kirschbaum et al., 2011b), but these feedbacks have rarely been included in analyses of changing water demands and availability.

Biological carbon sequestration in New Zealand is less water-challenged than in Australia, except where catchments are projected to become drier and/or are already completely allocated (MfE, 2007a; Rutledge et al., 2011), and would mostly improve water quality through reduced erosion (Giltrap et al., 2009). Policies to protect water quality by limiting nitrogen discharge from agriculture have reduced livestock production and greenhouse gas emissions in the Lake Taupo and Rotorua catchments and supported land-use change toward sequestration (OECD, 2013b).

Trade-offs between biofuel and food production and ecosystem services depend strongly on the type of sequestration activity and their management relies on the use of consistent principles to evaluate externalities and benefits of alternative land uses (PMSEIC, 2010b). First-generation biofuels have been modeled in Australia as directly competing with agricultural production (Bryan et al., 2010). In contrast, production of woody biofuels in New Zealand is projected to occur on marginal land, not where the most intense agriculture occurs (Todd et al., 2009). Falling costs and increasing efficiency of solar energy may limit future biofuel demand, given the limited efficiency of plants in converting solar energy into usable fuel (e.g., Reijnders and Huijbregts, 2007).

about global climate change impacts, economic effects, and policy responses.

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. Agriculture and forestry producer returns, for example, are estimated to increase by 14.6% under the A2 scenario by 2070 (Saunders et al., 2010) and real gross national disposable income by 0.6 to 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 would also increase global commodity prices and hence returns to New Zealand farmers (Saunders et al., 2009; Reisinger et al., 2012). Depending on global implementation, these could more than offset projected average domestic climate change impacts on agriculture (Tait et al., 2008a). In contrast, higher international agricultural commodity prices appear insufficient to compensate for the more severe effects of climate change on agriculture in Australia (see Section 25.7.2; Gunasekera et al., 2007; Garnaut, 2008).

Climate change could affect international tourism to Australasia through international destination and activity preferences (Kulendran and Dwyer, 2010; Rosselló-Nadal et al., 2011; Scott et al., 2012), climate policies, and oil prices (Mayor and Tol, 2007; Becken, 2011; Schiff and Becken, 2011). These potentially significant effects remain poorly quantified, however, and are not well integrated into local vulnerability studies (Hopkins et al., 2012).

Climate change has the potential to change migration flows within Australasia, particularly because of coastal changes (e.g., from the Torres Straits islands to mainland Australia), although reliable estimates of such movements do not yet exist (see Section 12.4; Green, D. et al., 2010a; McNamara et al., 2011; Hugo, 2012). Migration within countries, and from New Zealand to Australia, is largely economically driven and sustained by transnational networks, though the perceived more attractive current climate in Australia is reportedly a factor in migration from New Zealand (Goss and Lindquist, 2000; Green, A.E. et al., 2008; Poot, 2009). The impacts of climate change in the Pacific may contribute to an increase in the number of people seeking to move to nearby countries (Bedford and Bedford, 2010; Hugo, 2010; McAdam, 2010; Farbotko and Lazrus, 2012; Bedford and Campbell, 2013) and affect political stability and geopolitical rivalry within the Asia-Pacific region, although there is no clear evidence of this to date and causal theories are scarce (Dupont, 2008; Pearman, 2009; see Sections 12.4-5). Increasing climate-driven disasters, disease, and border control will stimulate operations other than war for Australasia's armed forces; integration of security into adaptation and development assistance for Pacific island countries can therefore play a key role in moderating the influence of climate change on forced migration and conflict (*robust evidence*, *high agreement*; Dupont and Pearman, 2006; Bergin and Townsend, 2007; Dupont, 2008; Sinclair, 2008; Barnett, 2009; Rolfe, 2009).

