



FEEDING A HUNGRY NATION: CLIMATE CHANGE, FOOD AND FARMING IN AUSTRALIA

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Preface

Australia is one of only a handful of countries that produces more food than it consumes and most Australians have access to an abundant and safe food supply. But Australia is also considered one of the most vulnerable developed countries in the world to impacts of the changing climate.

Rising temperatures, increased frequency and intensity of extreme weather events, and declining water availability in some of our most important agricultural regions pose significant risks for the nature, distribution, quality, and affordability of our food supply. At the same time, the Australian and global population continues to grow, competition for arable land continues to intensify, and our natural resource base continues to degrade, placing ever-increasing demands on food production systems.

The focus of this report is the way in which climate change may affect our food supply, both directly and indirectly. These impacts will in turn affect everyday Australian households as food prices and food availability become more volatile and affect the economies and social fabric of those communities that rely on agricultural production.

At the time of writing, many regions of Australia have been drought declared, including 80% of Queensland, the largest ever area officially recognised as being in drought. Further, the Bureau of Meteorology has just declared the beginning of an El Niño event, which brings with it an increased chance of warmer and drier conditions to some of our most important agricultural regions. These issues are of concern to many Australians, with more than half of those surveyed in the latest IPSOS climate change poll indicating they are concerned about the negative impacts of climate change on agricultural production (IPSOS 2015). There is no room for complacency in planning for our future food security.

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Key Findings

1

Climate change is making weather patterns more extreme and unpredictable, with serious consequences for Australia's agricultural production.

- › Climate change is driving an increase in the intensity and frequency of hot days and heatwaves in Australia, changing rainfall patterns, increasing the severity of droughts, and driving up the likelihood of extreme fire danger weather.
- › Average rainfall in southern Australia during the cool season is predicted to decline further, and the time spent in extreme drought conditions is projected to increase.
- › Water scarcity, heat stress and increased climatic variability in our most productive agricultural regions, such as the Murray Darling Basin, are key risks for our food security, economy, and dependent industries and communities.
- › Climatic challenges could result in imports of key agricultural commodities such as wheat increasingly outweighing exports.

2

More frequent and intense heatwaves and extreme weather events are already affecting food prices in Australia.

- › Climate change is increasing the variability of crop yields.
- › Food prices during the 2005-2007 drought increased at twice the rate of the Consumer Price Index (CPI) with fresh fruit and vegetables the worst hit, increasing 43% and 33% respectively.
- › Reductions of livestock numbers during droughts can directly affect meat prices for many years.
- › Rainfall deficiencies in parts of Western Australia and central Queensland are projected to reduce total national crop production by 12% in 2014-15, and the value of beef and veal exports by 4%.
- › Cyclone Larry destroyed 90% of the North Queensland banana crop in 2006, affecting supply for nine months and increasing prices by 500%.
- › The 2009 heatwave in Victoria decimated fruit crops, with significant production losses of berry and other fruit crops.

3

Climate change is affecting the quality and seasonal availability of many foods in Australia.

- › Up to 70% of Australia's wine-growing regions with a Mediterranean climate (including iconic areas like the Barossa Valley and Margaret River) will be less suitable for grape growing by 2050. Higher temperatures will continue to cause earlier ripening and reduced grape quality, as well as encourage expansion to new areas, including some regions of Tasmania.
- › Many foods produced by plants growing at elevated CO₂ have reduced protein and mineral concentrations, reducing their nutritional value.
- › Harsher climate conditions will increase use of more heat-tolerant breeds in beef production, some of which have lower meat quality and reproductive rates.
- › Heat stress reduces milk yield by 10-25% and up to 40% in extreme heatwave conditions.
- › The yields of many important crop species such as wheat, rice and maize are reduced at temperatures more than 30°C.

4

Australia is extremely vulnerable to disruptions in food supply through extreme weather events.

- › There is typically less than 30 days supply of non-perishable food and less than five days supply of perishable food in the supply chain at any one time. Households generally hold only about a 3-5 day supply of food. Such low reserves are vulnerable to natural disasters and disruption to transport from extreme weather.
- › During the 2011 Queensland floods, several towns such as Rockhampton were cut off for up to two weeks, preventing food resupply. Brisbane came within a day of running out of bread.

5

Australia's international competitiveness in many agricultural markets will be challenged by the warming climate and changing weather patterns.

- › Australia is projected to be one of the most adversely affected regions from future changes in climate in terms of reductions in agricultural production and exports.
- › Climate impacts on agricultural production in other countries will affect our competitiveness, especially if warmer and wetter conditions elsewhere boost production of key products such as beef and lamb.

6

If the current rate of climate change is maintained, adaptation to food production challenges will be increasingly difficult and expensive.

- › By 2061, Australia's domestic demand for food could be 90% above 2000 levels, with a similar increase in export demand.
- › Transitioning to a new, low-carbon economy is critical to avoiding the most dangerous impacts of climate change.
- › The longer action on climate change is delayed, the more likely it is that progressive, small-scale adaptive steps to cope with climate change will become increasingly inadequate and larger, more expensive changes will be required.

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1. | INTRODUCTION

There are few things more fundamental to our lives than food. A safe, affordable and reliable food supply is something most Australians take for granted, although many people in other countries are not so fortunate. The multiple components of a food system required to support a healthy lifestyle have been collectively termed “food security” defined by the United Nations Food and Agriculture Organisation (FAO) at the World Food Summit in 1996 as:

‘when all people at all times have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life’ (FAO 1996).

Food production is thus just one component of a desirable food supply system – food also needs to be of high quality, affordable, and distributed reliably and fairly.

There are many global and local drivers that affect a food system, and these drivers operate at a number of levels, from individuals and households to communities, nations and globally. Food supply drivers include the rate of agricultural productivity; availability of land and water and condition of natural resources; availability of technology and labour; climate; trade policies; biosecurity; competition; and production inputs such as fertilisers and irrigation (DAFF 2011). Food demand drivers include population growth and demography; consumption patterns and preferences; and wastage patterns (DAFF 2011).

With the world's population projected to increase to over 9 billion people by the middle of this century, and potentially to over 12 billion by 2100 (Gerland et al. 2014), together with increasing affluence leading to greater demand for protein-rich foods, the global food challenge is considerable. Climate change, coupled with the ongoing degradation of the world's natural resources, makes this challenge immense. Understanding the intimate connections between climate, energy, water and food is critical to meeting this challenge.

While Australia has enjoyed an unprecedented level of food security over the past 50 years (Michael and Crossley 2012), current agricultural practices across much of the continent are already being affected by the changing climate. Further, food prices and food distribution systems are subject to volatility and disruption from an increase in extreme weather events and changing climate variability. Over the next few decades, the risks posed by extreme heat, water scarcity, increasing climate variability, and more frequent and intense extreme weather events are expected to increase. At the same time, there is increasing competition for land and water for purposes other than food production – such as for biofuels, carbon storage, biodiversity conservation, industry and urban settlements. These challenges

are likely to intensify in coming decades, at the same time that population growth both in Australia and globally will place ever-increasing demands on food production.

These pressures will flow through to households in several ways. Indeed, more frequent and intense extreme weather events are already affecting prices, quality, seasonal availability and reliability of supply of many foods in Australia.

In this report, we firstly describe the nature of Australian food production and the challenging environmental context in which it occurs. Climate change has the capacity to greatly exacerbate these existing challenges. We then describe how the Australian climate has already changed over the past century; how it is projected to change in coming decades; the direct and indirect impacts expected on agricultural production, food quality, affordability and distribution; and the challenges and opportunities for effective adaptation. Finally we place Australian efforts to combat future climate change in a global context to emphasise that this is the critical decade for urgent and decisive action.



2. AUSTRALIAN FOOD PRODUCTION

Australia is the driest inhabited continent, a land of highly variable rainfall and climatic extremes, mainly covered by vegetation that is woody and of poor nutritional value for livestock.

About 85% of the population hugs the more fertile temperate coastal areas, with the remaining

population scattered across the vast inland regions. These features have presented enormous challenges for food production since European colonisation but Australian farmers have proved to be resilient and adaptive. Agriculture currently occupies more than half (52%) of the Australian landmass (ABS 2014a; 2015b).

2.1. Value to the Economy

Agriculture has been a major contributor to the Australian economy since European settlement. Indeed, in the first half of the 20th century, when agricultural production accounted for up to 80% of Australia's exports, our prosperity was said to "ride on the sheep's back" (ABS 2012a).

In recent decades, the agriculture sector has declined in relative percentage terms compared to other industries; in the first half of the 20th century agriculture was worth about 25% of Gross Domestic Product (GDP) but is now about 2% (ABARES 2015a). From 1991-2000, farm productivity growth was about 2.9% per year, but in 2002-2011 it was 1.4% per year, compared to the world average of 1.7% (Rabobank 2015). Some of this slowdown has been attributed to declining investment in agricultural research and development (R&D) especially since the 1970s (PMSEIC 2010; Mullen and Keogh 2013; Daly et al. 2015). The decline in undergraduates enrolled in agricultural degrees may also pose a future challenge to research underpinning food production (Office of the Chief Scientist 2012).

Nonetheless, Australia's agricultural output as a proportion of the economy remains among the highest in the OECD (ABS 2012a). Despite declining terms of trade, Australia's agricultural productivity has grown at about three times the rate of the productivity of the economy as a whole (ATSE 2014). The value of farm production in 2013-14 was worth \$51 billion (ABARES 2015a) and underpinned Australia's largest manufacturing sector – the food and beverage processing industry, worth \$25 billion (ABS 2015a). Government subsidies represent less than 2% of farming income, the second lowest level of any nation in the world for which data are available (OECD 2015).

The development of industries such as cotton, canola and lupins, and expansion of the wine industry have contributed to growth (ATSE 2014). Production of other grains, red meat, sugar and dairy products are strong but vary annually and seasonally due to climatic conditions, domestic economic reforms that have affected market protection, and international currency fluctuations (ATSE 2014). Wheat and beef products remain Australia's largest value products (Figure 1).

Australia's agricultural output as a proportion of the economy remains among the highest in the OECD.

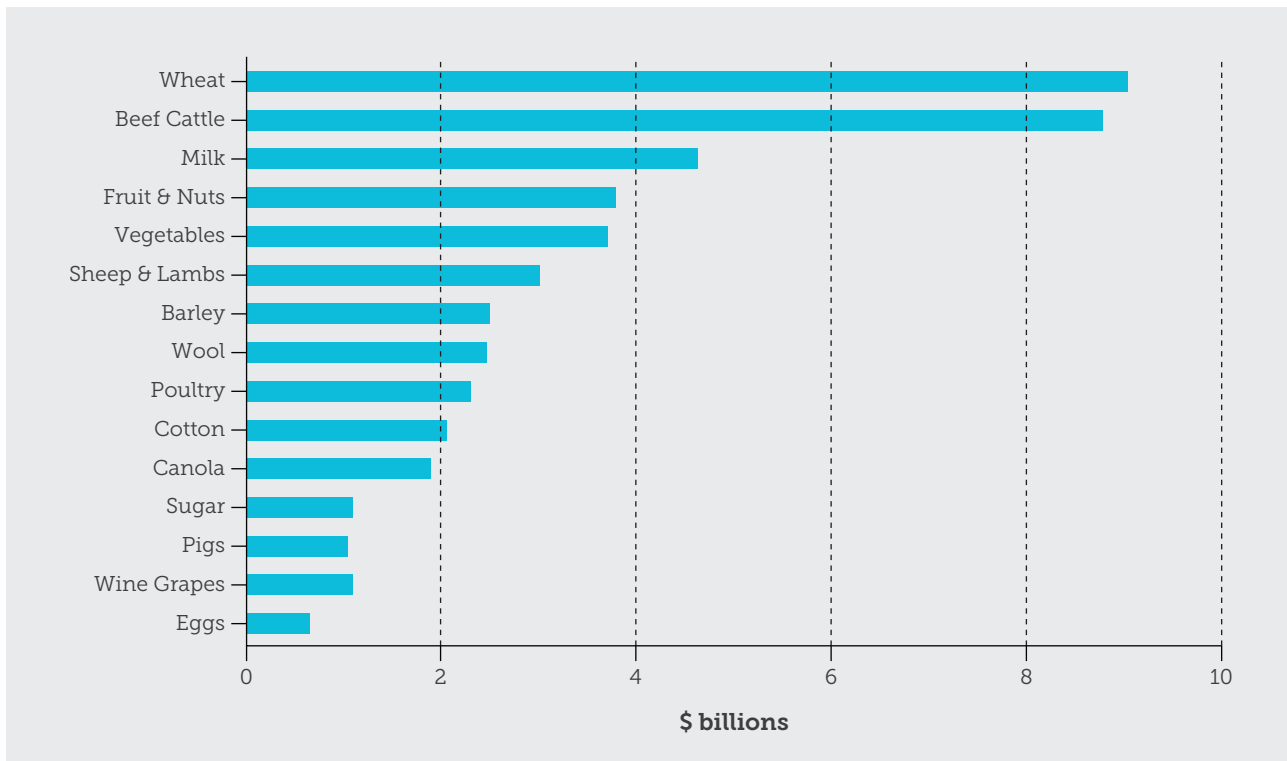


Figure 1: Value of Australian farm production, 2013–14. Source: CoA (2014) based on data from ABARES (2014b).

There are an estimated 115,000 enterprises in Australia that cite agriculture as their primary business, with a further 13,000 that cite agriculture as their secondary business (ABS 2014a); over 90% of these businesses are family owned (ABS 2012a). An estimated 270,000 people are employed in the agricultural sector, with a further 223,000 in food and beverage processing (ABARES 2015a). Grain, sheep and beef cattle production are collectively the largest employers, with 107,000 employees in 2013-14, followed by horticulture with 63,000 and dairy with 26,000 (ABS 2014b). Farm employment relative to other sectors has declined over the past few decades, from 8% in 1966-67 to just over 2% in 2013-14 (CoA 2015).

The majority of farm businesses are involved in beef cattle farming (28%), mixed grain-sheep or grain-beef cattle farming (9%), other grain growing (9%), or specialised sheep farming (8%). Other common types

of farming businesses include dairy cattle (6%), mixed sheep-beef cattle (5%) and grape growing (4%) (ABS 2012a). While production has become increasingly concentrated in large farms, the majority of Australia's farms are comparatively small with around a third covering less than 50 ha, and another third covering 50-500 ha. In 2010-11, just over half (55%) had an estimated value of agricultural operations of less than \$100,000 (ABS 2012a). Dryland livestock grazing is the dominant land use, accounting for 380 million ha (Barlow et al. 2011).

Forestry and fishing also play an important economic role in some regions, together employing 56,000 people (2010-11) and producing commodities worth nearly \$4.9 billion (2010-11) (ABS 2012b). Primary industries also support enterprises such as tourism and transport and a wide range of local cultural, economic and social activities (Barlow et al. 2011).

AGRICULTURE IN AUSTRALIA

A look at the diversity
of farming across
the States and
Territories

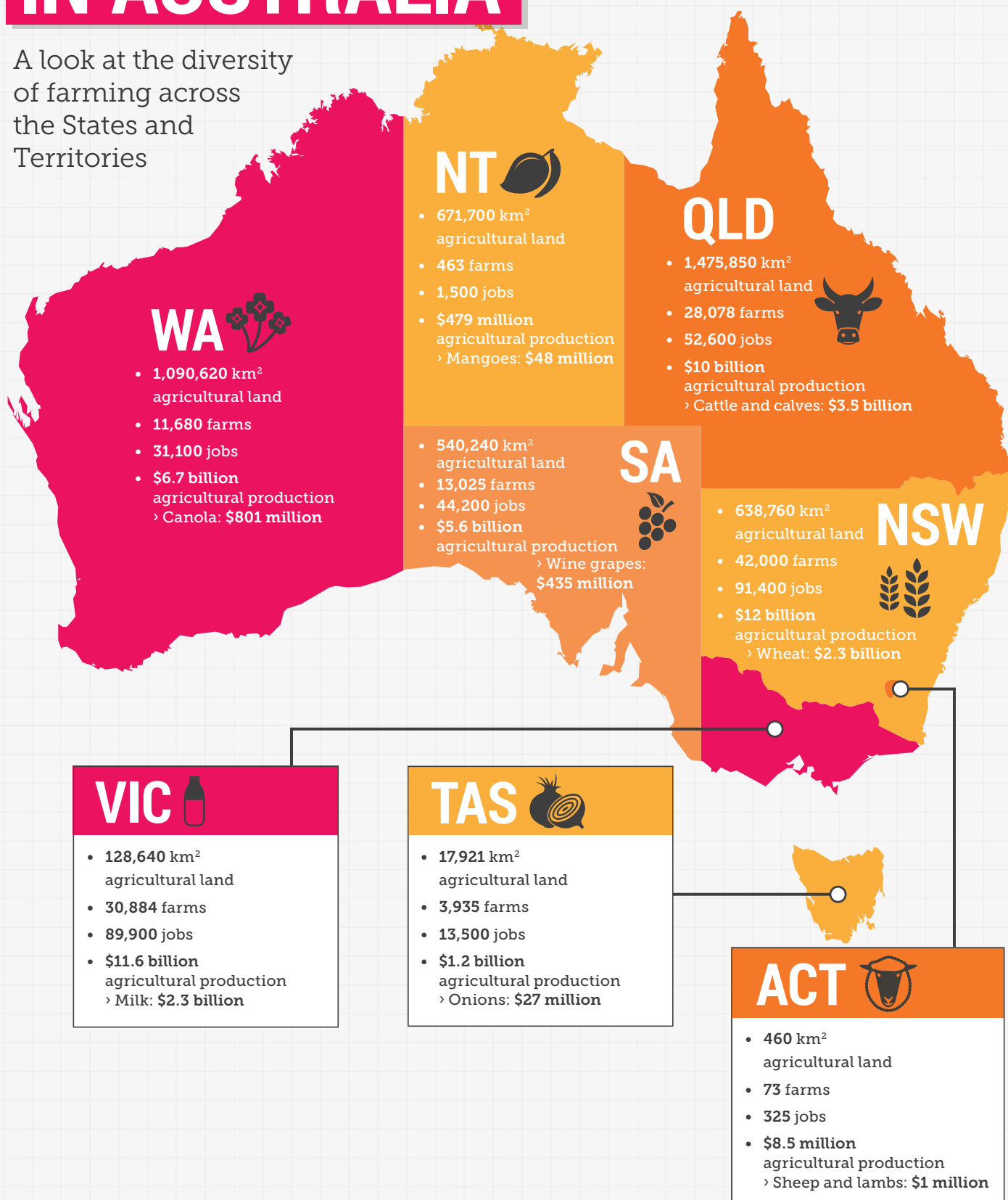


Figure 2: The diversity of farming in Australia. Source: Data from ABARES 2015d.

2.2. Exports

About 65% of Australia's total agricultural production is exported, valued at over \$41 billion in 2013-14 (ABARES 2015b). Australia is currently the sixth largest food-exporting nation (ATSE 2014).

More than half of Australia's food exports are sold to Asia, with Japan and China accounting for approximately 30% of the total (DFAT 2014). Most exported products are sold as bulk, undifferentiated commodities (Lawrence et al. 2013). Export earnings from farm commodities in 2014-15 are projected to be ~\$38.3 billion, of which crops represent \$20.3 billion and livestock ~\$18 billion (ABARES 2014a). Export quantity and value of individual commodities have varied over time, and from year to year, particularly in response to extreme events such as drought (see Box 2: Drought and the Australian Economy). For example, decreases in agricultural production between 2002 and 2003 due to drought resulted in a 1% reduction in GDP and a 28.5% fall in the gross value added for the agricultural industry, compared to the preceding year (ABS 2004).

Decreases in agricultural production between 2002 and 2003 due to drought resulted in a 1% reduction in GDP.

2.3. Imports

Despite our high volume of food exports, some horticultural, fisheries and forestry products are routinely imported (Growcom 2011; ATSE 2014), with New Zealand, the United States, Thailand, Singapore and Malaysia being the top five suppliers (ABARES 2015c). The balance between imports and exports with some of these key partners has changed markedly over the past few decades, with imports increasing relative to exports (McGovern 2015; Figure 3). In 2013-14, agricultural imports were valued at ~\$14 billion, largely comprising processed food, but also including fresh fruit and vegetables (ABARES 2014b); in the period 2005-2007, 34% of fruit consumed was imported, and 19% of vegetables (Growcom

2011). Many ingredients, additives and packaging materials that are important inputs to the food supply chain are imported; some foods such as canned fish and infant formula are fully imported (Sapere Research Group 2012). The rate of food importation has been steadily increasing, rising ~ 6% over the 18 year period to 2008, and accelerating in times of drought (PMSEIC 2010) (see Box 2: Drought and the Australian economy). Australian agriculture is also very reliant on imports of some farm inputs, especially fertilizer; fertilizer use has increased seven fold over the past four decades (Lawrence et al. 2013). In 2001-2009 56% of phosphorus fertilizer, 77% of nitrogen and 100% of potassium was imported (ABARES 2010).