25.10. Synthesis and Regional Key Risks

25.10.1. Economy-wide Impacts and the Potential of Mitigation to Reduce Risks

Globally effective mitigation could reduce or delay some of the risks associated with climate change and make adaptation more feasible beyond about 2050, when projected climates begin to diverge substantially between mitigation and non-mitigation scenarios (see also Section 19.7). Literature quantifying these benefits for Australasia has increased since the AR4 but remains very sparse. Economy-wide net costs for Australia are modeled to be substantially greater in 2100 under unmitigated climate change (A1FI; GNP loss 7.6%) than under globally effective mitigation (GNP loss less than 2% for stabilization at 450 or 550 ppm CO_2-eq, including costs of mitigation and residual impacts; Garnaut, 2008). These estimates, however, are highly uncertain and depend strongly on valuation of non-market impacts, treatment of potentially catastrophic outcomes, and assumptions about adaptation, global changes, and flow-on effects for Australia and effectiveness and implementation of global mitigation efforts (Garnaut, 2008). No estimates of climate change costs across the entire economy exist for New Zealand.

The benefits of mitigation in terms of reduced risks have been quantified for some individual sectors in Australia, for example, for irrigated agriculture in the Murray-Darling Basin (Quiggin et al., 2008, 2010; Valenzuela and Anderson, 2011; Scealy et al., 2012) and for net health outcomes (Bambrick et al., 2008). Although quantitative estimates from individual studies are highly assumption-dependent, multiple lines of evidence (see Sections 25.7-8) give *very high confidence* that globally effective mitigation would significantly reduce many long-term risks from climate change to Australia. Benefits differ, however, between States for some issues, for example, heat- and cold-related mortality (Bambrick et al., 2008). Few studies consider mitigation benefits explicitly for New Zealand, but scenario-based studies give *high confidence* that, if global emissions were reduced from a high (A2) to a medium-low (B1) emissions scenario, this would markedly lower the projected increase in flood risks (Ballinger et al., 2011; McMillan et al., 2012) and reduce risks to livestock production in the most drought-prone regions (Tait et al., 2008a; Clark et al., 2011). Mitigation would also reduce the projected benefits to production forestry, however, though amounts depend on the response to CO_2 fertilization (Kirschbaum et al., 2011a; see also Section 25.7.1).

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

The Australia/New Zealand chapter of the AR4 (Hennessy et al., 2007) concluded with an assessment of aggregated vulnerability for a range of sectors as a function of global average temperature. Building on recent additional insights, Table 25-8 shows eight key risks within those sectors that can be identified with *high confidence* for the 21st century, based on the multiple lines of evidence presented in the preceding sections and selected using the framework for identifying key risks set out in Chapter 19 (see also Box CC-KR). This combines consideration of biophysical impacts, their likelihood, timing, and persistence, with vulnerability of the affected system, based on exposure, magnitude of harm, significance of the system, and its ability to cope with or adapt to projected biophysical changes. These key risks differ in the extent to which they can be managed through adaptation and mitigation and their evolution over time, and some are more likely than others, but all warrant attention from a risk-management perspective.

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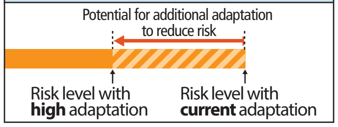
Table 25-8 | Key regional risks from climate change and the potential for reducing risk through mitigation and adaptation. Key risks are identified based on assessment of the literature and expert judgments by chapter authors, with evaluation of evidence and agreement in the supporting chapter sections. Each key risk is characterized on a scale from very low to very high and presented in three timeframes: the present, near-term (2030–2040), and long-term (2080–2100). For the near-term era of committed climate change (here, for 2030–2040), projected levels of global mean temperature increase do not diverge substantially across emissions scenarios. For the longer-term era of climate options (here, for 2080–2100), risk levels are presented for global mean temperature increase of 2°C and 4°C above preindustrial levels. For each timeframe, risk levels are estimated for a continuation of current adaptation and for a hypothetical highly adapted state. Relevant climate variables are indicated by icons. For a given key risk, change in risk level through time and across magnitudes of climate change is illustrated, but because the assessment considers potential impacts on different physical, biological, and human systems, risk levels should not necessarily be used to evaluate relative risk across key risks, sectors, or regions.