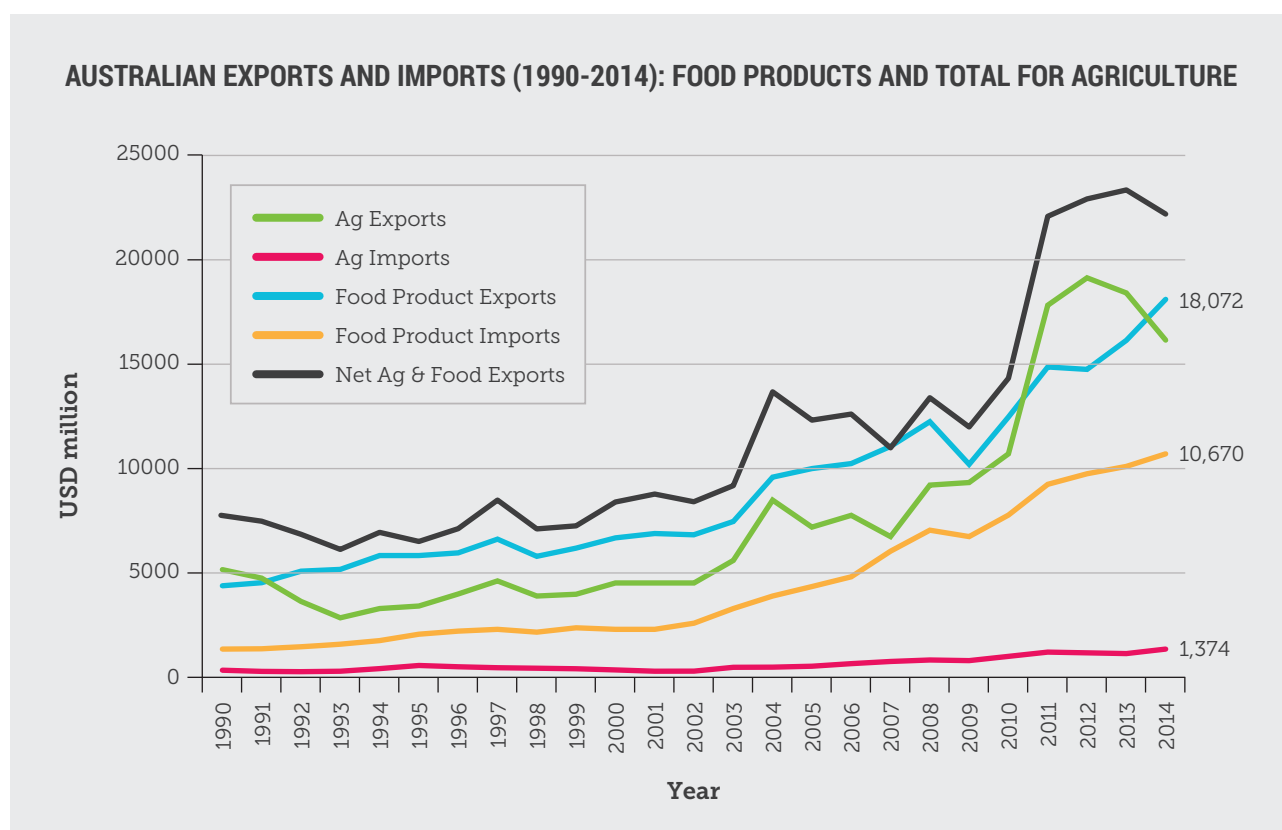


Figure 3: Australian exports and imports (1990-2014): food products and total for agriculture. **Source:** Adapted from McGovern 2015.

2.4. Land and Water Use

Food production in Australia uses approximately 450 million ha of land (more than half the continent), of which 32 million ha is used for crops (ATSE 2014). Two million ha of cropland is irrigated, using 8 gigalitres (GL) of water per year (ATSE 2014), equivalent to 3200 Olympic swimming pools.

While irrigated agriculture occupies less than 1% of agricultural land, it accounted for 28% of Australia's gross agricultural production value in 2010-11, half of which was produced in the Murray Darling Basin, which uses approximately 70% of all irrigation water (see Box 3: Climate Change and Australia's Food Bowl) (ABS 2012c; DAFF 2012).

Land and water resources in southern Australia are considered to be almost fully-developed, with some remaining opportunities for further irrigated production in Tasmania (ATSE 2014; Daly et al. 2015). New agricultural development in northern Australia is considered unlikely to exceed more than 5% of current cropped and irrigated lands (ATSE 2014) (see Box 6: The Northern Food Bowl). The amount of land devoted to agriculture in Australia has been steadily declining. Over the 10 years prior to 2009, about 5.9 million ha of agricultural land (an area equal to about five times the size of Sydney) were converted to other uses, including conservation and urban development (ABS 2010). The impact on total agricultural production from conversion to conservation uses has been relatively small because much of this land has low production capacity. Loss of agricultural land to urban expansion, however, is a serious issue. While only 3.5% in total area, land on the urban fringe conservatively accounts for 25% of the gross value of production in the five mainland states (Houston 2005). In recent years, prime agricultural land in some regions has also become increasingly subject to competition from mining (see Box 1: Hot Property: Farming vs Mining).

BOX 1: HOT PROPERTY FARMING VS MINING: COMPETITION FOR LAND AND WATER

Under many of the fertile soils suitable for intensive agriculture lie rich deposits of coal and gas. Competition for land and water by mining and farming interests has led to significant tensions in many regions. The Federal Government's conditional approval for the \$1.2 billion Shenhua coal-mining project in the heart of the fertile Liverpool Plains farming region in northern NSW (Figure 4) provides the most recent example. It is estimated that the mine will extract 268 million tonnes of coal over the next thirty years. While the government has promised

strong regulatory protection, local farmers argue that the mine will negatively affect groundwater supplies (The Guardian 2015). In Queensland, local residents are concerned that the New Acland coalmine will affect the economic sustainability of the Darling Downs region by removing prime agricultural land for mining development (Miller et al. 2012; ABC 2015a). Further north, the proposed opening of the Galilee Basin has been opposed by landholders concerned about the loss of rangelands for cattle and sheep grazing (Duus 2013).



Figure 4: The rich agricultural heartland of the Liverpool Plains in NSW facing competition from mining operations.

BOX 1: CONTINUED

Coal Seam Gas (CSG) operations (e.g. Figure 5) add another level of competition between natural resource industries and agriculture. CSG refers to the extraction of natural gas from pores and cracks in the coal seam at depths of 300-1000 m underground (CSIRO 2012a). To extract the gas, a well is drilled into the coal seam and the water is pumped out, allowing the gas to be released from the ground and brought to the surface (CSIRO 2012a). Because 90% of groundwater extraction is used in agriculture (Tan et al. 2015), one of the major areas of contention between farming and mining is the impact on aquifers (Lawrence et al. 2013; Tan et al. 2015). Water recovered from CSG can be salt affected, while chemicals used in extraction have the potential to enter bores and contaminate water used for both agriculture and human settlements (Lawrence et al. 2013). Environmental and water agencies have also identified the potential negative effect of CSG on irrigation and farming (e.g. MDBA 2012b; SEWPaC 2013).

Concerns over impacts on water and the loss of prime agricultural land from mining transcend political and traditional boundaries, with farming groups aligning with 'city greenies' (ABC 2013). Community concerns have resulted in Federal and State governments agreeing to tighten regulations that protect aquifers and limit pollution (Lawrence et al. 2013). For example, the Tasmanian State Government recently announced a ban on fracking[^] for another five years, based on considerable concerns from rural communities and farming families (ABC 2015b). However, many rural communities remain concerned by the perceived privilege of mining interests over agricultural land tenures and a lack of influence in government decision-making compared to the powerful mining industry (Duus 2013).

[^] Fracking is the process of drilling down into the earth before a high-pressure water mixture is directed at the rock to release the gas inside. Water, sand and chemicals are injected into the rock at high pressure which allows the gas to flow out to the head of the well.



Figure 5: Aerial view of Coal Seam Gas operations in Queensland, the competition for land between mining and farming.



Quality Produce
WHITE
ONIONS
\$5.99 Kg
PRODUCT OF AUSTRALIA

Quality Produce
BROWN
ONIONS
\$2.99 Kg
PRODUCT OF AUSTRALIA

WHITE & PURPLE
SWEET
POTATOES
\$6.99 Kg
PRODUCT OF AUSTRALIA

\$11.99

FRESH
YELLOW
CAPSICUM
\$11.99 Kg

LEBANESE
CUCUMBERS
\$4.99 Kg

CARROTS
\$2.99 Kg

BLACK
ZUCCHINI
\$5.99 Kg

3. FOOD SECURITY IN AUSTRALIA

Australia produces more food than the population consumes (DAFF 2011) and has been ranked the 15th most food secure country of 109 assessed by the Economist Intelligence Unit (EIU 2014). Not only have we enjoyed cheap, safe and high quality food for many decades, we export enough food to feed 60 million people (ABARES 2011).

We have efficient and largely unsubsidised production systems that provide significant surplus for export. Our food production systems also have many competitive advantages, including abundant land spanning across many climatic zones, a relatively stable business and political environment, strong scientific research, proximity to growing markets, skilled labour force, rigorous food safety regulation and well-developed biosecurity and quarantine systems (CoA 2014). Freedom from many of the pests and diseases that affect food production in other countries is particularly critical.

Australia has enjoyed cheap, safe and high quality food for many decades. We export enough food to feed 60 million people.

But while food security has thus far not been a significant issue for the country as a whole, it is an issue for some socially disadvantaged and remote communities, including indigenous communities, where the high cost of transport, lack of infrastructure, and difficult access mean that affordability and reliability of food supply can be a significant problem (DAFF 2011; Edwards et al. 2011). The price of healthy staple foods (such as fresh fruit and vegetables) can be 30% higher in remote communities than in cities (PMSEIC 2010), with flow-on impacts to health (Edwards et al. 2011).

The price of healthy staple foods (such as fresh fruit and vegetables) can be 30% higher in remote communities than in cities, with flow-on impacts to health.

Globally, an estimated 30-50% of all food produced never reaches a human stomach.

Food security is also an issue for a significant number of individuals and households right across the country because it is closely tied to poverty. It has been estimated that ~5-7% of the Australian population could be food insecure at any one time (NSW Department of Health 2005; Temple 2008; Foley et al. 2010). Groups at particular risk include rural, isolated, low-income and indigenous households, as well as the elderly and new migrants.

As in other wealthy countries, a considerable amount of food in Australia is wasted. One survey in 2004 estimated that \$5.2 billion of food is wasted every year after purchase (~15% of purchased household food) (TAI 2005); another estimate is that Australians waste about 360 kg per person per year (SEWPaC 2010). Australians are not alone in this respect: 40% of food (worth US\$ 165 billion) in the United States goes uneaten (Natural Resources Defense Council 2012; Figure 6), and globally, an estimated 30-50% of all food produced never reaches a human stomach (IME 2013).

In recent years, several expert bodies have warned against complacency with regard to Australian food production and profitability, recognising that the changing climate, coupled with increasing competition for land and water and ongoing land degradation, pose considerable long-term challenges, especially with Australia's population projected to grow to 35-40 million by mid-century (ABS 2013). By 2061, Australia's domestic demand for food could be 90% above 2000 levels, with a similar increase in export demand (Michael and Crossley 2012).



Figure 6: Food waste is a serious problem. Australians waste about 360 kg per person per year.

By 2061, Australia's domestic demand for food could be 90% above 2000 levels, with a similar increase in export demand.



4. AUSTRALIA'S CLIMATE – "A LAND OF DROUGHTS AND FLOODING RAINS"

4.1. Background

Australia is the driest inhabited continent on Earth. Its rainfall is fourfold more variable than that of Russia, threefold more than that of the United States, and more than double that of New Zealand, India and the United Kingdom (Hanna et al. 2011).

Much of Australia is also subject to extreme heat which, coupled with the highly variable water cycle and generally poor soils, presents a challenging environment for primary producers.

Figure 7: Diamantina cattle grazing country in South Australia.



4.2. Observed and Projected Changes in Australia's Climate

Long-term trends in many aspects of Australia's climate are difficult to discern given the high natural variability of our climate.

Nevertheless, several important multi-decadal trends can be identified, including a long-term trend towards higher temperatures and more extreme heat, and shifts in the amount and seasonality of rainfall at large regional scales. In the following sections on important features of Australia's climate, we present both observations of changes that are already occurring as well as projections of future changes. Technical details of projection methods are given in the box in the Appendix.

Figure 8: Failed crops in southwest NSW during the Millennium Drought in 2006.



4.2.1 Temperature, Extreme Heat and Bushfire Risk

The average surface temperature across Australia has increased by 0.9°C since 1910 (CSIRO and BoM 2015). There is significant regional variation, with some of the largest

increases occurring across inland Queensland and the Northern Territory (Figure 9). In general, warming has been stronger over inland areas than coastal regions.

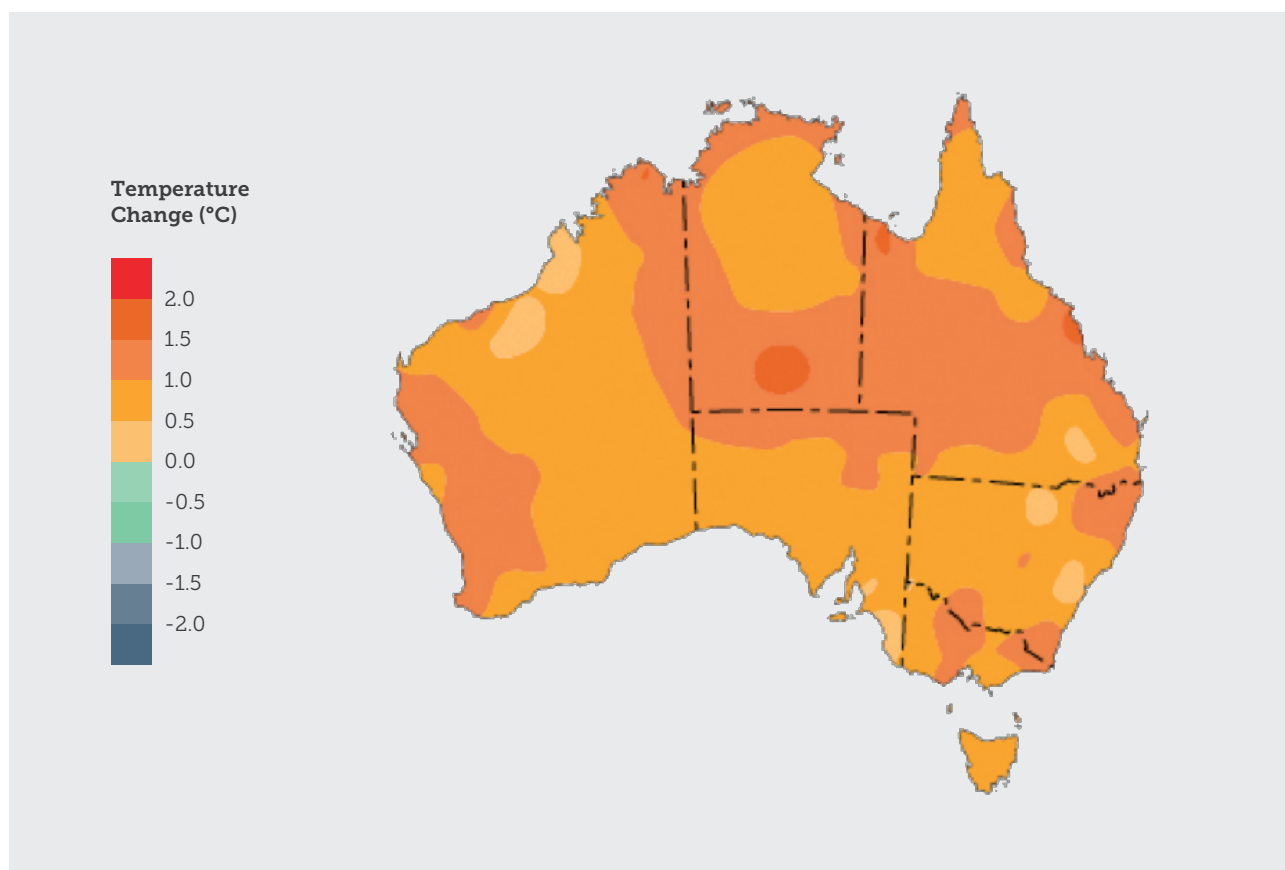


Figure 9: Linear trend in mean temperature from the Australian Climate Observations Reference Network (ACORN-SAT) calculated for the entire period 1910-2013. **Source:** BoM (2014).

There is no doubt that Australia will continue to warm substantially through the rest of this century.

Extreme heat is also on the increase. Since 1950, the annual number of record hot days has doubled (BoM 2014). Heatwaves have become more frequent, hotter, and occur earlier (Perkins and Alexander 2013). 2013 was Australia's hottest year on record, and during the summer of December 2012 through February 2013, the country experienced its hottest day, hottest week, and hottest month, as well as the longest and most far-reaching heatwave (BoM 2013).

Along with increasing hot weather, bushfire risk is also increasing. The McArthur Forest Fire Danger Index (FFDI), calculated from daily temperature, humidity and wind speed, has increased significantly at many sites in eastern Australia since the 1970s (Clarke et al. 2013).

There is no doubt that Australia will continue to warm substantially through the rest of this century. The annual average temperature by 2030 is projected to be 0.6-1.3°C above the 1986-2005 baseline, or about 1.2-1.9°C above the pre-industrial level, with little difference among the emission scenarios. By 2090, however, the success (or not) of reducing greenhouse gas emissions will play a large role in the level of temperature change we experience. Measured against the 1986-2005 baseline (henceforth, "the baseline"), the projected temperature rise ranges from 0.6-1.7°C for the low emissions scenario to 2.8-5.1°C for the high emissions scenario.

In general, warming will be greater across the inland regions than along the coast, especially in the southern coastal areas in winter. Figure 10 shows a comparison of the observed distribution of temperatures across the continent with the projected distribution at the end of the century under a high emissions scenario. There is a marked southward movement of hot/warm climates, corresponding to a shift of about 900 km in climate zones over this period.

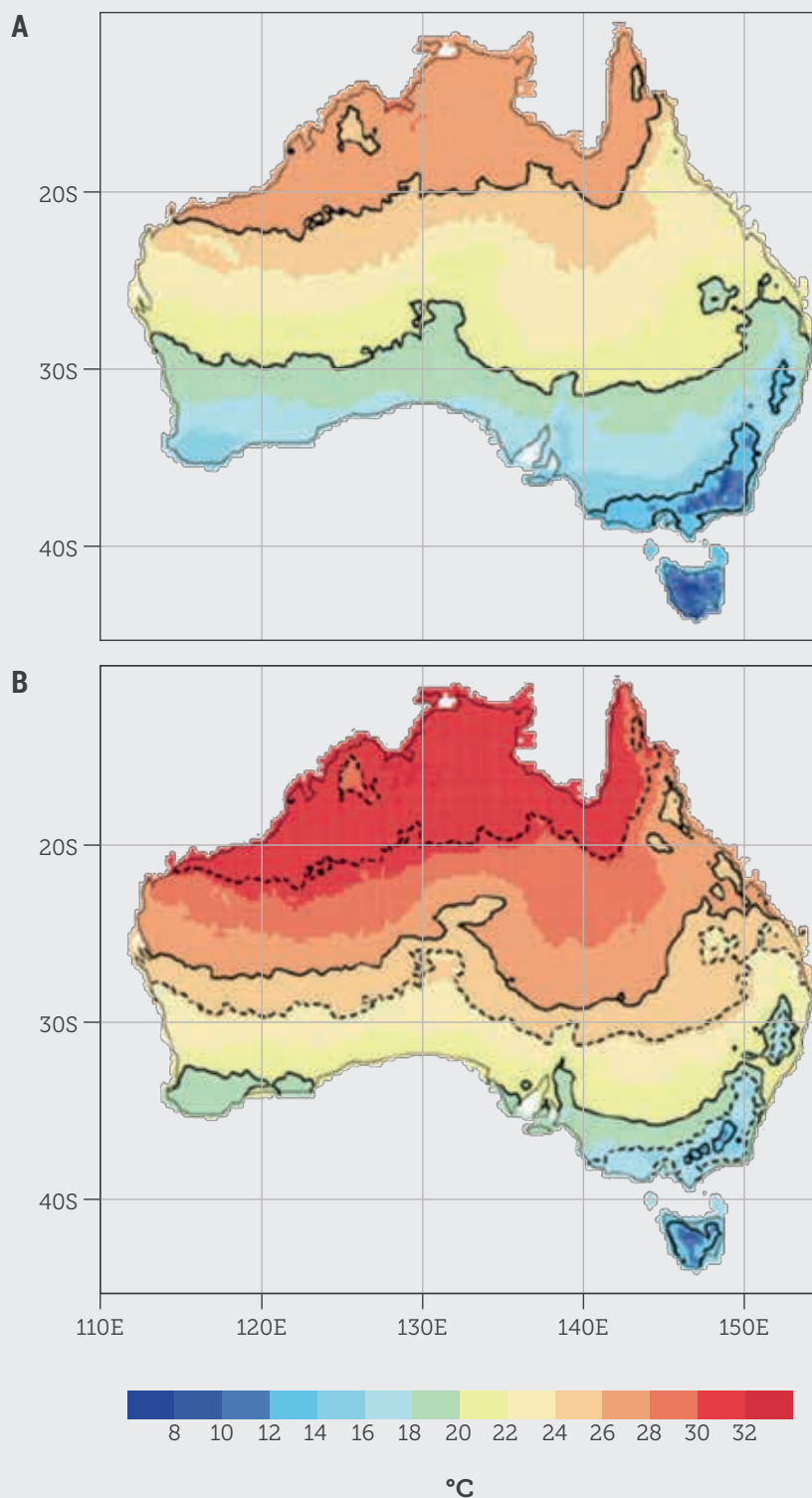


Figure 10: Annual mean temperature (in °C) for the present climate (a) and for the late 21st century (b). The future case is calculated by adding the median warming from 1986-2005 to 2080-2099 under a high emissions scenario to the mean temperature of the present climate. In each panel the 14, 20 and 26°C contours are shown with solid black lines. In (b) the same contours from the original climate are plotted as dotted lines. To provide the clearest depiction of the shifts in contours, the longer period 1950-2008 BoM dataset is used for the present climate, on a 25° grid (CSIRO and BoM 2015).

Of even more concern than projected increases in average temperatures are projections for increases in extreme heat (Figure 11). Dubbo, for example, which in today's climate experiences 22 days per year above 35°C, could see a trebling of hot days to 65 per year by 2090 under a high emissions scenario.

Consistent with the influence of a warmer climate on the projected increase in extreme heat, a warmer climate is also projected to reduce the incidence of frost across inland Australia, and virtually eliminate it

from coastal regions by 2090 under a high emissions scenario. However, over the next decade or two, frost may actually increase in the southern states due to an increase in clear, dry nights in winter. Increased frost occurs, for example, during strong El Niño events, which lead to drier conditions and a greater frequency of clear, dry nights.

More severe bushfire weather is expected in eastern and southern Australia, consistent with the rising temperatures and, in the south, the decrease in rainfall.