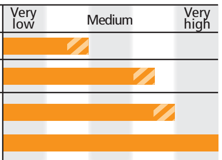
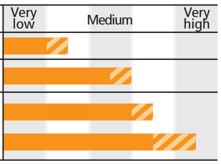
Climate-related drivers of impacts							
Warming trend	Extreme temperature	Drying trend	Extreme precipitation	Snow cover	Sea level rise	Damaging cyclone	Ocean acidification

Level of risk & potential for adaptation

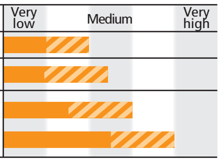
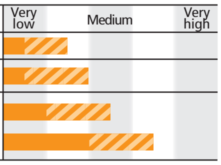
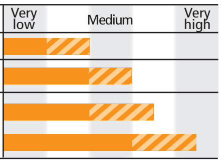
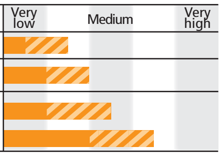


Key risk	Adaptation issues & prospects	Climatic drivers	Timeframe	Risk & potential for adaptation

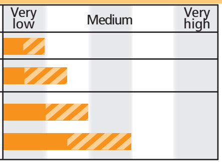
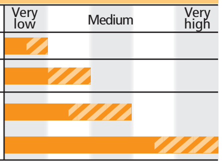
Impacts can be delayed but now appear very difficult to avoid entirely, even with combined globally effective mitigation and planned adaptation

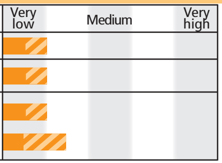
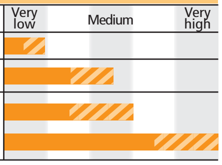
Key risk	Adaptation issues & prospects	Climatic drivers	Timeframe	Risk & potential for adaptation
Significant change in community composition and structure of coral reef systems in Australia (*high confidence*) [25.6.2, 30.5, Boxes CC-CR, CC-OA]	Ability of corals to adapt naturally appears limited and insufficient to offset the detrimental effects of rising temperatures and acidification. Other options are mostly limited to reducing other stresses (water quality, tourism, fishing) and early warning systems; direct interventions such as assisted colonization and shading have been proposed but remain untested at scale.	Warming trend Damaging cyclone Ocean acidification	Present Near term (2030–2040) 1.5°C Long term (2080–2100) 2°C 4°C	
Loss of montane ecosystems and some native species in Australia (*high confidence*) [25.6.1]	Direct adaptation options are limited, but reducing other stresses such as pests and diseases, predator control and enhancing connectivity of habitats provides immediate co-benefits; need to consider facilitating migration and assisted colonisation.	Warming trend Snow cover Drying trend	Present Near term (2030–2040) 1.5°C Long term (2080–2100) 2°C 4°C	

Impacts have the potential to be severe but can be reduced substantially by globally effective mitigation combined with adaptation

Key risk	Adaptation issues & prospects	Climatic drivers	Timeframe	Risk & potential for adaptation
Increased frequency and intensity of flood damage to infrastructure and settlements in Australia and New Zealand (*high confidence*) [Table 25-1, Boxes 25-8, 25-9]	Significant adaptation deficit in some regions to current flood risk. Effective adaptation includes land-use controls and relocation as well as protection and accommodation of increased risk to ensure flexibility.	Extreme precipitation	Present Near term (2030–2040) 1.5°C Long term (2080–2100) 2°C 4°C	
Constraints on water resources in southern Australia (*high confidence*) [25.5.1, Boxes 25-2, 25-9]	Water resources already struggling to meet unrestrained demand in many locations and exacerbated by projected population growth; effective adaptation relies on combination of demand and supply mechanisms.	Warming trend Drying trend	Present Near term (2030–2040) 1.5°C Long term (2080–2100) 2°C 4°C	
Increased morbidity, mortality and infrastructure damages during heat waves in Australia (*high confidence*) [25.7.4, 25.8.1]	Vulnerability is exacerbated by population growth and aging; transport and power infrastructure already severely stressed during heat waves in many regions, with significant financial costs from future upgrades.	Extreme temperature	Present Near term (2030–2040) 1.5°C Long term (2080–2100) 2°C 4°C	
Wild fire damages to ecosystems and settlements and risks to human life in southern Australia and many parts of New Zealand (*high confidence*) [Table 25-1, Box 25-6]	Part of integrated landscape management; trade-offs between different management objectives and settlement patterns and goals (biodiversity versus protection of human life and property).	Warming trend Extreme temperature Drying trend	Present Near term (2030–2040) 1.5°C Long term (2080–2100) 2°C 4°C	