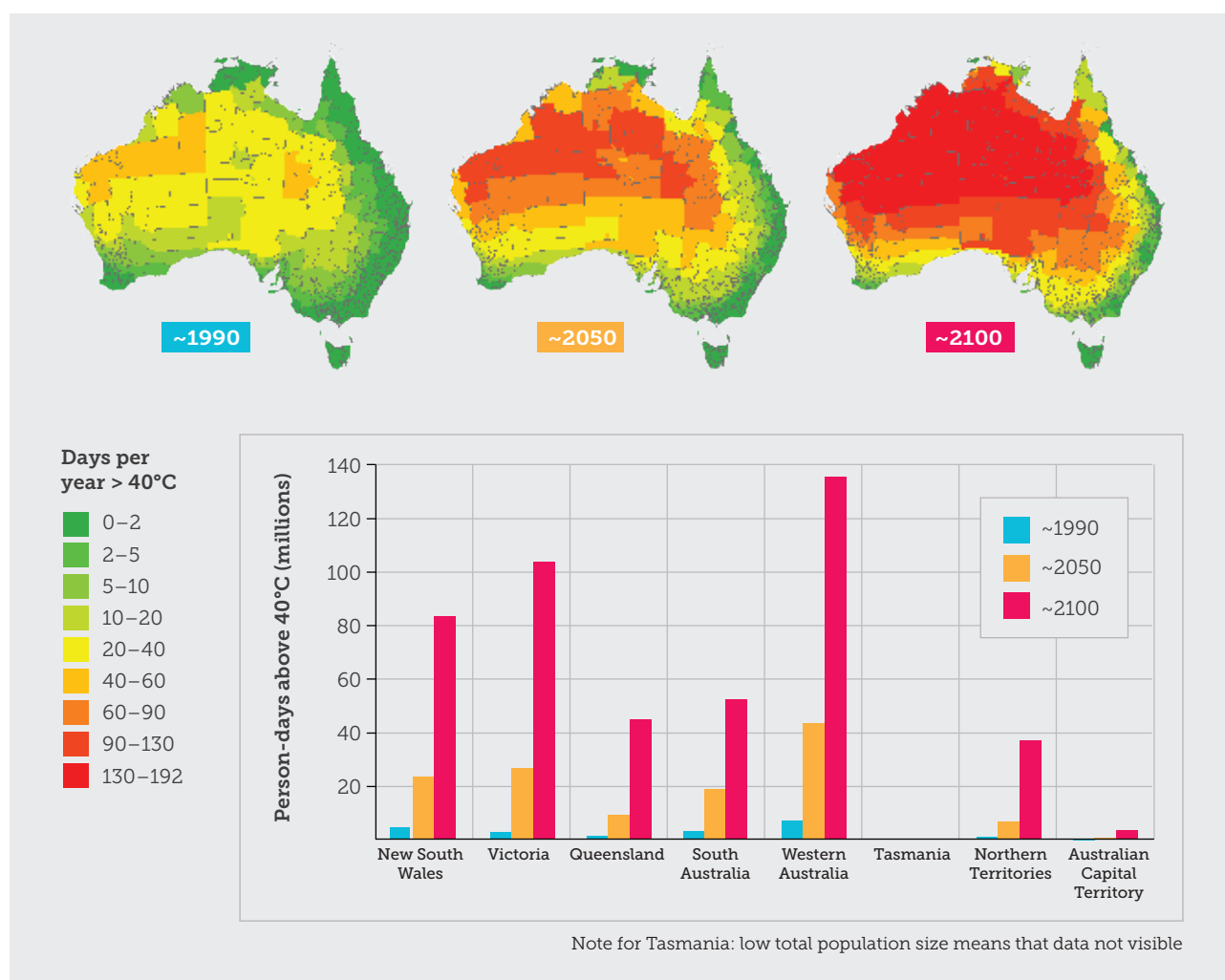


Figure 11: Projected changes in exposure to heat under a high emissions scenario. Maps show the average number of days with peak temperatures >40°C, for approximately 1990 (based on available meteorological station data for the period 1975–2004), approximately 2050, and approximately 2100. Bar charts 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. Note that figures for Tasmania are not apparent due to low population size relative to the other states. Source: Reisinger et al. (2014).

4.2.2 Rainfall

Changes in rainfall patterns are expected to be the major factor affecting future agricultural productivity and profitability (Crimp et al. 2014).

Total averaged rainfall across Australia increased slightly between the 1970-2013 period and the 1900-1960 period. However, over the past several decades there have been significant changes in regional and seasonal distribution of rainfall across the continent. Warm season (October to April) rainfall has increased across northern and central Australia since the 1970s, with rainfall very much above average over the 1997-2013 period (Figure 12a). In fact, in part due to two strong La Niña events, the period 2010-2012 recorded the highest 24-month rainfall totals for Australia as a whole (CSIRO and BoM 2015).

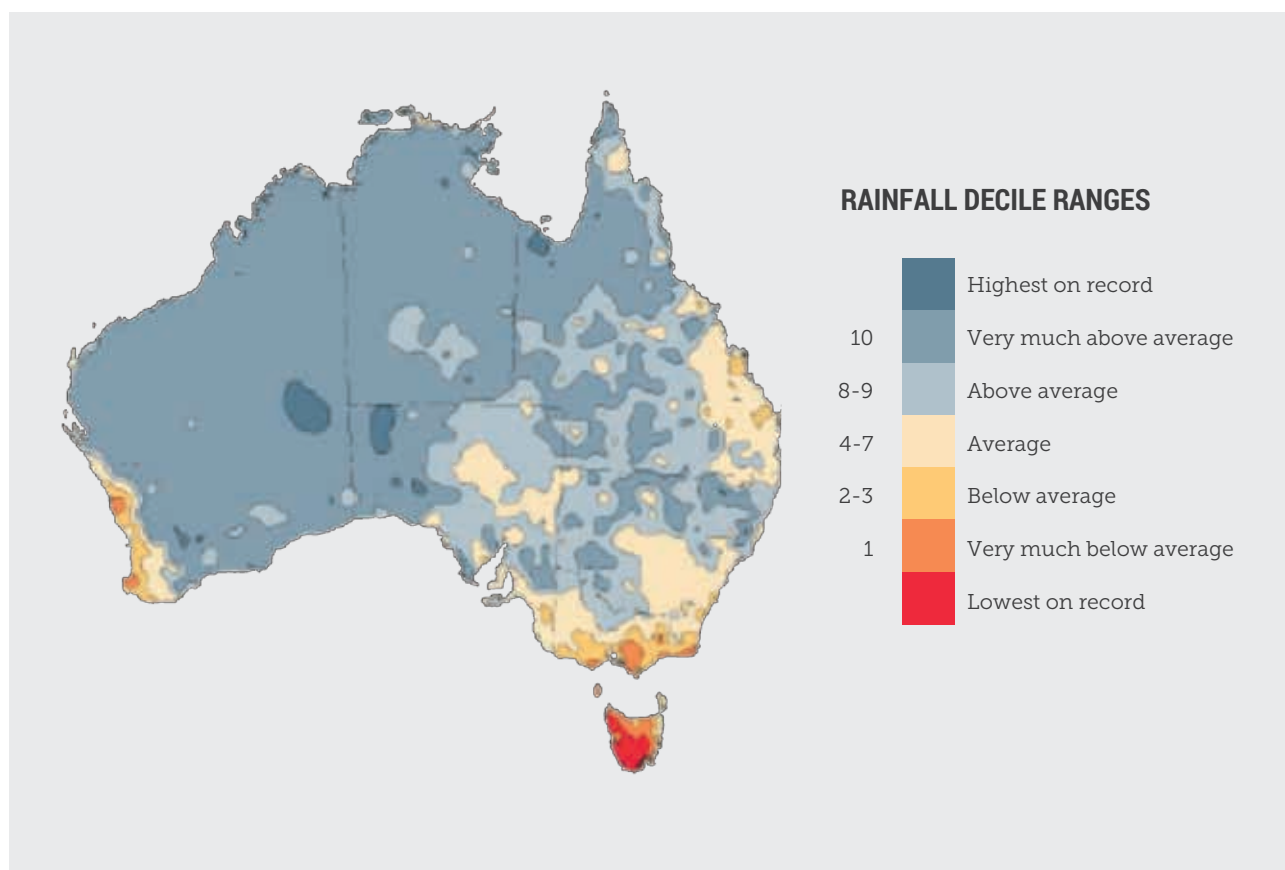


Figure 12a: Rainfall deciles for October to April (the northern wet season) from 1997 to 2013, relative to the reference period 1900-2013, based on AWAP data. **Source:** BoM (2014).

Cool season (May-September) rainfall trends showed marked decreases in rainfall in the southwest and the southeast of the continent (Figure 12b), the season in which these regions normally receive most of their rainfall. The more significant of these is in southwest Western Australia, where most of the reduction in rainfall has occurred in a series of step changes since the mid-1970s (CSIRO and BoM 2015). The decline has been as much as 40% in some regions of the southwest over the past 50 years (Cai and Cowan 2008), leading to even larger decreases in runoff (CSIRO 2012b). The

decline in the southeast has been most pronounced since the mid-1990s, and has persisted since then (Braganza et al. 2011).

Cool season (winter and spring) rainfall is projected to continue to decrease across southern Australia, a region that includes key agricultural production areas such as the southwest Western Australia wheat belt and the Murray Basin in the southeast. The decrease in rainfall in the southwest could be as much as 50% in winter under the highest emissions scenario.

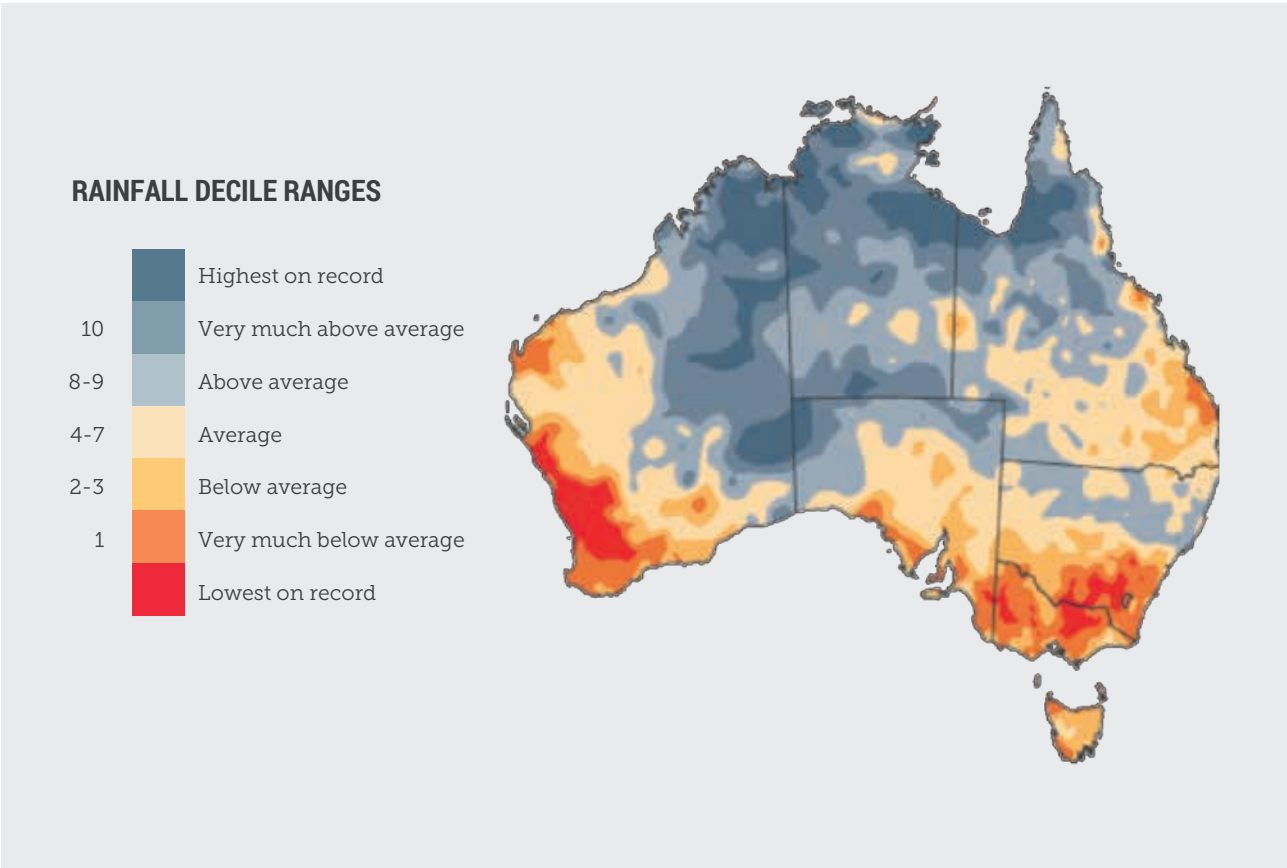


Figure 12b: Rainfall deciles for April to September 1997-2013, relative to the reference period 1900-2013, based on AWAP data. Source: BoM (2014).

Cool season (winter and spring) rainfall is projected to continue to decrease across southern Australia, a region that includes the southwest Western Australia wheat belt and the Murray Basin in the southeast.

The projected expansion of the tropics southwards and the contraction of the mid-latitude storm tracks towards the pole are expected to intensify through the century, especially under a high emissions scenario. This implies a shift of the summer-dominated rainfall zone to the south, as well as a southward expansion of the boundary between the summer and winter rainfall zones. This pattern of change in atmospheric circulation likely plays a strong role in the projected decrease in rainfall across southern Australia, especially in the cool months.

It is likely that evapotranspiration rates will rise through this century, consistent with the increasing atmospheric moisture capacity as the earth continues to warm. The combination of decreasing rainfall in southern Australia, especially in winter and spring, coupled with the higher evaporative demand will likely lead to decreasing soil moisture in the region. Soil moisture may also decrease elsewhere across the continent as evaporative demand is projected to increase but the changes in rainfall, even in direction, are uncertain. It is very likely that southwestern Western Australia and southern South Australia will experience decreases in runoff through the century, and decreases are also projected for the far southeast, with somewhat less confidence (Figure 13).

It is very likely that southwestern Western Australia and southern South Australia will experience decreases in runoff through the century.

Snowfall in the Australian Alps is projected to decrease, especially at low elevations, with an increase in snowmelt and reduced snow cover. Declines in snowfall have serious implications for streamflows in the Murray, Murrumbidgee and Goulburn River catchments (CSIRO 2006).

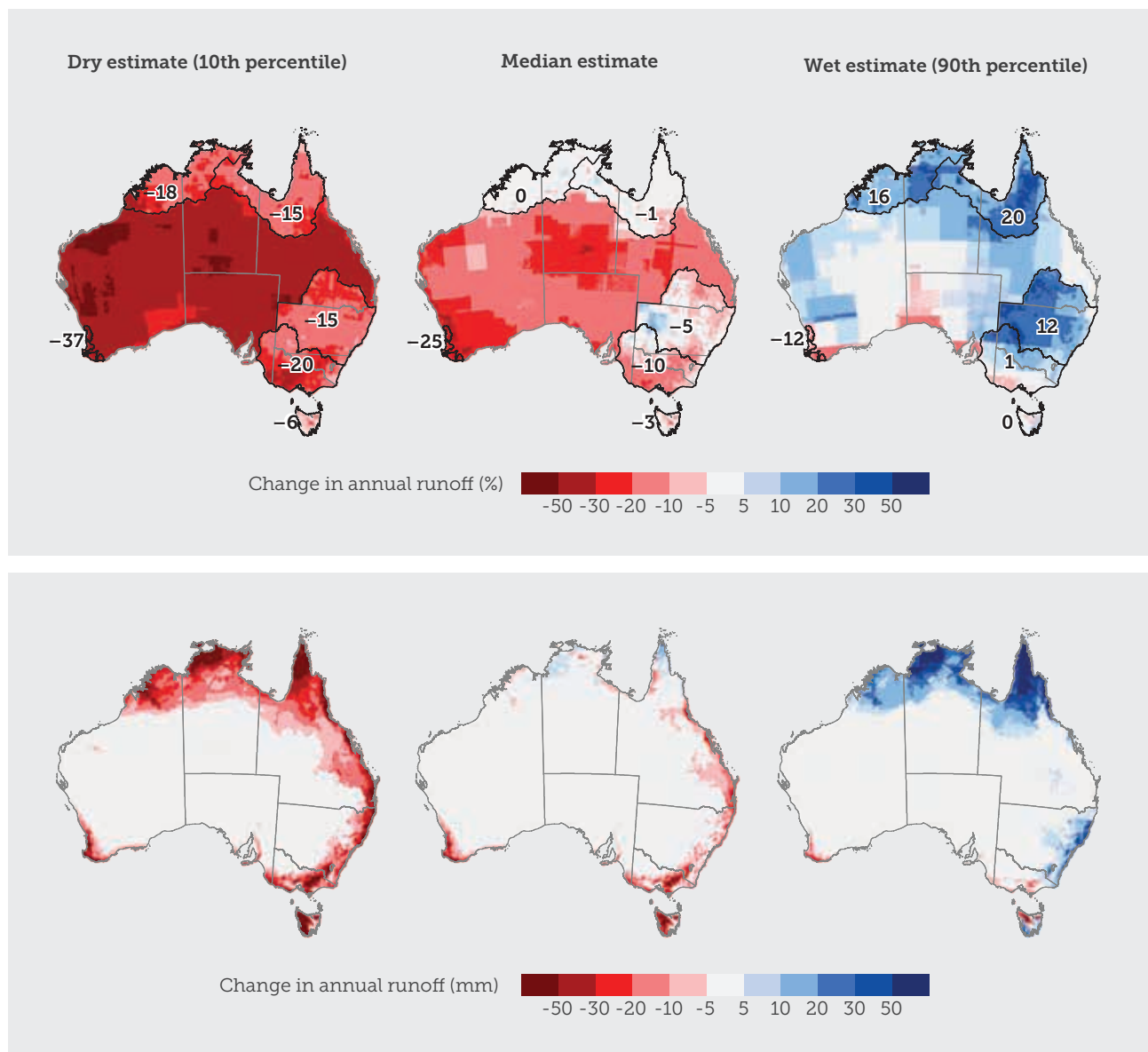


Figure 13: Estimated changes in mean annual runoff for 1°C global average warming above current levels. Maps show changes in annual runoff (percentage change; top row) and runoff depth (mm; bottom row), for dry, median, and wet (10th to 90th percentile) range of estimates, based on hydrological modelling using 15 CMIP3 climate projections. **Source:** Reisinger et al. (2014) and references therein.

4.2.3 Drought

Australia has experienced three major droughts over the past century or so – the “Federation Drought” (1895-1903), the “World War II Drought” (1939-1945) and the “Millennium Drought” (1996-2010) (see also the Climate Council (2015) report *Thirsty Country: Climate Change and Drought in Australia*). Comparison of studies of Australian droughts shows little evidence for trends in episodic drought (Hennessy et al. 2008). Where robust trends in drought have been found, such as in southwest Western Australia, these trends are related to the long-term declines in cool-season rainfall discussed above (Hennessy et al. 2008; Gallant and Karoly 2010).

Drought is projected to worsen in southern Australia through this century, consistent with the expected decline in winter and spring rainfall, normally the wettest time of year in this region. Figure 14 shows the projected change in proportion of time spent in drought for the four major regions of Australia. For all emissions scenarios and for all regions, time in drought is expected to increase, with the projections showing more certainty for southern Australia.

In addition to an increase in time spent in drought, the frequency of extreme droughts is projected to increase in all regions. Moreover, as temperature increases, so too will evapotranspiration, which in turn will further decrease water availability (Nicholls 2004). In summary, in southern Australia, droughts are projected to be more frequent and a higher proportion of them will be extreme, with serious consequences for water availability.

In southern Australia, droughts are projected to be more frequent, and a higher proportion of them will be extreme.

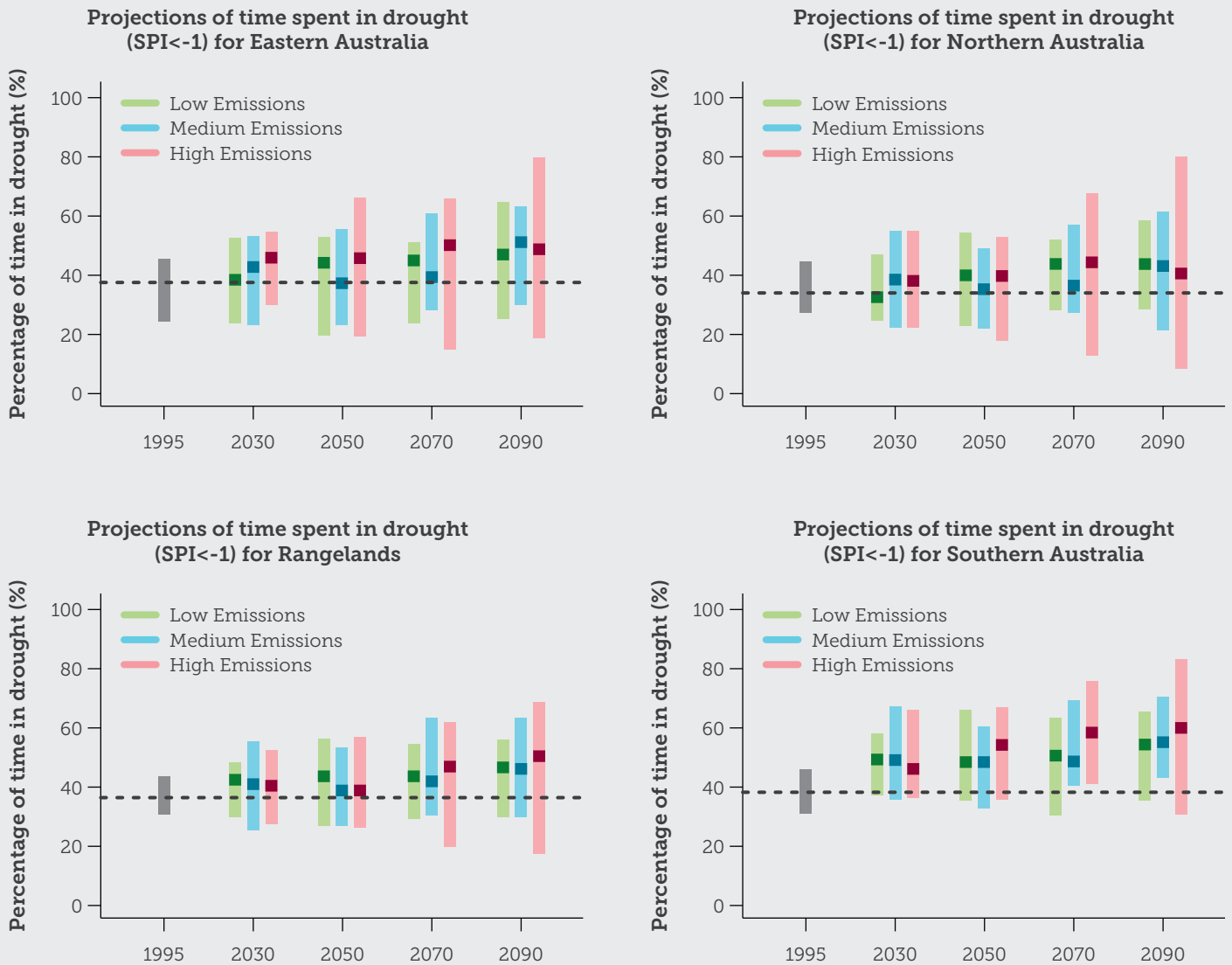


Figure 14: Median and 10th to 90th percentile range in projected change in proportion of time spent in drought for five 20-year periods. Results are shown for natural variability (grey), low emissions scenario (green), medium emissions scenario (blue) and high emissions scenario (magenta) for the four super-clusters (major regions). Proportion of the time in drought is defined as any time the SPI (Standardized Precipitation Index) is continuously (greater than or equal to three months) negative and reaches and intensity of -1.0 or less at some time during each event. **Source:** CSIRO and BoM (2015).

BOX 2: DROUGHT AND THE AUSTRALIAN ECONOMY

Drought has direct, substantial impacts on the Australian economy. Drought reduces the number of livestock, destroys crops, and results in soil erosion and loss. Local loss of production has flow-on effects to regional employment, local processing and other dependent industries, and to both domestic food prices and export earnings (ABS 2004; Quiggan 2007).

Particularly noteworthy droughts in recent history include the period from 1982–83 when Australia experienced one of the most intense droughts on record, with a loss of \$3 billion in agricultural production alone (ABARES 2012b). During this period, the Wimmera Southern Mallee region of Victoria experienced an 80% reduction in grain production and a 40% reduction in livestock production (BCG 2008).

Between 2002 and 2003, which was part of the Millennium Drought from 1996 to 2010, decreases in agricultural production due to drought resulted in a 1% fall in GDP and a 28.5% fall in the gross value added for the agricultural industry compared to the preceding year (ABS 2004). The Productivity Commission reported that government provided over \$1 billion in drought assistance to farmers in 2007–2008, with some farmers on continuous support since 2002 (Productivity Commission 2009).

Food prices during the 2005–2007 period increased at twice the rate of the Consumer Price Index (CPI) with fresh fruit and vegetables the worst hit, increasing 43% and 33% respectively (Quiggan 2007). Reducing the amount of livestock held during droughts means that meat production can be directly affected for many years. As producers destock there can be a short-term increase in meat supply, leading to reduction in meat prices. Prices then increase later as herds are slowly rebuilt (Quiggan 2007). The impact of drought on food affordability has been shown to affect mental stress and suicide rates for some members of the community, a combined impact of reduced food affordability and reduced incomes (Friel et al. 2014).

The Millennium Drought in southeast Australia, which lasted from 1996 to 2010, was one of the worst on record for the region (van Dijk et al. 2013) with the lowest 13-year rainfall total since 1865 (CSIRO 2012b). This drought contributed to falls in agricultural production from 2.9 to 2.4% of GDP between 2002 and 2009 (van Dijk et al. 2013). In 2008, wheat exports dropped to nearly match domestic consumption (PMSEIC 2010). During this period both the number of dairy farms and milk production declined, and numbers have still not recovered to pre-drought levels (Dairy Australia 2015).

Food prices during the 2005–2007 drought increased at twice the rate of the Consumer Price Index (CPI).

More recently, rainfall deficiencies in parts of Western Australia and central Queensland are projected to reduce total national crop production by 12% in 2014–15, and the value of beef and veal exports by 4% (ABARES 2014d).

Drought also has significant indirect impacts on farm management. Financial uncertainty during droughts has been found to stall investment planning, encouraging individual landholders to postpone decisions and reducing innovation and technology uptake (Marangos and Williams 2005).

Drought is also a considerable drain on the public purse. Successive governments have grappled with this area of costly, contentious and emotional policy debate. Prior to 1989, drought was treated as a natural disaster, attracting emergency relief as a crisis management measure (Kiem and Austin 2012; Sherval and Askew 2012). This approach was widely criticized for being reactive, relatively *ad hoc* and ineffective, reducing incentives for farmers to be self-reliant in a highly variable climate (Drought Policy Review Expert Social Panel 2008; Nelson et al. 2010a; Askew and Sherval 2012; Kiem and Austin 2013a). A major policy shift occurred in 1992, with the formulation of the National Drought Policy, in which drought was instead viewed as the natural manifestation of a highly variable climate.

BOX 2: CONTINUED

The primary rationale for providing government assistance was to ensure that long-term viability of production was not threatened by short-term circumstances; essentially, the policy shifted from one of crisis response to risk management (Botterill 2013). This policy provided eligible farmers in financial difficulty with family support payments and interest rate subsidies, with additional relief "in exceptional circumstances" during particularly severe periods. Such a policy did not come cheap – by mid-2010 the Australian government had paid \$4.4 billion in direct drought assistance to farmers (ABARES 2012b).

The National Drought Policy has undergone successive reviews and amendments but has now been effectively suspended (Botterill 2014). Several commentators have criticized the apparent return to "the language of natural disaster" and have noted the risk of *ad hoc* policymaking, especially at a time when large parts of the country remain drought-stricken (Botterill 2014).

In the most recent federal budget (May 2015), \$333 million in drought-relief measures were announced, including funds for extension of concessional loans to drought-stricken farmers and regional councils (Australian Government 2015).

As noted above, in southern Australia droughts are likely to become more frequent, and a higher proportion of them will be extreme. Climate change is projected to make drought "not so exceptional".

Climate change is projected to make drought "not so exceptional".

A projected doubling in the frequency of spring drought in the future has been estimated to potentially reduce national income \$7.4 billion annually, equivalent to lowering GDP by 1% p.a. (Carroll et al. 2007).



Figure 15: Lake Eppalock, a reservoir in North Central Victoria, at 7% capacity during drought in 2007.

4.2.4 El Niño

The El Niño Southern Oscillation (ENSO) phenomenon is the large-scale cycle of warm and cold surface water temperatures in the tropical central and eastern Pacific Ocean, and the associated changes in wind and precipitation patterns.

The El Niño and La Niña phases of this cycle each have a very strong influence on climate variability in Australia. The El Niño phase of the cycle, in which sea surface temperatures in the central and eastern tropical Pacific undergo prolonged warming, occurs approximately every 2 to 7 years, and may last from months to several years. In Australia, El Niño events are often associated with higher than normal temperatures, lower than normal rainfall, increased temperature extremes, increased frost risk, reduced tropical cyclone frequency, later onset of the northern monsoon, reduced snow cover and increased bushfire and drought risk (BoM 2015). Many of these ENSO-related changes – especially temperature extremes, increased frost risk, and increased drought risk – have serious consequences for food production.

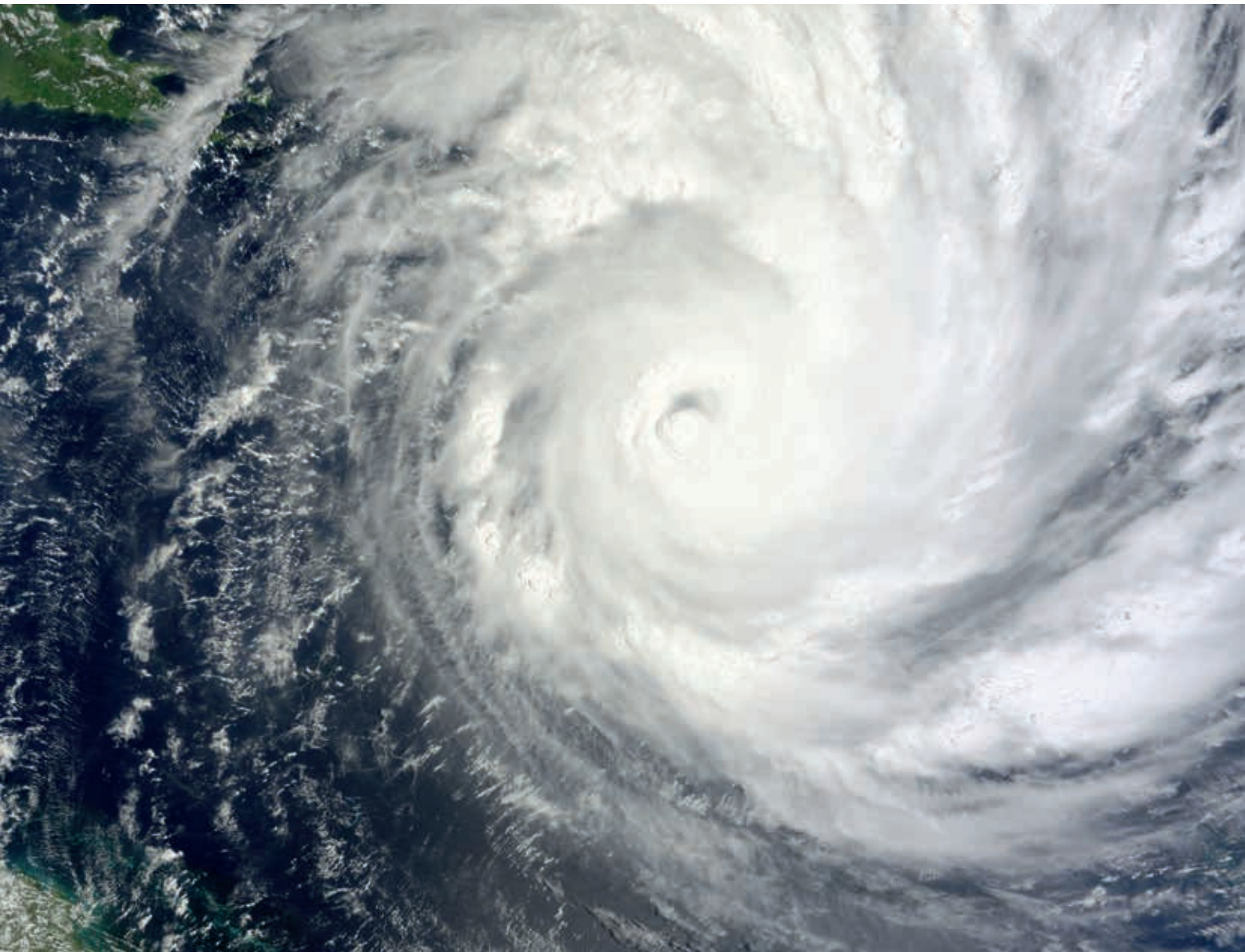
Temperatures during recent El Niño events have been exacerbated by overall warming trends, resulting in El Niño years tending to become progressively warmer since the 1950s (BoM 2015). While there is no consensus yet on how the ENSO phenomenon will change as the climate continues to warm (IPCC 2013), some possible changes carry large risks for Australian agriculture. For example, a recently published study suggests that the warming climate may enhance the probability of more extreme El Niño and La Niña events (Cai et al. 2015). The study found that climate change could approximately double the number of extreme El Niño events, with severe implications for drought risk and food production in Australia.

4.2.5 Tropical Cyclones

Tropical cyclones in Australia (see, for example, Figure 16) are characterised by very high wind speeds, storm surges, extreme heavy rainfall and flooding.

Clear trends in the frequency or intensity of cyclones are difficult to discern due to the short time period for which data are available, and the high year-to-year variability. However, there is some evidence for a decline in the occurrence of tropical cyclones over the period 1981–82 to 2012–13. In the future, tropical cyclones may occur less often, but become more intense (with stronger winds and greater rainfall) and extend further south.

Figure 16: Cyclone Yasi struck Queensland in February 2011 causing widespread destruction.





5. RISKS FROM CLIMATE CHANGE FOR AGRICULTURAL PRODUCTION AND FOOD SECURITY

Climate not only affects virtually every aspect of food production and farm profitability, it also has significant impacts on food affordability, accessibility, quality and safety, the other aspects that affect overall food security (Figure 17). The risks posed by climate change for Australia’s food production systems and our food security are complex and inter-connected. The chances of a food crisis directly affecting the Australian population may seem remote. However, as our population grows to 35-40 million and climate change affects food production, we may at times import more food than we export (PMSEIC 2010).

In this section we consider these risks under five broad categories:

1. Risks posed by ongoing degradation of Australia’s natural resource base.
2. Direct risks of changes in temperature, rainfall and other climatic impacts on agricultural production.
3. Direct impacts of extreme events on food supply, safety and distribution.
4. Economic risks posed by energy costs and policies, including those designed to reduce greenhouse gas emissions.
5. Changes to Australia’s competitiveness due to climatic changes in other countries.



Figure 17: Impacts of climate change on the main components of food security.

5.1. Climate Change and Our Natural Resource Base

A strong agricultural sector relies on a healthy and sustainable natural resource base. Every four to five years, the state of Australia's environment is assessed at both national and state/territory level. Successive State of the Environment (SoE) reports have charted the fact that Australia's economic success, particularly from food production, has come at a considerable cost to our natural resource base.

The most recent national level report (SoE 2011) notes that while some aspects of our environment are in good condition and improving, other sectors continue to deteriorate. Some of this decline arises as a legacy of past decisions and practices but ongoing challenges such as climate change and population increases are acknowledged as potential accelerators of existing declines (SoE 2011). Some of the most serious issues include ongoing land clearing, which over the decade to 2010 averaged around one million ha per year; soil degradation, from acidity, salinization, erosion and loss of carbon and nutrients; over-allocation of water and declining water quality; loss of biodiversity; invasive species; and over-fishing.

The area of land used for crops and sown pasture in Australia has approximately doubled over the last 150 years (Dunlop et al. 2002). The increased use of water for irrigation and livestock has increased at a similar rate. Given the fact that the supply of arable land is finite, and the likelihood that development to date has prioritised better soils, the rate of exploitation of our natural resources must inevitably level off. As a consequence, the proportion of agricultural land that is older, more degraded or inherently less productive will therefore increase over time (Harle et al. 2007). Climate change will exacerbate this existing resource constraint.

But even more important than the limitations of available land, the impact of climate change on water availability will be the most serious challenge. Agriculture already accounts for the extraction of about 70% of Australia's freshwater resource (World Bank 2015). Water has become a highly contested resource, subject to multiple competing demands (see Box 3 on Climate Change and Australia's Food Bowl). Future declines in freshwater resources (see section 4.2.2 above) have been identified as a key risk for Australian food production in the Fifth Assessment Report of the IPCC, should the projections of ongoing drying in southern Australia, and especially the Murray Darling Basin, be realised (Reisinger et al. 2014).

The projected increases in the frequency and/or intensity of extreme weather events may also directly exacerbate existing environmental degradation. The severe phase of the Millennium Drought in 2007-2010 resulted in the lowest water levels in the Murray Darling Basin ever recorded in South Australia. The drying led to increased soil acidification that persisted in floodplain sediments and water for two years following the drought (Mosley et al. 2014).

It is generally assumed that projected reductions in rainfall will reduce the incidence of dryland salinity by lowering the water table. However, as pressure on water resources becomes more intense, it is also likely that a greater proportion of water resources will be diverted for human use, reducing water supply in wetlands and increasing salt levels, with negative impacts on the quality of the water resource (Nielson and Brock 2009).

Increased temperatures, elevated levels of CO₂ and changing hydrological regimes will also affect soil carbon. Increasing temperatures will accelerate soil decomposition, in turn accelerating the rate of CO₂ released from soils –an example of a positive feedback to climate change (when climate change impacts bring about even more climate change) (Heimann and Reichstein 2008). Declining soil carbon stocks have a range of negative impacts on productivity, including hindering plant growth and increasing erosion (Lal 2004).

The impact of climate change on water availability will be the most serious challenge for agriculture.

5.2. Direct Climate Impacts on Food Production

Climate is the most fundamental determinant of where different types of agricultural production occur, as well as a critical influence on its profitability. The economic viability of agricultural production is not only influenced by the average climate at a particular location, but also by the magnitude of climate variability – the higher the variability from one year to the next, the greater the risks (Crimp et al. 2014).

The latest IPCC report concludes that impacts of climate change on food production are already evident in some parts of the world, with negative impacts outweighing positive impacts (Porter et al. 2014). Several periods of rapid food price rises in the last decade following climatic extremes provide evidence of the climate sensitivity of current food markets (Porter et al. 2014). Climate change has also affected harvests of aquatic species, both marine and freshwater, and aquaculture, especially in tropical areas, with impacts being felt by some of the most vulnerable communities (Porter et al. 2014).

Australia is projected to be one of the most adversely affected regions from future changes in climate in terms of reductions in agricultural production and exports (Gunasekera et al. 2007). Climate change will continue to affect Australia's primary industries sector in highly variable ways depending on the type and location of climate impacts and primary production activities (Table 1). Overall, declines in Australian agricultural production are expected in coming decades, but estimates vary considerably due to different assumptions, especially about the role of adaptation. An overall 17% decline in production was estimated by Cline (2007). Another study by Gunasekera et al. (2007), assuming no planned adaptation and a relatively high emissions scenario, estimated potential declines of Australia's major export commodities (wheat, beef, dairy and sugar) of 9-10% by 2030 and 13-19% by 2050, and overall declines of agricultural exports by 11-63% by 2030 and 15-79% by 2050. Analysis for the Garnaut review projected that by 2100, assuming no global mitigation, a 92% drop in irrigated agricultural production in the Murray Darling Basin could occur as a result of reduced runoff. With mitigation measures that keep atmospheric CO₂ to 550 ppm (compared to the current concentration of

Australia is projected to be one of the most adversely affected regions from future changes in climate in terms of reductions in agricultural production and exports.

about 400 ppm), a 20% decline in production is predicted; with atmospheric CO₂ limited to 450 ppm, the decline is projected to be only 6% (Garnaut 2008). A more recent study by Moore and Ghahramani (2015) estimated that the net primary production of grasslands in southern Australia could decline by 7% and 14% by 2050 and 2070 respectively. In the absence of adaptation, meat production at 25 locations was predicted to change between -92% and +10% (2050) and -95% to +2% by 2070. The predicted declines were largely driven by declines in sustainable stocking rates.

Experimental and observational evidence indicates that the yields of many important crop species such as wheat (see Figure 18), rice and maize are reduced at temperatures more than 30°C, especially if soil moisture is limiting (Porter et al. 2014). The sugar content and flavour of horticulture crops, including wine grapes, may also be negatively affected by high temperatures (Howden et al. 2014).

Figure 18: Wheat is Australia's most important agricultural export but yields can be substantially reduced by heat stress and drought.



Reduced rainfall and increased rainfall variability already limit irrigation water availability and allocations for key intensive irrigated enterprises such as horticulture, cotton, sugar, dairy, livestock and viticulture. This has extremely important economic impacts because approximately 50% of all profits from Australian agriculture derive from irrigated production (National Irrigators Council 2009). Runoff declines will continue to be exacerbated by rising temperatures with associated evaporation, reduced connection between surface and groundwater, interceptions by farm dams and water impoundments, and tree regrowth after more frequent fires. Drying will also continue to reduce vegetation cover, increasing the risk of soil erosion and loss of topsoil (Harle et al. 2007).

Increased average and extreme temperatures exacerbate heat stress for intensive livestock industries, especially dairy. Other detrimental impacts include more severe tropical cyclones (wind impacts, storm surges and flooding), increased waterlogging during the summer growing season in northern Australia, rising water tables, and reduced water quality including increased salinity (see Table 1). Increasing risks from bushfires also have implications for the profitability of farming enterprises; bushfires in 1983, 2003, 2006 and 2009 burnt significant areas of farmland in southern Australia causing loss of life, farm infrastructure, crops, livestock and public infrastructure, and bushfire smoke increased respiratory health problems and adversely affected wine grape quality (Millar and Roots 2012; Whittaker et al. 2012).

An analysis of climate change impacts on 10 agroclimatic zones by the Australian Agribusiness Group (2011) indicated that cropping, horticulture and viticultural enterprises are the most at risk but may also have the greatest adaptive capacity due to generally shorter life cycles. This analysis also identified the dry region of Australia (the vast area across the arid and semi-arid zone) as having the highest vulnerability due to reduced carrying capacity of pasture, increasing heat stress and drying, plus effects of ticks on cattle, a conclusion supported by Crimp et al. (2014).

The impacts of climate change on production via its impact on pests and diseases are difficult to predict. Interactions between climate change and pests are complex, and idiosyncratic. In some regions, pests and diseases already present may increase in population size and range, and/or become more virulent (Barlow et al. 2011). New pests and diseases are also likely to arise. Some key risks that have been identified include the southerly spread of the Queensland fruit fly (Sutherst et al. 2000; Figure 19) and the insect vector of blue-tongue disease (Sutherst 1990); increased blowfly strike (Sutherst 1990); and the increased risk of introduction of the Asiatic citrus psyllid, the vector of citrus greening (Finlay et al. 2009). If the pests and diseases are themselves negatively affected by changes in climate, for example, if higher temperatures reduce populations, or reduced rainfall reduces fungal infections, productivity could improve (Reisinger et al. 2014). It is generally expected, however, that climate change will enhance the distribution and competitiveness of crop weeds (Porter et al. 2014).



Figure 19: The Queensland fruit fly is a major pest of agriculture in Australia and climate change is likely to affect its distribution.

Increased atmospheric CO₂ concentrations also affect the productivity of primary industries both directly, and indirectly via interactions with changed temperature, frost, and water availability. Atmospheric CO₂ acts as a fertilizer for plant growth in some species, increasing rates of photosynthesis. From a theoretical perspective, increased yields are expected to be greater in C3 crop species (such as wheat, barley and canola) than in C4 species (such as maize). Some plant species grown under elevated CO₂ also show increased efficiency of water use. This means that under conditions of water shortage, elevated CO₂ can alleviate water stress. But positive impacts on plant growth are only realised if other factors, such as light or nutrients, are not limiting. Where plant growth is not water-limited, warming may continue to expand the length of the growing season of crops, especially in southern Australia (Reisinger et al. 2014). CO₂ fertilisation will also continue to favour the expansion of “woody weeds” at the expense of pasture (e.g. Harle et al. 2007) and reduce the nutritional value of many crop and pasture species (Myers et al. 2014; Porter et al. 2014). In particular, the protein content, and in some cases, the concentrations of important minerals of plants, generally decline under elevated CO₂ (Taub et al.

2008; Porter et al. 2014). Reduced protein content in wheat, in particular, has important implications for flour and bread quality (Fernando et al. 2015). Elevated CO₂ may also reduce the efficacy of chemical weed control agents (Porter et al. 2014).

Any positive impacts of elevated CO₂ on production are likely to be restricted by higher temperatures and reduced rainfall in some regions. The general rule of thumb is that a 10% reduction in rainfall counteracts any CO₂ fertilisation benefit (Howden et al. 1999; Crimp et al. 2002). Further, in the absence of adaptation measures, a 1.5-2°C increase in average temperature could cancel out any increased grain yield that resulted from a doubling of atmospheric CO₂ (Howden 2002).