Impacts whose severity depends on changes in climate variables that span a particularly large range; the most severe end would present major challenges

Key risk	Adaptation issues & prospects	Climatic drivers	Moderate sea level rise (AR5 WGI 13.5; Box 25-2)		High end sea level rise	
Increasing risks to coastal infrastructure and low-lying ecosystems in Australia and New Zealand, with widespread damages toward the upper end of projected sea level rise ranges (*high confidence*) [25.6, 25.10, Box 25-1]	Adaptation deficit in some locations to current coastal erosion and flood risk. Successive building and protection cycles constrain flexible responses. Effective adaptation includes land-use controls and ultimately relocation as well as protection and accommodation.	Sea level rise Damaging cyclone	Present Near-term (2030-2040) 1.5°C Long-term (2080-2100) 2°C 4°C		Present Near term (2030–2040) 1.5°C Long term (2080–2100) 2°C 4°C	

Key risk	Adaptation issues & prospects	Climatic drivers	Wet end of scenario (25.2, 25.5.2, Figure 25-4)		Dry end of scenario	
Significant reduction in agriculture production in the Murray-Darling Basin and far south-eastern and south-western Australia (*high confidence*) [25.2, 25.6.1, 25.7.2, Table 25-1, Boxes 25-2, 25-5]	Immediate co-benefits from improved management of over-allocated water resources and balancing competing demands, but the extreme dry end would threaten agricultural production as well as ecosystems and some rural communities.	Drying trend Warming trend Extreme temperature	Present Near-term (2030-2040) 1.5°C Long-term (2080-2100) 2°C 4°C		Present Near term (2030–2040) 1.5°C Long term (2080–2100) 2°C 4°C	

One set of key risks comprises damages to natural ecosystems (significant change in community structure of coral reefs and loss of some montane ecosystems) that can be moderated by globally effective mitigation but to which some damage now seems inevitable. For some species and ecosystems, climatically constrained ecological niches, fragmented habitats, and limited adaptive movement collectively present hard limits to adaptation to further climate change (*high confidence*). A second set of key risks (increase in flood risk, water scarcity, heat waves, and wildfire) comprises damages that could be severe but can be reduced substantially by globally effective mitigation combined with adaptation, with the need for transformational adaptation increasing with the rate and amount of climate change. A third set of key risks (coastal damages from sea level rise, and loss of agriculture production from severe drying) comprises potential impacts whose scale remains highly uncertain within the 21st century, even for a given global temperature change, and where alternative scenarios materially affect levels of concern, adaptation needs, and strategies. Even though scenarios of severe drying (see Section 25.5.2) or rapid sea level rise approaching 1 m or more by 2100 (see Box 25-2; WGI AR5 Section 13.5) have low or currently unknown probabilities, the associated impacts would so severely challenge adaptive capacity, including transformational changes, that they constitute important risks.

A first comparative assessment for Australia of exposure and damages from different hazards up to 2100 indicates that river flooding will continue to be the most costly source of direct damages to infrastructure, even though the largest value of assets is exposed to bush fire. Exposure to and damages from coastal inundation are currently smaller, but would rise most rapidly beyond mid-century if sea level rise exceeds 0.5 m (Baynes et al., 2012).

An *emerging risk* is the compounding of extreme events, none of which would constitute a key risk in its own right, but that collectively and cumulatively across space and time could stretch emergency response and recovery capacity and hamper regional economic development, including through impacts on insurance markets or multiple concurrent needs for major infrastructure upgrades (NDIR, 2011; Phelan, 2011; Baynes et al., 2012; Booth and Williams, 2012; Karoly and Boulter, 2013). Efforts are underway to better understand the potential importance of cumulative impacts and responses, including the challenges arising from impacts and responses across different levels of government (Leonard, M. et al., 2010; CSIRO, 2011), but evidence is as yet too limited to identify this as a *key risk* consistent with the definitions adopted in this report (see Chapter 19).