Climate change is likely to improve profitability of some industries in cases where increasing temperatures or changes to water availability enable higher productivity or allow a primary industry to expand. These advantages are likely to peak by the middle of the century, with progressively more negative impacts evident in the later decades if strong mitigation efforts do not take place (Stokes and Howden 2008).

5.2.1 Core Cropping Regions

Reduced rainfall, increasing rainfall variability, and increased evaporation will continue to reduce the overall area suitable for cropping in Australia, with the margins of the cropping belt inland moving towards the coast (Howden et al. 2014). Other land use pressures will limit compensatory expansion at coastal margins (Nidumolu et al. 2012).

Changes in the seasonality of rainfall could be as, or more important, than changes in the absolute amount, especially in southern Australia. Observed declines in cool season rainfall, of critical importance for crops and pasture, have been observed over the past few decades and continuation of this trend has significant implications for profitability. Crop yields in regions such as southwest Western Australia, southern South Australia, and Victoria and southern New South Wales are negatively affected by reduced water availability, increased summer temperatures and increased evaporation (Turner et al. 2011; Reisinger et al. 2014). Selection of appropriate wheat cultivars and changes in sowing times may increase yields in wetter areas such as southern Victoria, or maintain

Increasing variability of rainfall, and especially reduction in cool season rain, may have more impact on production than changes in total rainfall.

current production in some drier areas, such as northwest Victoria (Turner et al. 2011; Reisinger et al. 2014). If the extreme dry end of future rainfall scenarios is realised, however, such adaptation measures are not expected to maintain current yields by later this century (Luo et al. 2009). Indeed, under the more extreme climate scenarios, Australia could become a net importer of wheat (Howden et al. 2010), as occurred in 2001-2 and 2007-8 during severe drought (Butler 2009).

Under the more extreme climate scenarios, Australia could become a net importer of wheat.

5.2.2 Livestock

Climate change presents major challenges for grazing in Australian rangelands because it is resulting in lower and more variable pasture productivity, reduced forage quality, and increased heat stress for livestock (Harle et al. 2007; Stokes and Howden 2010; Crimp et al. 2014; Moore and Ghahramani 2014). Heat stress reduces animal growth, feeding rates, reproduction, and milk quality and raises issues of animal welfare, especially during transport and in saleyards and feedlots.

As climatic conditions become harsher, there will be increased use of more heat-tolerant breeds such as zebu cattle (*Bos indicus*) and their crosses, or sheep such as the Dorper breed, some of which have lower meat quality and lower reproductive rates (Stokes and Howden 2008).

The most arid and least productive rangelands are already economically marginal and will be the most negatively affected by further reductions in rainfall, as well as increased temperature. Some of the more productive eastern and northern rangelands may become more productive, at least in the short term, provided rainfall does not decrease (McKeon et al. 2009). Rainfall changes will alter the relative competitiveness of grazing vs cropping. These changes are already evident in the

Wimmera region of western Victoria – as the climate has become drier, cropping has shifted southwards into former grazing areas which had previously been too water-logged to be suitable (Cocklin and Dibden 2009). However, a more common future scenario expected is for cropping to increase at the expense of grazing in regions that become wetter, and vice versa in drier areas (Harle et al. 2007; Carberry et al. 2011).

In the longer term, a 3°C increase in average temperature is projected to result in a 4% reduction in gross value of the beef, sheep and wool sector (McKeon et al. 2009). A decline of dairy production in all regions except Tasmania is also projected under mid-range climate scenarios by the middle of the century (Hanslow et al. 2013).

Increased atmospheric CO₂ may partially offset the negative impacts of reduced rainfall in some regions (Stokes et al. 2010) and in southern regions there may be reduced winter mortality of lambs and other stock (Harle et al. 2007).

Increased risks from pests such as cattle ticks are likely in areas of southern Queensland and northern New South Wales unless more resistant breeds are introduced (White et al. 2003). Higher temperatures, especially during winter, will enable some pests to increase in population and impact, requiring increased pesticide use.

5.2.3 Intensive Plant Crops and Horticulture

Many intensive plant industries such as fruit crops, vegetables, cotton and sugar are highly vulnerable to climate change impacts, especially those based on plants that are sensitive to heat stress, loss of winter chilling requirements, or extreme events such as heatwaves, frost, drought, high winds and hail (see Table 1). Tropical fruit crops in Northern Australia are vulnerable to increased intensity of tropical cyclones. Cyclone Larry in 2006, for example, destroyed 90% of the North Queensland banana crop, affecting supply for nine months; Cyclone Yasi in 2011 had similar impacts.

For viticulture and horticulture, higher rates of evaporation and reduced runoff to dams and rivers will likely have a greater impact than rainfall reduction itself, because these industries are highly reliant on irrigation (Potter et al. 2010). Even where rainfall is sufficient, higher evapotranspiration will increase salinity on productive land (Stokes and Howden 2010).

Figure 20: The 2009 heatwave in Victoria caused significant production losses in raspberry, blackberry and blueberry crops, as well as 20-25% loss of apples and late season apricots, and 60-80% loss of strawberries in the Port Phillip region (DPI 2009 cited in Edwards et al. 2011).



5.2.4 Intensive Animal Industries

Intensive animal industries include dairy, beef and sheep feedlots, poultry production, and piggeries. Direct climate impacts on these systems include the increased incidence of extreme hot days, in turn leading to increased heat stress and increased energy demand for cooling (in indoor production facilities), as well as increased water demand for drinking. Water scarcity and reduced water quality in some regions represent risks to livestock health.

These industries rely heavily on feed produced off-farm. Quality and costs of supplementary feed also depend on changed climate conditions, as well as global feed demands and competition from biofuels.



Figure 21: Pigs are particularly vulnerable to heat stress because they lack sweat glands.

5.2.5 Fisheries and Aquaculture

Australian sea surface temperatures have increased $\sim 1^{\circ}\text{C}$ in northern waters and more than 2°C in southern waters (Koehn et al. 2011). Between 1990 and 2009, sea levels rose 1-3 cm/decade in the south and east and 7-10 cm/decade in the north and west (Lough and Hobday 2011). Climate models project that by 2050, sea surface temperatures in the southeast could increase by 2.5°C and by 1.5°C in other regions (Koehn et al. 2011). There have been many observations of southerly shifts in the distributions of marine species, especially pelagic fish, associated with warming (Last et al. 2011).

Australian wild fisheries and aquaculture industries are being affected by rising sea levels, increasing ocean acidification, increasing ocean temperatures, changes in the strength and direction of ocean currents, changes in the ENSO, increased storm surges, and changing rainfall patterns, especially affecting runoff from the land to the sea that in turn affects the productivity of estuaries and nearshore coastal areas (Koehn et al. 2011). Any ongoing degradation of key habitats such as coral reefs, seagrass beds, mangroves and kelp forests will have also have important flow-on effects to fish populations. Fisheries production in tropical areas is projected to decline $\sim 40\%$ by 2055, but increases may be seen at higher latitudes due to the large-scale redistribution of fish populations (Cheung et al. 2010).

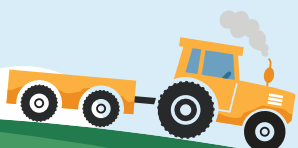


Figure 22: Commercial fishing fleet in Ulladulla, New South Wales.

Table 1: Observed and projected impacts of climate change on Australia's major agricultural commodities.

OBSERVED AND PROJECTED IMPACTS OF CLIMATE CHANGE ON AUSTRALIA'S MAJOR AGRICULTURAL COMMODITIES

Crop	Characteristics	Observed and projected climate change impacts
Grains 	The grain industry includes wheat, barley, canola, sorghum, oats, rice and pulses; from 2013-14 Australia exported over \$2.5 billion of grain. Production is divided into winter and summer crops. Most regions are only able to produce one crop per year. Wheat production is particularly variable from year to year (up to 60%) depending on rainfall. More than 1 million tonnes of rice per year grown, worth ~\$800 million p.a. and accounting for ~2% of world trade; grown in paddy cultivation and highly dependent on irrigation, requiring (on average) 1000 mm water p.a.	Cereal crops are sensitive to the timing of frosts, and crops such as wheat in southern Australia rely on winter-spring rainfall patterns that are already declining. CO₂ fertilisation effects may mitigate some reductions in yield but also reduce protein and micronutrient concentrations, leading to poorer nutritional quality; reduced rainfall in core cereal regions such as SW WA and Victoria are having substantial negative impacts on yields of existing cultivars and Australia could become a net importer of wheat in future decades. Reduced rainfall in core rice growing areas and/or the headwaters of rice irrigation water sources such as the Murrumbidgee River would reduce rice production; higher CO₂ levels typically increase biomass production but not necessarily yield; higher temperatures can also reduce yield by causing flowers to become sterile; possible adaptations to water declines in southerly regions include shifts of cultivation to more northerly regions (although this could increase the risk of high temperature impacts), irrigating more efficiently and using dryland varieties.
Wine grapes 	Australian wine exports have increased dramatically to ~5% global supply in the 2000s (1.4 billion L) and wine-grape growing is Australia's largest fruit industry. From 2013-2014 Australia exported \$1,847 million worth of wine. Most production comes from areas with a favourable temperate or Mediterranean climate; grapes are highly sensitive to temperature and water availability during critical growth stages.	Up to 70% of Australia's wine-growing regions with a Mediterranean climate will be less suitable for grape growing by 2050; iconic grape-growing regions such as Margaret River (WA), the Barossa and Riverland (SA), Sunraysia (VIC) and the Riverina (NSW) will be the most affected by higher temperatures and lower rainfall, especially for red varieties such as Shiraz, Cabernet Sauvignon and Merlot; higher temperatures likely to continue to cause earlier ripening and consequent reductions in grape quality; expansion to new regions such as Tasmania is already occurring.
Fruit 	From 2013-2014 Australia exported \$724 million worth of fruit. Most deciduous fruit and nut crops need sufficient accumulated chilling (vernalisation) to break winter dormancy.	Higher night temperatures are a risk for some late harvested varieties; extreme day time temperatures cause sunburn and reduce yield; shorter frost seasons may be a benefit but inadequate chilling due to warmer winter temperatures result in prolonged dormancy in pome and stone fruit, leading to reduced fruit yield and quality; increased intensity of rainfall causes increased losses; increased intensity of tropical cyclones pose ongoing risks for northern crops such as bananas.
Sugar 	Grown from northern NSW through to far-north QLD, requires strong sunlight and at least 1.1 m of annual rainfall, or irrigation. Australia is the 3rd largest supplier of raw sugar globally; 80% crop exported with a \$1.7-2 billion value p.a.	Increased sunshine associated with reduced rainfall enhances sugar content and yields in sugar crops in northern and north-eastern cropping regions, but reduced rainfall in winter/spring and early summer affects overall irrigation and water supply; plantations on coastal flats are vulnerable to sea-level rise and salt-water flooding from cyclone-induced storm surges.



Crop	Characteristics	Observed and projected impacts
Vegetables 	Vegetable growing uses less than 1% of Australia's agricultural land but was valued at \$3.7 billion (gross) in 2013-14, with 93% produced for domestic consumption; the sector employs 25% of all agricultural workers. All vegetable crops are sensitive to temperature which influences yield and quality; many vegetable crops are highly water-intensive.	Maximum temperature limits exist for many vegetable crops; reduced rainfall threatens irrigation supply; extreme heat causes sunburn, reduced flower number, reduced pollination, and affects quality and flavour; higher temperatures and humidity increase risk of diseases such as powdery mildew.
Dairy 	Australia's national dairy herd comprises 1.5 million cows and is highly reliant on water availability. Australia currently accounts for more than 10% of the global dairy export market.	Dairy cows are highly susceptible to heat stress and the industry is reliant in some regions on irrigation; producers in warmer regions will be disadvantaged compared to those in cooler areas where these have adequate water availability for pasture; heat stress reduces milk yield by 10-25%, and by up to 40% in extreme heatwave conditions; these impacts can last a considerable period after the stress event.
Lamb 	Production system of "spring lamb" relies on availability of nutritious pastures in winter and spring.	Higher rainfall areas favour cropping at the expense of grazing while lower rainfall favours expansion of wool-producing sheep into marginal cropping regions, although prime lamb requires more reliable rainfall; reduced spring rainfall and greater variability in rainfall patterns in southern Australia are already posing challenges; in some regions greater use of drought-tolerant native shrubs such as saltbush and/or feedlot-finishing will be needed.
Beef 	Australia is the world's 3 rd largest beef exporter, with 67% of production sold to more than 100 countries, with a gross value of over \$7 billion p.a. Beef production in southern Australia typically relies on cattle breeds of temperate origin, such as Angus and Hereford, grazing intensively managed pastures.	Pasture-growing seasons will contract, leading to lower and more variable animal stocking rates and increased reliance on supplementary grain feeding; reduced rainfall limits capture of runoff to supply drinking water, an issue highlighted during the Millennium Drought; increased heat stress is already leading to the choice of more heat-tolerant cattle breeds of lower meat quality.
Intensively farmed livestock (chicken, pork etc) 	Australians spend \$5.6 billion p.a. on chicken meat, with production increasing 160% over past 20 years. In 2011, the pork industry was worth ~\$880 million with pork comprising ~10% meat consumption in Australia; ~10% pork exported.	Increased temperatures and more frequent heat waves are likely to increase heat stress for intensively produced livestock. Heat stress causes reduced feed intake, poor weight gain and poor meat quality, poor laying rate, reduced egg weight and shell quality, reduced fertility and increased mortality in chickens. Pigs are also very sensitive to heat stress as they do not possess sweat glands; Any negative effects on grain production will have flow on effects to animal producers.
Fisheries and aquaculture 	The gross value of coastal fisheries and aquaculture was \$2.4 billion (2012-13), comprising \$1.4 billion from wild caught fish and \$1 billion from aquaculture.	Increasing water temperatures, decreasing oxygen levels, more suspended solids, increased incidence and severity of algal blooms, higher pH (ocean acidification), higher ammonia concentration, and increased variability in water supplies pose risks, especially to production of cold water species such as trout and Atlantic salmon, from heat stress, low oxygen content and disease. Warm water and tropical species can generally tolerate poorer water quality, have wider temperature tolerance ranges and higher optimal temperatures. Warming and the extension of the East Australian Current are associated with southerly migration of many tropical and temperate fish species. Modelling studies indicate increases and decreases of commercial fish catches, depending on the species.

Main sources: Harle et al. (2007); Deuter (2008); Webb et al. (2008); Cullen et al. (2009); HAL (2009); Howden et al. 2010; Stokes & Howden (2010); ACMF (2011); Barlow et al. (2011); Fulton (2011); Hobday and Poloczanska (2011); Koehn et al. (2011); PWC (2011a,b); ABARES (2012a,b); Henry et al. (2012); Webb et al. (2012); Ausveg (2013); Bonada et al. (2013); Hanslow et al. (2013); Lawrence et al. (2013); MLA (2013); Pearce et al. (2013); Potgeiter et al. (2013); Qureshi et al. 2013a; ABARES (2014a,b,c,d); ATSE (2014); Collet (2014); IRRRI (2014); Luo et al. (2014); Nymadori (2014 a,b); Porter et al. 2014; Reisinger et al. (2014); Thomson et al. (2014); ABS (2015b); Australian Pork (2015); Canegrowers (2015); RGA (2015).

BOX 3: CLIMATE CHANGE AND AUSTRALIA'S FOOD BOWL: THE MURRAY-DARLING BASIN

Covering over 1 million km² (14% of Australia's land area) and extending from Queensland to South Australia, including 75% of New South Wales, the whole of the ACT, and half of Victoria, the Murray-Darling Basin is Australia's largest and most diverse river system (MDBA 2014a). Apart from its sheer size, the Basin has enormous national significance for its economic, environmental, social and cultural values. The Basin supports about two million people directly within its boundaries, accounts for over 40% of Australia's agricultural produce and generates about \$15 billion per year for the national economy (MDBA 2014a,b). Another 1.3 million people rely on the Basin for household water supply.

Agricultural production in the Basin could be significantly reduced if the climate scenarios predicting substantial drying are realised, even with comprehensive adaptation.

Australia's three longest rivers — the Darling, the Murray and the Murrumbidgee — run through the Basin. Despite having one of the world's largest catchments, river flows in the Basin are among the lowest in the world because much of the catchment is semi-arid (receiving on average 250-300 mm per year) and only about 4% of the rainfall received is available as runoff. The remaining rainfall is either transpired through plants, evaporated, or drained into groundwater (2%). This low flow volume means that the water in the rivers is relatively salty and prone to algal outbreaks, and the surrounding soils acidic. The water that does flow down the rivers is highly valued for competing uses, including agriculture, tourism and recreation, urban use and supporting ecosystems (environmental water flows).

The Basin produces about one third of Australia's total food supply and contains 40% of its farms and 70% of its irrigated land area (MDBA 2013). Agriculture in the Basin uses nearly 70% of all irrigation water in Australia (ABS 2012c; DAFF 2012). In 2012-13, irrigated agriculture in the Basin supported nearly 100% of Australia's rice production, as well as 96% of its cotton, 75% of grapes, 54% of fruit and 45% of dairy (MDBA 2013).

Drought during 2006-2009 reduced national GDP by about 0.75% (RBA, 2006) and regional GDP in the southern Murray-Darling Basin by 5.7% below forecast in 2007/08, along with the temporary loss of 6000 jobs (Wittwer and Griffith 2011). The Millennium drought (1996 to 2010) had wide-ranging repercussions, with mean annual rainfall approximately 16% lower than the long-term average across the MDB, runoff 39% lower, and inflows into the MDB river system during 2006 at their lowest in 117 years of records (MDBC 2008). Groundwater storage in the Basin declined continuously throughout the drought, by approximately 100 km³ per year (Taylor et al. 2014). Agricultural production fell from 2.9% to 2.4% of GDP between 2002 and 2009, with drought playing a significant role in these observed declines (van Dijk et al. 2013). Since that time, production has increased from approximately \$4.3 billion in 2008-9, to \$6.8 billion in 2012-13 (MDBA 2013).

Agricultural production in the Basin could be significantly reduced if the climate scenarios predicting substantial drying are realised, even with comprehensive adaptation (Garnaut 2008, 2010; Quiggin et al. 2010; Qureshi et al. 2013a,b). Indeed, water security in the MDB was highlighted in the Fifth Assessment Report of the IPCC as one of Australia's key risks (Reisinger et al. 2014). By 2030 the Basin is likely to be hotter (0.3–1.28°C) and drier (2–5% less annual rainfall). Mean annual rainfall is projected to decrease in southern Australian (including the Murray Basin) over the course of the century, particularly in winter and spring (CSIRO and BoM 2015).

 BOX 3: CONTINUED

Projected climate change risks include more frequent droughts, more intense heavy rainfall events, livestock heat stress, reduced quality and productivity of pasture, greater risks of soil loss and degradation, and changed distributions of pests and weeds (Crimp et al. 2010). Mildura, for example, currently has on average 33 days of 35°C per year. This is projected to increase to between 37 and 46 days by 2030 (mid-range scenario), and between 44 and 73 days by 2090 (low and high emission scenarios, respectively) (CSIRO and BoM 2015). Pasture productivity may decline by up to 15% in the east and 8-40% along the dry western edge, where farming conditions are already marginal (Crimp et al. 2010). Under hotter drier conditions, pasture composition may shift to species that are more heat tolerant, but less palatable for stock (Crimp et al. 2010). The most marginal, least productive areas are projected to be the most severely affected, but with potential opportunities for increased production in the eastern and northern grazing regions (Crimp et al. 2010).

Several recent policy initiatives in Australia include goals to reduce vulnerability to climate variability and change, including the establishment of the Murray-Darling Basin Authority to address over-allocation of water resources (Connell and Grafton 2011; MDBA 2011). The Murray Darling Basin Plan (MDBA 2011, 2012a,b) commits to return 2750 GL per year of consumptive water (about one-fifth of current entitlements) to river ecosystems in the Basin and outlines water sharing mechanisms designed to cope with current and future climates (Reisinger et al. 2014).

Projected climate change risks include more frequent droughts, more intense heavy rainfall events, livestock heat stress, reduced quality and productivity of pasture, greater risks of soil loss and degradation, and changed distributions of pests and weeds.

BOX 4: BIOFUEL PRODUCTION: SAVIOUR OR COMPETITOR?

Global production of biofuels (ethanol and biodiesel) has increased five-fold over the past decade (BP 2013). These fuels are mainly produced from sugarcane, sugar beets and oilseed crops such as canola and have been termed “1st-generation” biofuels. In many regions these crops compete directly for land, and sometimes water, with food production. Indeed there are claims that the use of grains as fuels drove up global cereal prices by 30% in 2000-2007 (PMSEIC 2010). Any future policy restrictions on fossil fuel production is likely to increase conversion of land to biofuel production and increase food insecurity in some regions.

The current amount of productive land diverted to biofuel production in Australia is low (Keating and Carberry 2010). Some bioenergy technologies are well established and are currently in commercial use (Geoscience Australia 2015) but contribute less than 1% of total electricity production and 7% of renewable electricity production (ARENA 2015; Clean Energy Council 2015). Biofuel production could, however, accelerate in the future. For example, an ethanol plant using grain sorghum – usually grown as a feedstock – is operating in the Darling Downs regions of Queensland (Lawrence et al. 2013). There is a current commitment to

expand Australia’s biofuel production to 2-5% of all fuels sold (Lawrence et al. 2013). Such expansion will require greater deployment of new energy technologies, and will depend on a range of economic and policy settings (Farine et al. 2012).

There are also significant social and environmental issues (e.g. health, poverty, biodiversity) associated with bioenergy, which may be positive or negative depending on local conditions and the design and implementation of specific projects (Chum et al. 2011; Farine et al. 2012). On the one hand, bioenergy offers the potential for considerable economic benefits, including increasing Australia’s energy security, stimulating regional development, and reducing greenhouse gas emissions (IEA 2010; Chum et al. 2011; Kraxner et al. 2013; ARENA 2015). Conversely, pristine forests, biodiversity, agricultural land, and soil and water resources will all be under additional pressure from increases in the use of biomass from agriculture and forestry for producing energy (Kraxner et al. 2013). In Australia, most cleared land is already used for some form of agriculture (cropping or grazing), and therefore any substitution with 1st-generation bioenergy crops will involve some trade-off with food production (Herr and Dunlop 2011; Farine et al. 2012).

Concerns about sustainability of 1st-generation biofuels, and their competition for land and water with food production has increased interest in so-called “2nd-generation” biofuels – those produced from non-food biomass such as cereal straw, bagasse, forest residues and purpose-grown energy crops such as grasses and short-rotation forests (Sims et al. 2008).

Production of aviation fuel from the oils produced by mallees (Figure 23) is one example of a 2nd-generation biofuel opportunity with potential environmental and economic benefits. A preliminary analysis of the viability of such an industry in the Katanning/ Great Southern region of Western Australia indicated that there could be both environmental benefits (via improvements to habitat and soil), and economic benefits to farmers (Goss et al. 2014). 100% mallee bio-jet fuel could also reduce greenhouse gas emissions by 40% compared to traditional fuel sources.



Figure 23: Mallees are a potential source of 2nd generation biofuel.

5.3. Direct Impacts of Extreme Events on Food Supply, Safety and Distribution

Extreme weather events are part and parcel of food production and food supply in Australia.

A survey of more than 24,000 agribusinesses in 2009, for example, found that 84% of respondents had experienced droughts, severe frosts, hail, severe storms, floods or an increase in seasonal variation during the period 2007-2008 (ABS 2009). These estimates ranged from almost 90% of agricultural businesses in New South Wales and Victoria, to just over half in Western Australia. Nearly a third of those surveyed reported using financial reserves and or taking on increased debt in response.

Most food supply chains in Australia operate on a “just in time” basis. There is typically less than 30 days supply of non-perishable food, and 3-5 days supply of perishable food in the supply chain at any one time (ECRA 2006, cited in DAFF 2011), and major supermarkets generally hold only a few weeks supply (Haug et al. 2007). Households generally hold about a 3-5 day supply of food. Such low reserves are vulnerable to natural disasters and disruption to transport (DAFF 2011; Edwards et al. 2011).



Figure 24: In 2006, Cyclone Larry had devastating impacts on banana plantations in North Queensland. In the aftermath of the cyclone the price of bananas in supermarkets increased from about \$2 per kg to \$12 (McCarthy 2014). Cyclone Yasi in 2011 had similar impacts (see images of before (left) and after (right) Cyclone Yasi and the damage to banana plantations).

Australian households generally hold about a 3-5 day supply of perishable food.

This vulnerability was demonstrated in Queensland during 2010 and 2011 when floods affected large parts of the state (Slade and Wardell-Johnson 2013). Towns such as Rockhampton were cut off by road, rail and air for up to two weeks. During this period more than 100 large retail stores and many more smaller food outlets were inundated and Brisbane came within a day of running out of bread (Sapere Research Group 2012). Interviews with people involved in the food supply chain after this event revealed four key vulnerabilities: loss of transport links and distribution centres in major cities; fuel shortages; labour shortages; and disruption to supply of imported foods and food inputs. This research also highlighted problems such as the confusion of roles between different levels of government and different agencies during the relief effort, regulatory restrictions such as retail trade hours, and an over-estimation of the capacity of the Australian Defence Forces to help maintain reliable food supplies (Sapere Research Group 2012). Restocking during and after the floods was made possible through supply links from Sydney and Melbourne and routing stock via far west Queensland. It has been noted that if a second disaster had occurred simultaneously, such as a major bushfire, such restocking would not have been possible (Sapere Research Group 2012).

Extreme events that follow on from one another within a short time frame also reveal the fragility of our food supply chains. Successive flood and cyclone events in 2010-2011 in the Northern Rivers region of NSW resulted in 155 road closures and 14 highway closures (Singh-Peterson et al. 2013). The main food distribution centre supplying the region, the Rocklea Market in Brisbane, was submerged by the floods in December

2010 (Singh-Peterson et al. 2013). Rural communities are more vulnerable than urban areas (Singh-Peterson et al. 2013), and smaller food retail outlets more likely to be forced to increase prices, compared to the larger supermarkets that have greater capacity to absorb the costs of supply disruptions (Singh-Peterson and Lawrence 2014).

Other recent extreme events in Queensland have also highlighted potential future risks. In February 2011, 30,000 residents of Cairns were evacuated in anticipation of Cyclone Yasi, which fortunately crossed the coast at Mission Beach, 150 km to the south. Since that time there has been considerable speculation as to what the impacts on food supply may have been if the cyclone had hit a major centre such as Cairns or Townsville, especially with regard to perishable food such as meat, dairy and fresh fruit and vegetables, (Sapere Research Group 2012).

Food processing industries are also highly vulnerable to adverse or highly variable supply chains of raw materials. The costs of "doing business" are already increasing due to rising costs of water, energy and transport, requiring increasing investments in logistics systems to ensure standards of hygiene and temperature control (Edwards et al. 2011).

The impact of extremes on food safety is also of concern. The most common food-borne disease in Australia is gastroenteritis, with 5 million cases per year (Edwards et al. 2011). Disruptions to electricity supply, and therefore refrigeration, during and after extreme events such as storms and flooding, are relatively common occurrences. Excessive heat can also affect food safety as pathogens multiply quickly at high temperatures (Edwards et al. 2011).

5.4. Indirect Economic Impacts on Agricultural Production

Agricultural production, including indirect emissions associated with land-cover change, contributes 80 to 86% of the total food system emissions, and up to one third of total global emissions (Vermeulen et al. 2012; Smith et al. 2014). Over the decade 2000-2010, global emissions from agriculture increased 1.1% per year (Tubiello et al. 2013).

Energy use by the agricultural sector in Australia has been increasing at about 3.3% per year (1989-90 compared to 2009-10) (BREE 2012). Less favourable weather conditions such as drought are associated with higher energy use. The agriculture sector was responsible for about 15% of Australia's greenhouse gas emissions in the year to September 2014, the second largest source after the energy sector (Department of Environment 2015). Emissions from savanna burning and other land use changes contributed an additional 2%. The largest single source of emissions associated with agriculture is land clearing, but fermentation in the guts of ruminants and from manure, fertilizer application, savanna and field burning, and cropping (mainly rice cultivation) also contribute (Department of Environment 2015). Changes in savanna burning practices represent an important carbon sequestration and emissions reduction opportunity as well as sustainable livelihoods for Indigenous people on country (NAILSMA 2012).

The urgent need to reduce greenhouse gas emissions (see Section 8 This is the Critical Decade), combined with the potential for global oil supplies to peak and decline, is likely to have significant impacts on the cost of farm inputs and thus the profitability of food production systems (PMSEIC 2010; Growcom 2011). Agricultural inputs such as fuel, electricity and fertilizer are likely to become more expensive as national and international policies develop to limit greenhouse gas emissions (Keating and Carberry 2010). Australia's low nutrient soils mean that much of our agricultural production is reliant on imported fertilizer, controlled by a handful of manufacturers, and highly energy-intensive to produce; 1 kg of nitrogen-based fertilizer, for example, requires 1 kg oil (PMSEIC 2010). National policies to comply with international mitigation agreements could also mean higher costs for the agricultural sector, especially the livestock industry if methane emissions are included in any future comprehensive polluter pays scheme (Cocklin and Dibden 2009).

Over the decade 2000-2010, global emissions from agriculture increased 1.1% per year.

5.5. Global Interactions

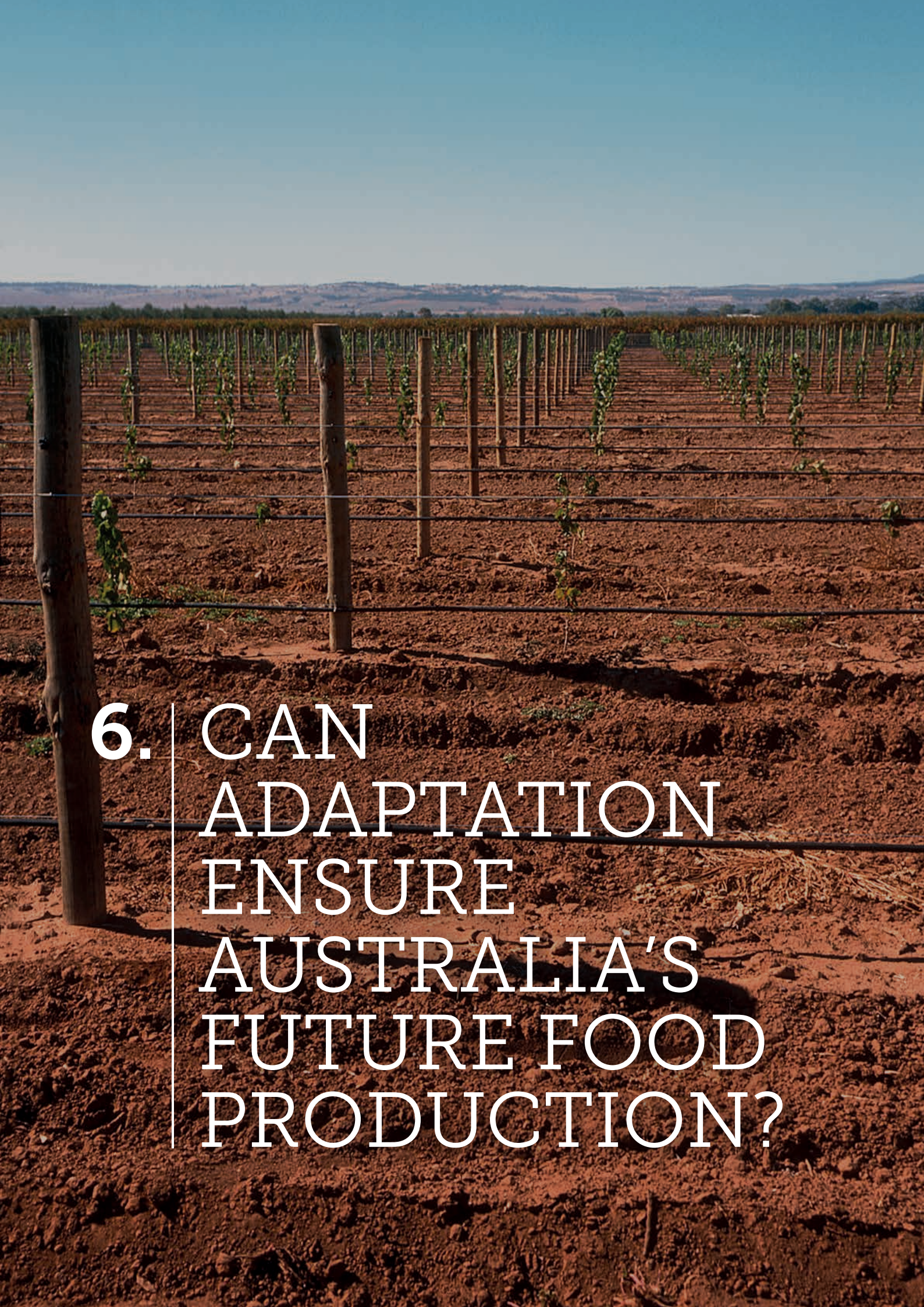
As both an importer and exporter of food, Australia's domestic food security is affected by productivity of our trading partners and competitors. The impacts of climate change on primary industries in other countries, together with growing population pressures (see Box 7: Feeding a Hungry World) will therefore increasingly affect Australia's domestic food security in complex ways. The net impacts of these forces are very difficult to predict (Beerman 2011).

An analysis by ABARE projects declines of global wheat, beef, dairy and sugar production by 2-6% by 2030 and 5-11% by 2050 (Gunasekera et al. 2007). Other estimates indicate that irrigated wheat yields in developing countries could decline 13% and irrigated rice by 15% by 2050 (Thornton and Cramer 2012). While such outcomes may mean higher profitability for Australian exporters, changes in trade balances may have important flow-on impacts for domestic food availability and prices.

Climate impacts on major trading partners such as China will be particularly important. Projections of a grain deficit as a result of growing water scarcity and population pressures in China (Mu and Khan 2009) could, for example, advantage Australia's grain exporters. By contrast, sheep production in New Zealand and China may be advantaged as warmer and wetter regional conditions extend grazing zones, increasing competition with Australia (Cocklin and Dibden 200).

Global food shortfalls are likely to become more severe because of growing populations and climate change could limit production in many densely populated areas (PMSEI 2010). Finally, some economists have warned that climate change is likely to cause a general economic slowdown at a global level in future decades, as a result of both market and non-market forces, and the increasing costs of extreme events. Such a slowdown would likely have significant, yet difficult to predict consequences for Australia's balance of trade (Stern 2007; Gunasekera et al. 2007).

Global food shortfalls are likely to become more severe because of growing populations and climate change could limit production in many densely populated areas.

A photograph of a vineyard in a dry, arid landscape. The ground is reddish-brown and cracked, indicating drought conditions. Rows of young grapevines are planted in the field, supported by wooden stakes. The background shows a clear blue sky and distant hills.

6. | CAN ADAPTATION ENSURE AUSTRALIA'S FUTURE FOOD PRODUCTION?

Australia's harsh physical environment, characterised by low nutrient soils and a highly variable climate, has provided challenges for agricultural enterprises since European settlement. These physical challenges have been coupled with the changing nature of world commodity markets, and fluctuations in currencies and national policies.

Resilience and the capacity to adapt have been amply demonstrated at many levels – from individuals to communities (Steffen et al. 2011; Bryan et al. 2014; Reisinger et al. 2014). This capacity will support ongoing adaptation to climate change but there are considerable barriers to achieving the level of change required (Barlow et al. 2011; Reisinger et al. 2014). Further, several analyses have suggested that Australian farmers are already operating close to the limits of technical efficiency (Daly et al. 2015).

Adaptation to climate change can occur at a range of scales from *incremental* – consisting of relatively small, progressive adjustments to current practices – to changes at the *system level* – to *transformational* change in which current activities might be completely relocated or otherwise undergo substantial change *in situ* (Figure 25).

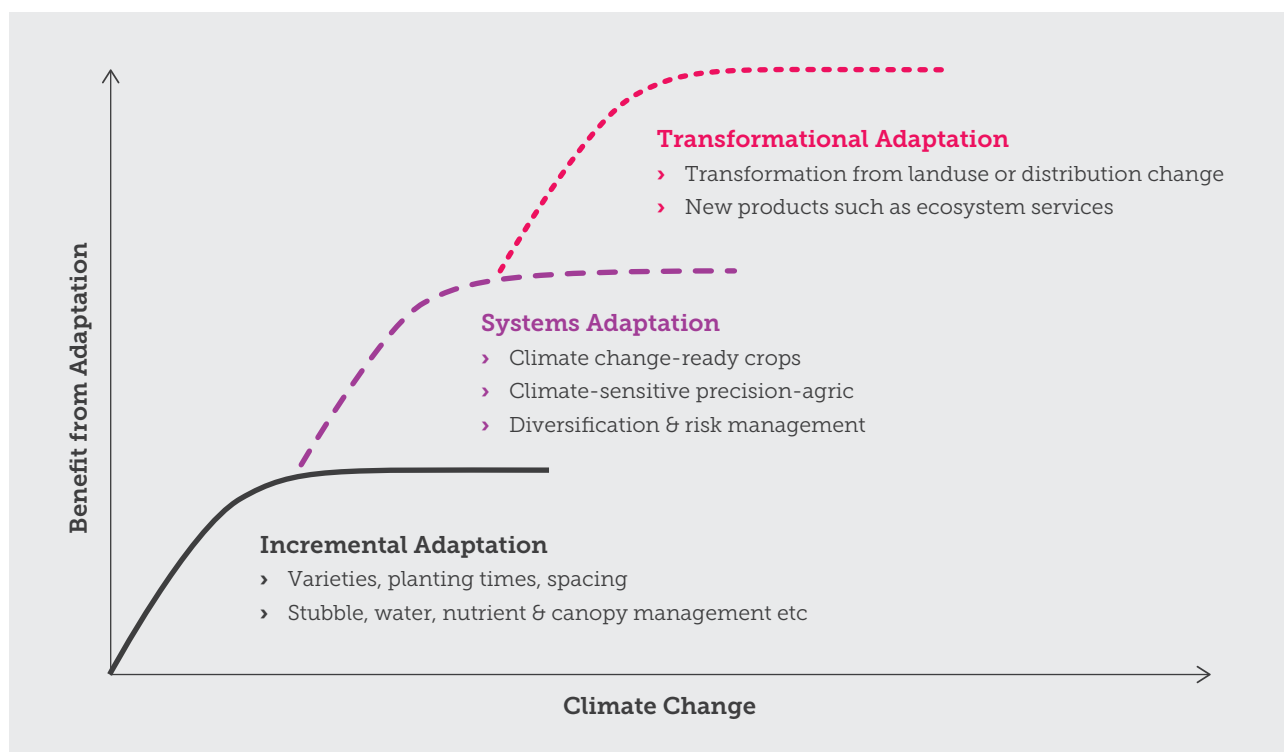


Figure 25: Levels of adaptation in relation to benefits from adaptation actions and degree of climate change, with illustrative examples (from Howden et al. 2010).

6.1. Incremental and Systems Adaptation

Coping with an already variable climate has necessitated a long history of flexible farming practices in Australia. Changing crop varieties and livestock breeds, and altering sowing and harvesting dates, are examples of incremental adaptation already occurring in response to Australia's changing climate (Crimp et al. 2014).

In Northern Australia, for example, a shift away from European livestock breeds towards cross-breeding or replacement with *Bos indicus* (Figure 26), a cattle breed from Asia that is more tolerant of hot conditions, has been occurring for some time (Barlow et al. 2011). Varieties of pome and stone fruits that have lower chilling requirements may replace existing varieties (Barlow et al. 2011; Thomson et al. 2014). Crop varieties specifically selected for high responsiveness at higher CO₂ levels may have particular promise (Ziska et al. 2012). Some researchers have concluded that despite the southwest WA undergoing a 20% reduction in rainfall over the past few decades, broadacre dryland farmers with access to new crop varieties and technologies that support cropping have high adaptive capacity (Kingwell et al. 2013). Another study indicated that adaptation could reduce the projected decline in wheat production by 2030 in NSW and WA from 8.4% and 8.9% respectively, to 5% and 4.8% (Heyhoe et al. 2007). Even more dramatic impacts on Australian wheat production were modelled by Crimp et al. (2014) who showed

that changing the variety of the wheat planted, as well as changing the timing of planting, could potentially result in benefits of 5 to 15% of production, saving the national wheat industry \$100 million to \$500 million. These adaptations, however, could not remove all risk, especially under the driest and hottest projections of future climates.

In some cases, adaptive change is occurring at a far broader scale than individual farms. An example of change in a whole production system is the expansion of grain cropping in western Victoria, where reduced rainfall and reduced waterlogging is now making such crops profitable (Barlow et al. 2011). Changes to whole production systems may be opportunistic, occurring on a year-to-year or season-to-season basis, or become more permanent. They may require new skills to be developed and new capital investment in machinery and other infrastructure.

Many adaptive changes, even those at a relatively small scale, will entail tradeoffs. For example, dairy cows are particularly susceptible to heat stress (e.g. Nidumolu et al. 2014). Cows selected by breeding programs to be more heat tolerant may come at the expense of lower milk production per cow. Producers may thus face the choice of reducing production versus spending more on infrastructure for cooling systems (Barlow et al. 2011). Incremental adjustments by producers will need to be supported by ongoing research to evaluate potentially beneficial varieties and breeds.

Adaptation measures to adjust to increasing water scarcity are also evident. Increased water use efficiency at the farm level, changes to cropping systems with lower water requirements, adoption of water saving technologies, and increased use of groundwater are some examples (Alston and Whittenbury 2011). Some farmers with financial capacity have already diversified by buying land in other areas to spread their risk, or have moved their water entitlements between different areas (Alston and Whittenbury 2011). Others have bought dryland pasture to grow feed for livestock, rather than relying on irrigation.

Primary producers are not the only group gradually adjusting to the changing climate in rural and regional areas. For example, increasing investment of emergency services such as fire-fighting facilities and capacity is occurring in response to increasing bushfire risk (Beer et al. 2013).

Some researchers warn that under some circumstances, certain types of incremental adaptation could actually hinder later transformational adaptation (see next section) by encouraging persistence of location or practice in systems beyond their response capacity (Park et al. 2012; Rickards and Howden 2012).



Figure 26: *Bos indicus*, a cattle breed from Asia, is replacing European breeds in Australia because it is more tolerant of hot conditions.

6.2. Transformational Adaptation

The complex, multiple, and interacting dimensions of climate change described in the previous sections of this report, all of which have a degree of associated uncertainty as to the rate, degree, scale and direction of change, mean that the types of adaptation that have previously served Australian farmers well may simply not be enough in the future (Howden et al. 2014; Ghahramani and Moore 2015). Larger transformational changes will therefore eventually be necessary, with associated risks, uncertainties and costs (Howden et al. 2010; Rickards and Howden 2012).

The present day match between suitable climate, and the requirements of some agricultural enterprises, will become progressively decoupled. For example, cropping systems in some regions may become increasingly marginal if rainfall in those regions continues to decline, to the point they will no longer be viable (Crimp et al. 2014). Similarly, there will likely be limits to how effective breeding for more heat tolerant livestock may be (Moore and Ghahramani 2014). Wholesale movement of some

industries, such as dairy, to different regions may prove necessary. Indeed, some wine producers have already taken this step (Dowd et al 2014) (See Box 5: Tasmania's Grape Expectations).

Transformational change will require the development of new skills, an understanding of new markets, and considerable new infrastructure, and will therefore be associated with significant costs and risks (Rickards and Howden 2012; Herzler et al. 2013). For example, switching between production systems may require new investments in infrastructure, and may leave stranded assets (Herzler et al. 2013). The ability to undergo such substantial change in practice will depend on many factors, such as the magnitude of climate change in a region (both observed and anticipated), the physical nature of the environment, the transaction and opportunity costs of the transformation, and the farmers' perception of risks, both associated with making a bad decision and as a result of inaction (Marshall et al. 2014; Rickards and Howden 2012; Herzler et al. 2013). There has been relatively little research conducted to aid our understanding of the benefits and challenges of transformative adaptation (Reisinger et al. 2014).

Larger transformational changes may eventually be necessary, with associated risks, uncertainties and costs.

BOX 5: TASMANIA'S GRAPE EXPECTATIONS

Australia's wine industry contributes significantly to the economy; in 2013-2014 Australia exported nearly \$2 billion worth of wine (ABARES 2014b). Viticulture is highly sensitive to changes in climate. Increases in average annual temperature of 0.2-1.2°C by 2030 and 0.4-3°C by 2050 are projected to occur in many of Australia's most important wine-growing areas (Webb et al. 2007). The effects of warmer temperatures include shortening of the growing season and decline in grape quality. Ripening may occur approximately 15 days earlier by 2030 or 30 days earlier by 2050, depending on the region (Webb et al. 2007). Earlier ripening of grapes has already been detected in vineyards in southern Australia, with grapes maturing eight days earlier per decade from 1985-2009 (Webb et al. 2012). The quality of grapes is also affected by warming; by 2030 the quality of grapes in the Riverina region of NSW is projected to decline by 16% (Webb et al. 2008).