Climate change is projected to bring benefits to some sectors and parts of Australasia, at least under limited warming scenarios associated with globally effective mitigation (*high confidence*). Examples include an extended growing season for agriculture and forestry in cooler parts of New Zealand and Tasmania, reduced winter mortality (*low confidence*), and reduced winter energy demand in most of New Zealand and southern States of Australia, and increased winter hydropower potential in New Zealand's South Island (Sections 25.7.1-2, 25.7.4, 25.8.1).

The literature supporting this assessment of key risks is uneven among sectors and between Australia and New Zealand; for the latter, conclusions in many sectors are based on limited studies that often use a narrow set of assumptions, models, and data and that, accordingly, have not explored the full range of potential outcomes.

25.10.3. Challenges to Adaptation in Managing Key Risks, and Limits to Adaptation

Two key and related challenges for regional adaptation are apparent: to identify when and where adaptation may imply transformational rather than incremental changes; and, where specific interventions are needed to overcome adaptation constraints, in particular to support transformational responses that require coordination across different spheres of governance and decision making (Productivity Commission, 2012; Palutikof et al., 2013). The magnitude of climate change, especially under scenarios of limited mitigation, and constraints to adaptation suggest that incremental and autonomous responses will not deliver the full range of available adaptation options nor ensure the continued function of natural and human systems if some key risks are realized (*high confidence*; see also Section 25.4).

Most incremental adaptation measures in natural ecosystems focus on reducing other non-climate stresses but, even with scaled-up efforts, conserving the current state and composition of the ecosystems most at risk appears increasingly infeasible (Sections 25.6.1-2). Maintenance of key ecosystem functions and services requires a radical reassessment of conservation values and practices related to assisted colonization and the values placed on "introduced" species (Steffen et al., 2009). Divergent views regarding intrinsic and service values of species and ecosystems imply the need for a proactive discussion to enable effective decision making and resource allocation.

In human systems, incremental adjustments of current risk management tools, planning approaches, and early warning systems for floods, fire, drought, water resources, and coastal hazards can increase resilience to climate variability and change, especially in the near term (IPCC, 2012; Productivity Commission, 2012; Dovers, 2013). A purely incremental approach, however, which generally aims to preserve current management objectives, governance, and institutional arrangements, can make later transformational changes increasingly difficult and costly (*medium evidence*, *high agreement*; e.g., Howden et al., 2010; Park et al., 2012; McDonald, 2013; Stafford-Smith, 2013). Examples of transformational changes include: shifting emphasis from protection to accommodation or avoidance of flood risk, including managed retreat from eroding coasts; the translocation of industries in response to increasing drought, flood, and fire risks or water scarcity; and the associated transformation of the economic and social base and governance of some rural communities (Boxes 25-1, 25-2, 25-5 to 25-9; Nelson et al., 2010; Linnenluecke et al., 2011; Kiem and Austin, 2012; O'Neill and Handmer, 2012; McDonald, 2013; Palutikof et al., 2013).

Consideration of transformational adaptation becomes critical where long life- or lead-times are involved, and where high up-front costs or multiple interdependent actors create constraints that require coordinated and proactive interventions (Stafford-Smith et al., 2011; Productivity Commission, 2012; Palutikof et al., 2013). Deferring such adaptation decisions because of uncertainty about the future will not necessarily minimize costs or ensure adequate flexibility for future responses,

Frequently Asked Questions

FAQ 25.2 | What are the key risks from climate change to Australia and New Zealand?