Commercial winemakers from the mainland are already responding to the warming climate by securing both fruit contracts and vineyards in Tasmania (TIA 2012). For example, Victorian winemaker Brown Brothers has purchased a \$32.35 million wine estate in Tasmania, citing higher temperatures and increasing bushfire risk due to climate change as the motivation for the move (The Age 2010). Whilst Tasmania's cooler climate currently presents an alternative for mainland winemakers faced with warmer temperatures, Tasmania is also experiencing a warming trend with five of the state's hottest years on record occurring in the last ten years (BoM 2014). By 2070, the climate for wine production in northern Tasmania may be similar to the Coonawarra region of South Australia (TIA 2012). In addition, Tasmania currently specialises in the production of cool-climate wine and the character of this wine may also be affected as temperatures rise. This means, however, that different parts of Tasmania that were previously too cool for wine production will potentially become suitable (TIA 2012).



Figure 27: Tamar Valley vineyards.

6.3. Barriers to Adaptation

While small-scale, incremental adaptation to a changing climate is already occurring, the substantial capital investment needed for new infrastructure and skills development to support more transformational change represents a significant barrier, especially at the level of individual farms and farmers (Nelson et al. 2010 a,b; Barlow et al. 2011; Hogan et al. 2011; Crimp et al. 2014; Marshall et al. 2014;).

Existing financial hardship will limit the capacity of farmers to make new investments. The capacity to adapt in the intensive animal production sector, in particular, is likely to be constrained by the high cost of fixed assets (Barlow et al. 2011). Some researchers have also identified that a major barrier to adaptation is the disconnect between the output from research on climate change impacts and adaptation and the information that end-users need. Problems include confusion about terminology, perception of the uncertainty of the science, and the complexity of interactions between climate change and other drivers of change (Hogan et al. 2011; Kiem and Austin 2013b; Raymond and Spoehr 2013).

Some researchers have noted that an over-emphasis on climate change projections, especially at a fine-scale, can be an impediment to effective adaptation, firstly by delaying action – as the next, more up to date report is anticipated – or by encouraging planning for an unrealistically narrow range of future climates (Sarewitz 2010; Hayman et al. 2012).

Existing financial hardship will limit the capacity of farmers to make new investments to help cope with climate change.

Adaptation or greenhouse gas mitigation in some sectors may conflict with adaptation in others (Reisinger et al. 2014). For example, enhancing water security in some regions by diverting water or increasing storage in dams is likely to have negative impacts on biodiversity and water users downstream. Enhancing flood protection, combined with rapid re-building after extreme events, can accumulate expensive fixed assets which can then become increasingly costly to protect as extreme events continue to increase (Reisinger et al. 2014).

BOX 6: THE NORTHERN FOOD BOWL – NEXT FRONTIER OR RECURRING MYTH?

Expanding agricultural production in northern Australia (Figure 28) has been proposed to help alleviate the potential impacts of a warmer and drier climate in southern Australia's agricultural zones, to feed a growing Australian population, and possibly become the "food bowl for Asia". Yet several studies on the feasibility of significant agricultural expansion of northern Australia have highlighted formidable challenges (Davidson 1972; CSIRO 2009; Campbell and Turnour 2013).

Northern Australia experiences some of the highest daily rainfall intensities on the planet, while in the drier months parts of the region become desert-like (NAIF 2007; Blanch, 2008; CSIRO 2009). The majority

of rivers in the region are ephemeral due to extremely high evaporation rates. Annual discharge and recharge rates of groundwater basins are poorly understood, making sustainable abstraction rates difficult to estimate (NAIF 2007). A CSIRO Northern Australia Land and Water Science Review concluded that there are serious challenges to realising the dream of expanding agricultural production in northern Australia, including significant difficulties in capturing the huge runoff from rain along the coast and poor soil quality (CSIRO 2009). These soils would generally need substantial amounts of fertiliser to be productive and their sandy and rocky nature would result in much of the applied fertiliser being leached into groundwater (Wilson et al. 2009).

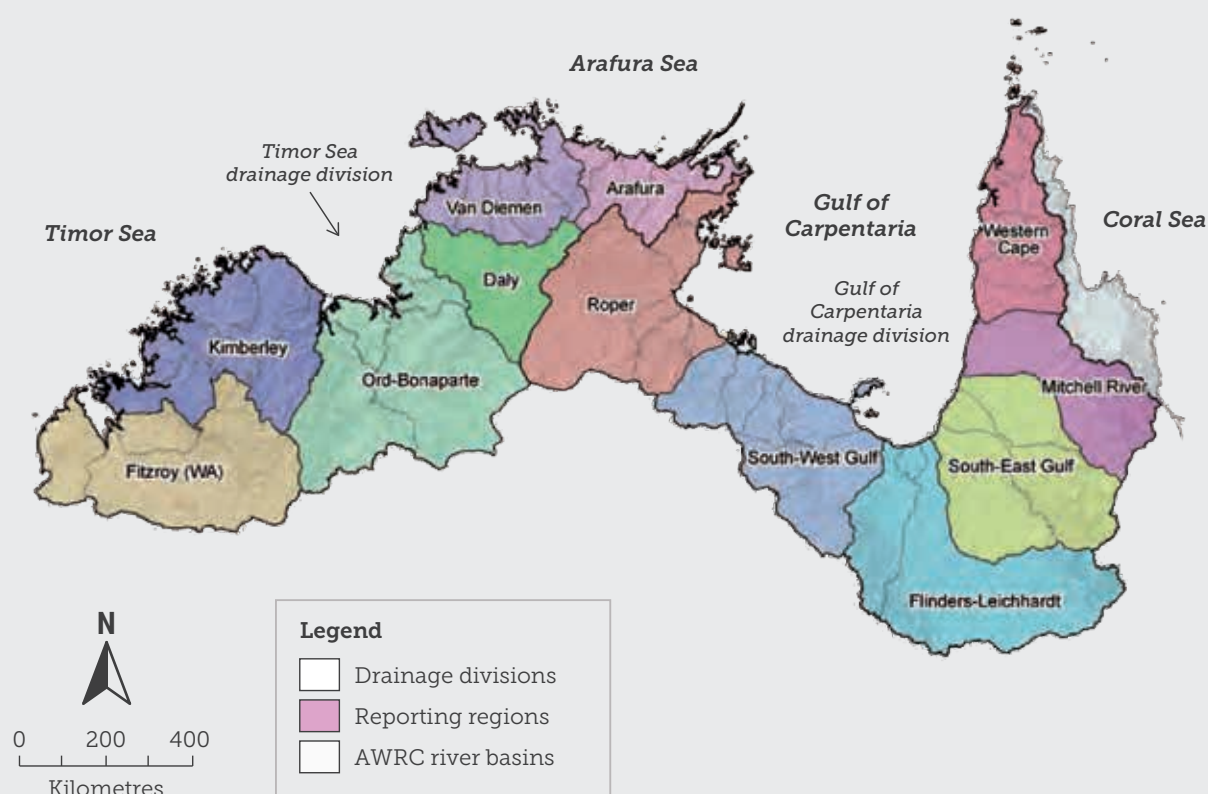


Figure 28: Geographic bounds of 'northern Australia' as defined in this report. Source: CSIRO (2009).

BOX 6: CONTINUED

As in the Murray-Darling Basin (see Box 3: Australia's Food Bowl), competition for water in northern Australia is fierce, with the 1 million GL of rainfall received each year supporting a multitude of competing uses. These include aquatic and terrestrial ecosystems; Indigenous livelihoods; recreational and commercial fisheries and tourism; irrigated agriculture; livestock; urban settlements; and mining (CSIRO 2009). While it has been estimated that 17 million ha of northern Australia has soils that could support cropping, only 1% of the area has appropriate water availability (Webster et al. 2009). The Northern Australian Land and Water Taskforce estimated that 20,000 ha of northern Australia is already being irrigated, and in a best case scenario - where significant groundwater reserves are overlaid with tracts of suitable soil - this number could triple to 60,000 ha, an area far too small to support significant agricultural expansion (CSIRO 2009; Campbell and Turnour 2013). Furthermore, the environmental, social and cultural impacts of a network of dams and irrigation schemes across one of the world's largest regions of free-flowing rivers would be significant (Campbell and Turnour 2013).

Whilst research suggests that extensive agricultural expansion in northern Australia may not be viable, there may be opportunities for alternative irrigation regimes (NAIF 2007). For example, irrigation mosaics – a technique that distributes smaller areas of irrigation across a landscape – can have a number of benefits such as reducing the rise of the water table (thereby decreasing the risk of salinity), reducing erosion, and potentially preserving the habitats of natural wildlife (Story et al. 2008). While their success is very site-dependent, such regimes could potentially provide opportunities for Indigenous communities to operate sustainable agricultural ventures (Story et al. 2008). Other opportunities for income generation in the region include a voluntary carbon market for landowners (Blanch 2008), and electricity generation from geothermal, tidal and solar sources that could be sold on to service grids in both northern Australia and into Asia (Campbell et al. 2013).



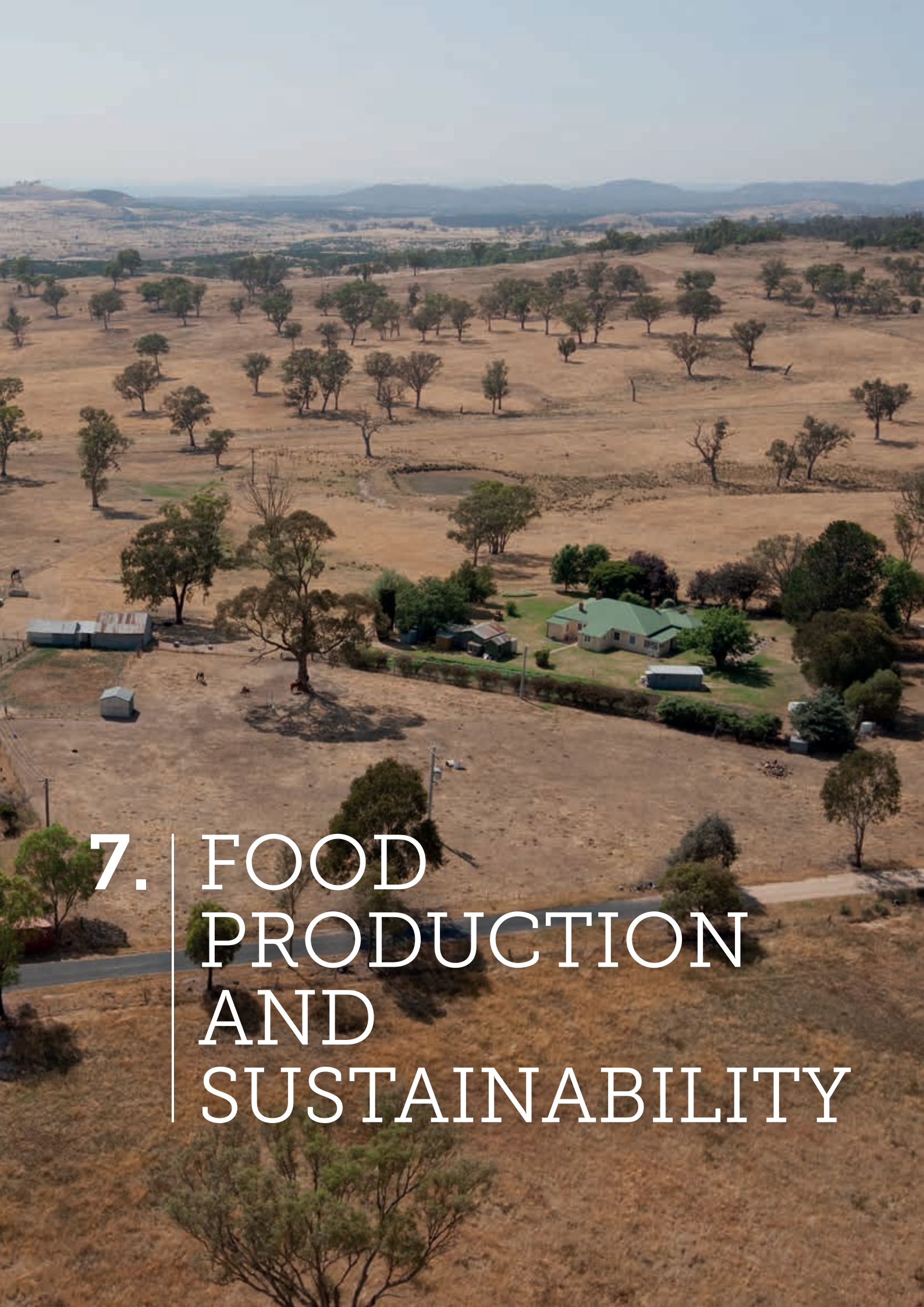
Figure 29: Floods in Kakadu illustrate highly variable rainfall patterns in the Northern Territory.

6.4. Maladaptation

Policies and practices that increase, rather than reduce, vulnerability to climate change are said to be maladaptive. Barnett and O'Neill (2010) define five different potential types of maladaptation: practices that increase emissions of greenhouse gases; those that disproportionately affect the most vulnerable; those that have high opportunity costs; those that reduce the incentive to adapt; and those that create "path dependency", for example by committing capital and institutions to development trajectories that are difficult to change in the future.

One example of an adaptation measure to past conditions that now increases rural vulnerability is irrigation. Irrigation has allowed agricultural expansion into some regions that may not be able to support such industry in the future. Adaptation in some sectors to the changing climate may also be damaging for others. For example, the need to increase water security for both agricultural and urban uses may favour the development of dams and other forms of water reallocation which have significant negative impacts on the natural environment and on downstream water users (see Box 6: The Northern Food Bowl).

The need to increase water security for both agricultural and urban uses may favour the development of dams and other forms of water reallocation which have significant negative impacts on the natural environment and on downstream water users.



7.

FOOD
PRODUCTION
AND
SUSTAINABILITY

The challenge facing Australian food production systems is to continue to increase production in response to both domestic and international demand, while at the same time adapting to the changing physical and economic environment without further degrading the natural resource capital of the Australian environment (Campbell 2009). Some recent studies have concluded that with significant investment in R&D, efficiency of resource use, new innovation, and greater recognition of the need for more sustainable use of both environmental and human resources, it should be possible to double production per unit area for both crop and livestock systems over the next few decades (Carberry et al. 2011; Mullen et al. 2012). As discussed throughout this report, however, climate change is adding another dimension to this formidable challenge.

Influential scientific bodies such as the Australian Academy of Technological Sciences and Engineering have urged Australian governments and agricultural organisations to work toward differentiating Australian agricultural products from those of competitors by promoting “Brand Australia” as clean, green and sustainable, living within the means of our natural capital (ATSE 2014; Daly 2015). There is rapidly growing interest in “local food networks”, as a way of increasing the resilience of our food supply, and our communities, to reduce risks such as that posed by climate change, as well as increasing sustainability in general (McCarthy 2014). Shifting the current paradigm of productivity enhancement and short-term profitability as the core focus of primary industry to one focused on production efficiency and value, in the context of environmental impacts and the changing physical environment, is vital if we are to meet the challenge of maintaining not only the safety, accessibility and affordability of our own domestic food supply, but to contribute our fair share to global food security in the coming decades (Campbell 2009; Wentworth Group 2014; McKenzie and Williams 2015).

With significant investment in R&D, efficiency of resource use, new innovation, and greater recognition of the need for more sustainable use of both environmental and human resources, it should be possible to double production per unit area for both crop and livestock systems over the next few decades.

 BOX 7: FEEDING A HUNGRY WORLD

Over the past 50 years there has been a significant growth in food production, leading to a dramatic decrease in the proportion of people that are hungry, despite a doubling of the global population (Godfray et al. 2010). Yet in 2014, an estimated 842 million people still experienced chronic hunger (EIU 2015). A further two billion people are estimated to suffer from “hidden hunger”, caused by deficiencies of micronutrients (Godfray and Garnett 2014). The problem is widely acknowledged to be mainly one of inequitable food distribution, rather than a lack of production. Paradoxically, obesity also poses a significant health problem in many developed, and in some cases developing, countries.

The world now faces the challenge of matching the rapidly changing demand for food from a larger and more affluent population to its supply, in ways that are environmentally and socially sustainable, while ensuring that the world’s poorest people attain food security. This challenge requires changes across the whole global food system (Gregory et al. 2005; Ericksen 2007; FAO 2015).

By 2050, the world’s population is projected to reach more than 9 billion (UN 2015). At the same time, the per capita wealth in many developing countries is increasing, leading to growing demand for protein-rich diets. Collectively, these trends are expected to increase the global demand for food by 70-100% by the middle of the century (FAO 2009; Godfray et al. 2010; Alexandratos and Bruinsma 2012). Shifts to diets with a higher proportion of animal protein also have a range of complex health and environmental implications (Garnett 2014).

Global demand for food is expected to increase by 70-100% by the middle of the century.

International food trade accounts for 23% of global food production (D’Odorico et al. 2014). The globalisation of the food system provides opportunities for some local food producers to access larger markets and capital for investment. Globalisation may also increase the global efficiency of food production by allowing regional specialisation in the production of the most appropriate locally grown foods (Godfray et al. 2010). A counter argument to this, however, is that globalisation may also result in increased exposure (for example, from an extreme weather event) at particular nodes in food supply chains (e.g. Fleming et al. 2014). The environmental costs of food production may also increase with globalisation, for example, because of increased greenhouse gas (GHG) emissions associated with increased production and food transport (Pretty et al. 2005; Godfray et al. 2010).

Whilst there have been substantial gains in global productivity over the past few decades due to technological developments and economies of scale (Eriksen 2007; Carberry and Keating 2010), there is considerable concern that the rate of productivity increase is reaching a plateau. Growth in global yields per hectare of maize, rice, wheat and soybean crops was slower in 1990-2007 than 1961-1990 (Alston et al. 2009) and overall crop production growth is falling to at or below the level of population growth, although the rate of productivity increase in developing countries has increased (Fuglie and Rada 2014). The narrow genetic base of most of the world’s staple food crops is a further source of vulnerability, given rapid environmental change (Bardsley 2015).

BOX 7: CONTINUED

More than half of the calories consumed globally come from just three staple crops – maize, wheat and rice – and each of these will be severely challenged by the changing climate (Thornton and Cramer 2012). The latest Intergovernmental Panel on Climate Change Report (IPCC 2014) contends that the effects of climate change on crop and food production are already evident in several regions of the world. In recent years, there have been periods of rapid food and cereal price increases following climate extremes in key producing regions, highlighting the sensitivity of current markets and flow-on impacts to communities. In 2008, for example, low levels of global food stocks and high prices created social unrest in several regions (FAO 2008, Homer-Dixon et al. 2015). Recent analyses by the Global Food Security Programme (2015) concluded that the risk of a 1-in-100 year food production shock as a result of extreme weather is likely to increase to 1-in-30 or more by 2040.

Climate change impacts on the agriculture sector, combined with competition for land from biofuel production and urban expansion, could potentially stall advances toward a world without hunger.

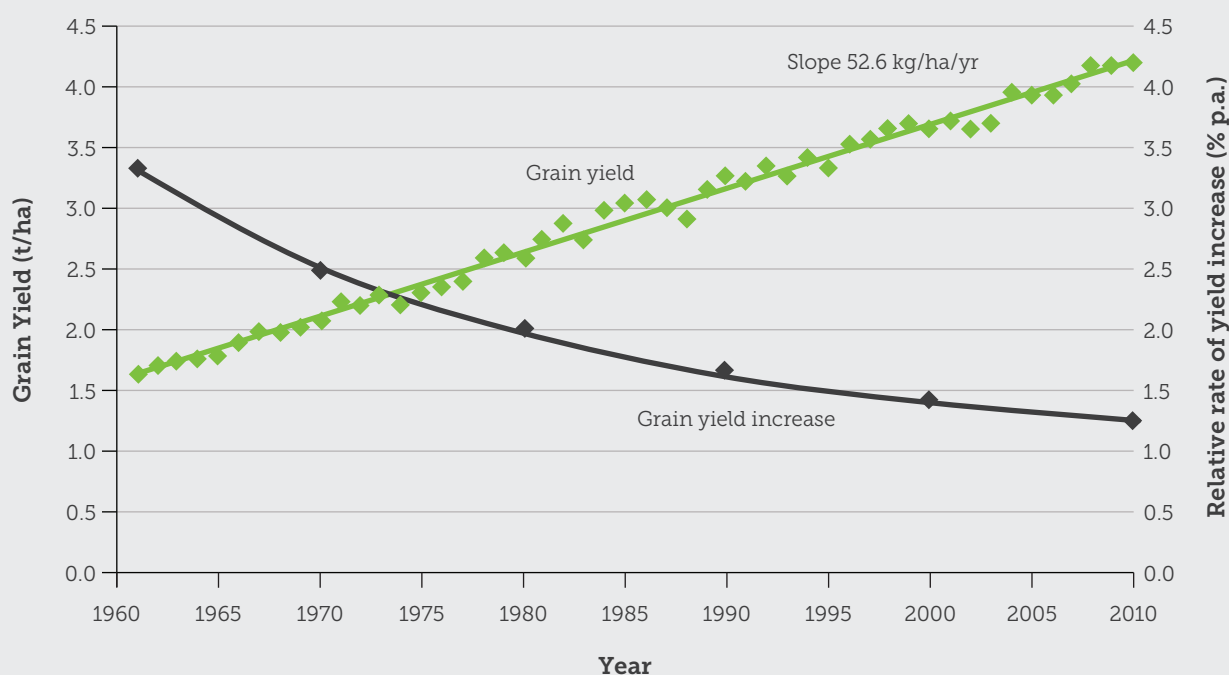


Figure 30: Trends in global cereal yields (1960-2010). Source: FAOSTAT 2013; ACIAR 2014.

 BOX 7: CONTINUED

Without adaptation, local temperature increases in excess of about 1°C above pre-industrial levels is projected to have negative effects on yields for the major crops of wheat, rice and maize in both tropical and temperate regions, although individual locations may benefit (Thornton 2012; Porter et al. 2014). The bottom line is that climate change impacts on the agriculture sector, combined with competition for land from biofuel production and urban expansion, could potentially stall advances toward a world without hunger (Wheeler and von Braun 2013). There is a need for substantial investment in adaptation and mitigation actions toward a “climate-smart food system” that is more resilient to climate change influences on food security (Wheeler and von Braun 2013).