Our assessment identifies eight key regional risks from climate change. Some impacts, especially on ecosystems, are by now difficult to avoid entirely. Coral reef systems have a limited ability to adapt naturally to further warming and an increasingly acidic ocean. Similarly, the habitat for some mountain or high elevation ecosystems and their associated species is shrinking inexorably with rising temperatures. This implies substantial impacts and some losses even under scenarios of limited warming. Other risks, however, can be reduced substantially by adaptation, combined with globally effective mitigation. These include potential flood damages from more extreme rainfall in most parts of Australia and New Zealand; constraints on water resources from reducing rainfall in southern Australia; increased health risks and infrastructure damages from heat waves in Australia; and increased economic losses, risks to human life, and ecosystem damage from wildfires in southern Australia and many parts of New Zealand. A third set of risks is particularly challenging to manage robustly because the severity of potential impacts varies widely across the range of climate projections, even for a given temperature increase. These concern damages to coastal infrastructure and low-lying ecosystems from continuing sea level rise, where damages would be widespread if sea level turns out to be at the upper end of current scenarios; and threats to agricultural production in both far southeastern and far southwestern Australia, which would affect ecosystems and rural communities severely at the dry end of projected rainfall changes. Even though some of these key risks are more likely to materialize than others, and they differ in the extent that they can be managed by adaptation and mitigation, they all warrant attention from a risk management perspective, given their potential major consequences for the region.

although up-front investment and opportunity costs of adaptation can present powerful arguments for delayed or staged responses (Stewart and Wang, 2011; Gorddard et al., 2012; Productivity Commission, 2012; McDonald, 2013). Whether transformational responses are seen as success or failure of adaptation depends on the extent to which actors accept a change in, or wish to maintain, current activities and management objectives, and the degree to which the values and institutions underpinning the transformation are shared or contested across stakeholders (Park et al., 2012; Stafford-Smith, 2013). These views will differ not only between communities and industries but also from person to person depending on their individual value systems, perceptions of and attitude to risk, and ability to capitalize on opportunities (see also Section 25.4.3).

25.11. Filling Knowledge Gaps to Improve Management of Climate Risks

The wide range of projected rainfall changes (averages and extremes) and their hydrological amplification are key uncertainties affecting the scale and urgency of adaptation in agriculture, forestry, water resources, some ecosystems, and wildfire and flood risks. For ecosystems, agriculture, and forestry, these uncertainties are compounded by limited knowledge of responses of vegetation to elevated CO_2, changes in ocean pH, and interactions with changing climatic conditions. The uncertainties in future impacts are most critical for decisions with long lifetimes, such as capital infrastructure investment or large-scale changes in land and water use. Uncertainties about the rate of sea level rise, and changes in storm paths and intensity, add to challenges for infrastructure design. The use of multi-model means and a narrow set of emissions scenarios in many past studies implies that the full set of climate-related risks and management options remains incompletely explored.

Understanding of ecological and physiological thresholds that, once exceeded, would result in rapid changes in species, ecosystems, and their services is still very limited. The literature is noticeably sparse in New Zealand and for arid Australia. These knowledge gaps are compounded by limited information about the effect of global climate change on patterns of natural climate variability, such as ENSO. Better understanding the effect of evolving natural climate variability and long-term trends, along with rising CO_2 concentrations, on pests, invasive species, and native and managed ecosystems could support more robust ecosystem-based adaptation strategies.

Vulnerability of human and managed systems depends critically on future socioeconomic characteristics. Research into psychological, economic, social, and cultural dimensions of vulnerability, adaptive capacity, and underpinning values remains limited and poorly integrated with biophysical studies. This limits the level of confidence in conclusions regarding future vulnerabilities and the feasibility and effectiveness of adaptation strategies.

These multiple, persistent, and structural uncertainties imply that, in most cases, adaptation requires an iterative risk management process. Though decision-support frameworks are being developed, it remains unclear to what extent existing governance and institutional arrangements will be able to support more transformational responses, particularly where competing public and private interests and particularly vulnerable groups are involved. The enabling or constraining influences on adaptation from interactions among market forces, institutions, governance, policy, and regulatory environments have only recently begun to attract research attention, mostly in Australia.

Climate change impacts, adaptation, and mitigation responses in other world regions will affect Australasia, but our understanding of this remains very limited. Existing studies suggest that transboundary effects, mediated mostly via trade but potentially also migration, can be of similar if not larger scale than direct domestic impacts of climate change for economically important sectors such as agriculture and tourism. However, scenarios used in such studies tend to be highly simplified. Effective management of risks and opportunities in these sectors would benefit from better integration of relevant global scenarios of climatic and socioeconomic changes into studies of local vulnerability and adaptation options.

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