And what might be Australia’s role in feeding the world? The OECD predicts that Asia could account for 66% of the world’s middle class by 2030, up from 30% currently (Kharas 2010); the market for Australian food exports could thus expand considerably. But Australia currently exports enough food to feed only about 60 million people (ABARES 2011) – less than 1% of the world’s population, and less than a quarter of the population of Indonesia, our nearest neighbour (PMSEIC 2010). With Australia facing significant challenges to its agricultural systems, especially from water scarcity, our role in feeding the world is likely to remain limited. Indeed, some analyses indicate that the expected negative impacts of water scarcity as a result of climate change in regions such as the Murray Darling Basin are likely to greatly *reduce* Australia’s capacity to contribute to global food security (Qureshi et al. 2013a).



Figure 31: Climate change is expected to have negative effects on rice yields in Indonesia and elsewhere in tropical regions.

The land use sector can play a very important role in reducing Australia's emissions, especially from changes in agricultural practices and revegetation (Garnaut 2011a,b; BZE 2014; Daly et al. 2015; Rodale Institute 2015). A report by Beyond Zero Emissions (BZE 2014) has calculated that revegetation of 13% of cleared land could draw down enough carbon to offset emissions from all other land use activities in Australia. (Lam et al. 2013; Rodale Institute 2015).

Energy use by the farming sector is increasing, although the amount of energy used to produce a unit of production is declining. For example, energy consumption increased 15% in the 20 year period to 2011, but the index of energy production, a measure of efficiency, almost doubled over that period, that is, the average grain farm in Australia in 2010 used half as much energy to produce the same amount of grain as in 1980 (Che et al. 2011).

Significant research is focused on reducing methane emissions from livestock and nitrous oxide emissions from fertilizers. In some cases, there are synergies between mitigation actions and adaptation. For example, planting trees can provide shade for stock and also increase carbon sequestration. Using current best practice for applying fertiliser can reduce emissions of nitrous oxide as well as increasing productivity and reducing costs (WA Department of Agriculture and Food 2013).

8. | THIS IS THE
CRITICAL
DECADE

The climate is warming, and many other changes to the Earth System – patterns of precipitation, sea-level rise, melting ice, acidification of the ocean – are also occurring. It is beyond reasonable doubt that the emission of greenhouse gases by human activities, mainly CO₂ from the combustion of fossil fuels, is the primary cause for the changes in climate over the past half-century.

There are some promising signs that the first steps are being taken towards decarbonising the global economy. In 2014, there were record installations of wind and solar PV globally and some of the world's biggest emitters are beginning to take meaningful actions to limit and reduce emissions (for further information see the Climate Council's report *The Global Renewable Energy Boom: How Australia is missing out*). However, the rapid consumption of the carbon budget, not to mention the discovery of many new fossil fuel reserves, highlights the enormity of the task. Much more needs to be done to reduce emissions... and quickly.

Australia continues to enjoy a safe, accessible, relatively affordable and reliable food supply, largely produced within our own boundaries. But climate change poses enormous challenges for our food production, mainly from the impacts of extreme heat and water scarcity. When combined with the pressure of feeding growing populations, growing protein demand both at home and globally, ongoing degradation of our natural resource base, and uncertainties in patterns of global trade, there is no room for complacency.

Australian farmers have demonstrated great resilience in the face of harsh physical and social challenges. Many individuals, business and communities are already demonstrating adaptation to the climatic change experienced so far, and many are planning for further change. But progressive, small-scale adaptive steps may become increasingly inadequate, warranting expensive and disruptive transformational change in coming decades. Further, if the present rate of climate change is maintained, there will be many challenges to which adaptation is simply not possible.

Transitioning urgently to a new, low carbon economy is critical. At the same time, we must also become better stewards of the natural environment that sustains us. Achieving carbon neutrality in the land-based sector, including agriculture, will play a vital role in the transition we must embrace.

This is the critical decade to get on with the job.

Appendix

FUTURE CLIMATE PROJECTIONS

Projected changes to Australia's climate described in this report are based on a synthesis of (i) understanding of the climate system and how it operates, (ii) observed trends in important climate indicators such as temperature and rainfall, and (iii) quantitative projections from simulations of the climate system by a suite of global climate models that have contributed to the IPCC Fifth Assessment Report (IPCC 2013). These projections have been explored in detail for Australia in a recent CSIRO and BoM (2015) study that, unless otherwise stated, is the primary source of material in this appendix.

The model simulations are driven by several assumptions about the trajectory of human greenhouse gas emissions through the rest of this century, ranging from a scenario of rapid and deep emission reductions (called "RCP2.6" by the IPCC; in essence, a strong

mitigation pathway) to a business-as-usual scenario of increasingly high annual emissions through the century (RCP8.5), with an intermediate scenario (RCP4.5) (referred to in this report as "low", "high" and "medium" emission scenarios respectively). The differences in projected climate changes among these three emissions scenarios are not great for the next couple of decades, but become quite large by the end of the 21st century.

The baseline for the projections is usually taken as the average climate of 1986-2005, so the projections must be added on to the average climate of that period. Significant changes to the climate had already occurred by the 1986-2005 period, so these observed changes must be added to the projections if the projections are to be evaluated against a pre-industrial baseline.

RESOURCES FOR A CHANGING RURAL WORLD: A TOOLBOX

THE FOOD CLIMATE RESEARCH NETWORK

The Food Climate Research Network at the Oxford Martin Programme on the Future of Food at Oxford University has a wide range of resources, tools and publications on the relationship between climate and the food system.

www.futureoffood.ox.ac.uk/project/food-climate-research-network

CLIMATE KELPIE: ROUNDING UP TOOLS FOR AUSTRALIAN FARMERS

Climate Kelpie connects Australian farmers and their advisors to tools and information about climate to assist decision-making about farm businesses.

www.climatekelpie.com.au

SOUTHERN LIVESTOCK ADAPTATION: TOOLS PRODUCED BY MEAT AND LIVESTOCK AUSTRALIA (MLA)

www.SLA2030.org.au

GREENHOUSE GAS ACCOUNTING TOOLS

www.greenhouse.unimelb.edu.au/tools

BUREAU OF METEOROLOGY CLIMATE RESILIENT WATER SOURCES

Online portal allows you to view, download and contribute to data on Australia's alternative water sources including recycled water and desalinated water. It includes a national overview, a site explorer, data download facility and the ability to upload datasets.

www.bom.gov.au/water/crews/introduction.shtml

CLIMATE PROJECTIONS FOR AUSTRALIA (CSIRO AND BUREAU OF METEOROLOGY)

www.climatechangeinaustralia.gov.au

This website provides access to a wide range of tools, datasets and guidance material. These tools include:

- › **Climate analogues tool** – Helps users find analogue towns with a current climate that matches the future climate of a selected site, e.g. the user can select Dubbo, and ask what it would look like under (a) a warming of X°C and rainfall change of Y% or (b) a plausible climate change scenario for a given year and emission scenario. There are over 100 sites to choose from.
- › **Thresholds calculator** – Users can explore projected changes in the annual-average number of days above or below selected thresholds for maximum and minimum temperatures at over 100 sites.
- › **Australian Climate Futures** – A tool that tabulates projected changes in two climate variables, selected from a list of up to 16 variables. It shows the clustering and spread of projections from up to 40 climate models, for selected years and emission scenarios. This information can guide the selection of a small subset of climate models for use in impact assessment. Users can select a 'worst case' scenario, a 'best case', or a 'maximum consensus' case that is relevant to their context.
- › **Map explorer** – This tool allow users to produce a map of climate projections for individual climate models across a range of variables, time periods and emissions scenarios. Users can zoom into regions of interest and download data in different formats.

Other tools on the site include an **Extremes Explorer** (to view projections for cold nights, hot days and extreme rainfall) and the **Marine Explorer** (for sea level rise and other oceanic variables).

Further information about climate science, climate models, projections and data can be found in the Climate Campus, designed to build knowledge in key climate science areas.

 RESOURCES FOR A CHANGING RURAL WORLD: A TOOLBOX. *CONTINUED***STATE-BASED CLIMATE CHANGE TOOLS****New South Wales**

NARcliM has produced an ensemble of robust regional climate projections for southeastern Australia that can be used by the NSW and ACT community to plan for the range of likely future changes in climate.

www.climatechange.environment.nsw.gov.au/Climate-projections-for-NSW/About-NARcliM

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Tasmania

Climate Futures for Tasmania project: This project is managed by the Antarctic Climate and Ecosystems Cooperative Research Centre provides the first fine-scale climate information for Tasmania by downscaling six global climate models with two emission scenarios (high emissions scenario – A2; and lower emissions scenario – B1) to generate climate information from 1961 to 2100.

www.dpac.tas.gov.au/divisions/climatechange/adapting/climate_futures

Western Australia

The Western Australian Local Government Association has developed a toolkit to help local governments adapt to climate change.

www.walgaclimatechange.com.au

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Victoria

The climate change adaptation navigator is a web-based tool to assist the local Victorian government with climate change adaptation and planning.

www.adaptation-navigator.org.au

Climatedogs: explanations using animations of the drivers that influence Victoria's climate

www.depi.vic.gov.au/agriculture-and-food/farm-management/weather-and-climate/understanding-weather-and-climate/the-climatedogs-the-four-drivers-that-influence-victoriaas-climate

References

- ABARES (Australian Bureau of Agricultural and Resource Economics and Sciences) (2010) Australian commodity statistics 2010. Accessed at http://www.agriculture.gov.au/abares/publications/display?url=http://143.188.17.20/anrdl/DAFFService/display.php?fid=pe_abares99001762.xml.
- ABARES (2011) Global food security: facts, issues and implications. *Science and Economic Insights* Issue 1. Accessed at http://data.daff.gov.au/data/warehouse/pe_abares99010538/SEI1_2011GlobalFoodSecurityReport.pdf.
- ABARES (2012a) Agricultural commodity statistics 2012. Accessed at http://www.agriculture.gov.au/abares/publications/display?url=http://143.188.17.20/anrdl/DAFFService/display.php?fid=pb_agcstd9abcc0022012_12a.xml.
- ABARES (2012b) Drought in Australia: context, policy and management. Accessed at http://www.daff.gov.au/SiteCollectionDocuments/abares/publications/clientreports/Drought_in_Australia_2012.pdf.
- ABARES (2014a) Agricultural commodities: March Quarter 2014. Accessed at http://www.agriculture.gov.au/abares/publications/display?url=http://143.188.17.20/anrdl/DAFFService/display.php?fid=pb_agcomd9abcc004201403_11a.xml.
- ABARES (2014b) Agricultural Commodity Statistics 2014. Accessed at http://data.daff.gov.au/data/warehouse/agcstd9abcc002/agcstd9abcc0022014/ACS_2014_1.0.0.pdf.
- ABARES (2014c) Australian fisheries and aquaculture statistics 2013. Accessed at http://data.daff.gov.au/data/warehouse/9aam/afstad9aamd003/2013/AustFishAquacStats_2013_v1.2.0.pdf.
- ABARES (2014d) Australian Crop Report: September 2014. Accessed at: http://data.daff.gov.au/data/warehouse/aucrpd9abcc003/aucrpd9abcc201409/AustCropRrt20140909_v1.0.0.pdf.
- ABARES (2015a) Agricultural commodities: June quarter, Canberra. Accessed at http://www.agriculture.gov.au/abares/publications/display?url=http://143.188.17.20/anrdl/DAFFService/display.php?fid=pb_agcomd9abcc20150616_11a.xml.
- ABARES (2015b) Agricultural commodities: March quarter, Canberra. Accessed at http://www.agriculture.gov.au/abares/publications/display?url=http://143.188.17.20/anrdl/DAFFService/display.php?fid=pb_agcomd9abcc20150303_11a.xml.
- ABARES (2015c) Profiles of agricultural, forestry and fisheries industries by regions of Australia April 2015. Accessed at http://www.agriculture.gov.au/abares/display?url=http://143.188.17.20/anrdl/DAFFService/display.php?fid=pb_myregr9ab__010201504_11a.xml.
- ABARES (2015d) About My Region - profiles of agricultural, forestry and fisheries industries by regions of Australia April 2015. Accessed at http://www.agriculture.gov.au/abares/display?url=http://143.188.17.20/anrdl/DAFFService/display.php?fid=pb_myregr9ab__010201504_11a.xml.
- ABC (2013) Gas leak! Carney M, Agius C, April 3, 2013. Accessed at <http://www.abc.net.au/4corners/stories/2013/04/01/3725150.htm>.
- ABC (2015a) Coal mine expansion on prime agricultural land set to go ahead. Peter McCutcheon. 1 May 2015. Accessed at <http://www.abc.net.au/7.30/content/2015/s4228060.htm>.
- ABC (2015b) Fracking banned for five years by Tasmanian Government. Stephen Smiley. 26 February 2015. Accessed at <http://www.abc.net.au/news/2015-02-26/fracking-banned-for-five-years-by-tasmanian-government/6265378>.
- ABS (Australian Bureau of Statistics) (2004) Yearbook Australia 2004 -Economic impact of drought in 2002-03. Accessed at <http://www.abs.gov.au/ausstats/abs@.nsf/0/81A2E2F13AA7994BCA256DEA00053932?opendocument>.
- ABS (2009) Principal agricultural commodities 2007-08 Preliminary Report. Accessed at [http://www.ausstats.abs.gov.au/Ausstats/subscriber.nsf/0/32DA97E8FED7E82BCA25750000F22C5/\\$File/71110_2007-08.pdf](http://www.ausstats.abs.gov.au/Ausstats/subscriber.nsf/0/32DA97E8FED7E82BCA25750000F22C5/$File/71110_2007-08.pdf).
- ABS (2010) Agricultural commodities 2008/2009, Catalogue No. 7121.0. Accessed at www.abs.gov.au/AUSSTATS/abs.
- ABS (2012a) Australian farming and farmers. Accessed at <http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/4102.0>Main+Features10Dec+2012>.
- ABS (2012b) 1301.0 - Year Book Australia, 2012. Accessed at <http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/by%20Subject/1301.0~2012~Main%20Features~Home%20page~1>.
- ABS (2012c) Gross value of irrigated agricultural production, 2010-11. Catalogue No. 4610.0.55.008. Accessed at www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/4610.0.55.0082010-11.
- ABS (2013) 3222.0 - Population Projections, Australia, 2012 (base) to 2101. Accessed at <http://www.abs.gov.au/ausstats/abs@.nsf/mf/3222.0>.
- ABS (2014a) Land management and farming in Australia, 2012-2013. Accessed at <http://www.abs.gov.au/ausstats/abs@.nsf/mf/4627.0>.
- ABS (2014b) Employed persons by Industry (ANZSIC group), State and Territory, Status in employment and Sex, August 1991 onwards, Labour Force, Australia, Detailed, Quarterly, Aug 2014, cat. no 6291.0.55.003. Accessed at <http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/6291.0.55.003May%202014?OpenDocument>.
- ABS (2015a) Australian national accounts: national income, expenditure and product, cat.no. 5206.0, Canberra. Accessed at <http://www.abs.gov.au/ausstats/abs@.nsf/mf/5206.0>.
- ABS (2015b) Agricultural commodities Australia 2013-14. Accessed at <http://www.abs.gov.au/ausstats/abs@.nsf/mf/7121.0>.

- ACIAR (Australian Centre for International Agricultural Research) (2014) Crop yields and global food security: Will yield increase continue to feed the world? Accessed at http://aci.gov.au/files/mn158_web_5_0.pdf.
- ACMF (Australian Chicken Meat Federation Inc) (2011) The Australian chicken meat industry in profile. Accessed at http://www.chicken.org.au/industryprofile/downloads/The_Australian_Chicken_Meat_Industry_An_Industry_in_Profile.pdf.
- Alexandratos N and Bruinsma J (2012) World agriculture towards 2030/2050: the 2012 revision. *ESA Working paper No. 12-03*. Rome, FAO.
- Alston JM, Beddow JM and Pardey PG (2009) Agricultural research, productivity, and food prices in the long run. *Science* 325: 1209–1210.
- Alston M and Whittenbury K (2011) Climate change and water policy in Australia's irrigation areas: a lost opportunity for a partnership model of governance. *Environmental Politics* 20: 899–917.
- ARENA (Australian Renewable Energy Agency) (2015) Bioenergy. Accessed at <http://arena.gov.au/about-renewable-energy/bioenergy/>.
- Askew LE and Shervall M (2012) Short-term emergency or recurring climatic extreme: a rural town perspective on drought policy and programs. *Australian Journal of Public Administration* 71: 290–302.
- ATSE (Australian Academy of Technological Sciences and Engineering) (2014) Food and fibre: Australia's opportunities. A report of a study by the Australian Academy of Technological Sciences and Engineering (ATSE). March 2014. Accessed at <http://www.atse.org.au/Documents/Publications/Reports/Agriculture/atse-food-and-fibre-full-report.pdf>.
- Australian Agribusiness Group (2011) Will climate change impact Australian agriculture? November 2011. Accessed at http://www.ausagrigroup.com.au/assets/files/111216%20Impact%20of%20Climate%20Change%20on%20Australian%20Agriculture_Final.pdf.
- Australian Government (2015) Drought package. May 2015. Accessed at http://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/pubs/rp/BudgetReview201415/Drought.
- Australian Pork (2015) Pork Facts. Accessed at <http://australianpork.com.au/facts-figures/faqsindustry-overview/>.
- Ausveg (2013) Value of Australian Vegetable Production. Accessed at <http://ausveg.com.au/media-release/value-of-australian-vegetable-industry-at-all-time-high>.
- Bardsley DK (2015) Limits to adaptation or a second modernity? Responses to climate change risk in the context of failing socio-ecosystems. *Environment, Development and Sustainability* 17: 41–55.
- Barlow S, Grace P, Stone R et al. (2011) National Climate Change Adaptation Research Plan for Primary Industries, National Climate Change Adaptation Research Facility, Gold Coast, 64pp.
- Barnett J and O'Neill S (2010) Maladaptation. *Global Environmental Change* 20: 211–213.
- BCG (Birchip Cropping Group) (2008) Critical breaking point? The effects of drought and other pressures on farming families. Final report of the twelve month study. Accessed at http://www.daff.gov.au/__data/assets/pdf_file/0008/842246/Birchip_Cropping_Group.pdf.
- Beer A, Tually S, Kroehn M, et al. (2013) Australia's country towns 2050: What will a climate adapted settlement pattern look like? National Climate Change Adaptation Research Facility, Gold Coast, 139 pp.
- Beerman M (2011) Linking corporate climate adaptation strategies with resilience thinking. *Journal of Cleaner Production* 19: 836–842.
- Blanch S (2008) Steps to a sustainable Northern Australia. *Ecological Management & Restoration* 9: 110–115.
- BoM (Bureau of Meteorology) (2013) Special Climate Statement 43 – Extreme heat in January 2013. Accessed at www.bom.gov.au/climate/current/statements/scs43e.pdf.
- BoM (2014) State of the climate. Accessed at <http://www.bom.gov.au/state-of-the-climate/>.
- BoM (2015) What is El Niño and what might it mean for Australia? Accessed at <http://www.bom.gov.au/climate/updates/articles/a008-el-nino-and-australia.shtml>.
- Bonada M, Sadras V, Moran M and Fuentes S (2013) Elevated temperature and water stress advance shrivelling, mesocarp cell death and sensory traits in Shiraz berries. *Australian Journal of Grape and Wine Research* 31: 1317–1331.
- Botterill LC (2013) Are policy entrepreneurs really decisive in achieving policy change? Drought policy in the USA and Australia. *Australian Journal of Politics and History* 59: 97–112.
- Botterill L (2014) Death of National Drought Policy takes us back to policy on the run. The Conversation 20/2/14. Accessed at <http://theconversation.com/death-of-national-drought-policy-takes-us-back-to-policy-on-the-run-23289>.
- Braganza B, Power S, Trewin B et al. (2011) Update on the state of the climate, long-term trends and associated causes. In Keenan TD and Cleugh HA Climate Science Update: a report to the 2011 Garnaut Review. BoM and CSIRO.
- BREE (Bureau of Resources and Energy Economics) (2012) Economic Analysis of End-use Energy Intensity in Australia. Accessed at <http://www.industry.gov.au/Office-of-the-Chief-Economist/Publications/Pages/Economic-analysis-of-end-use-energy-intensity-in-Australia.aspx>.

- Bryan BA, Miller E and Zhao G (2014) Influence of management and environment on Australian wheat: information for sustainable intensification and closing yield gaps. *Environmental Research Letters* 9: 044005.
- BP (British Petroleum) (2013) Statistical Review of World Energy June 2013, BP. Accessed at http://www.bp.com/content/dam/bp/pdf/statistical-review/statistical_review_of_world_energy_2013.pdf.
- Butler CD (2009) Food security in the Asia-Pacific: climate change, phosphorus, ozone and other environmental challenges. *Asia Pacific Journal of Clinical Nutrition* 18: 590-597.
- BZE (Beyond Zero Emissions) (2014) Zero Carbon Australia Land Use: Agriculture and Forestry Discussion Paper. Beyond Zero Emissions Melbourne Sustainable Society Institute, The University of Melbourne pp 184.
- Cai W and Cowan T (2008) Dynamics of late autumn rainfall reduction over southeastern Australia. *Geophysical Research Letters* 35: L09708.
- Cai W, Wang G, Santoso A et al. (2015) Increasing frequency of extreme El Niño events due to greenhouse warming. *Nature Climate Change* 5: 132-137.
- Campbell A (2009) Paddock to plate: policy propositions for sustaining food and farming systems. Report for the Australian Conservation Foundation. 48pp.
- Campbell A, Blakers A and Blanch S (2013) The north's future is electrifying: powering Asia with renewables. *The Conversation*, 21 August 2013. Accessed at <https://theconversation.com/the-norths-future-is-electrifying-powering-asia-with-renewables-17286>.
- Campbell A and Turnour J (2013) We need a smarter debate on developing northern Australia. *The Conversation*, 13 August 2013. Accessed at <https://theconversation.com/we-need-a-smarter-debate-on-developing-northern-australia-16846>.
- Canegrowers (2015) Accessed at <http://www.canegrowers.com.au/>.
- Carberry PS, Bruce SE, Walcott JJ and Keating BA (2011) Innovation and production in dryland agriculture: a return-risk analysis for Australia. *Journal of Agricultural Science* 149: 77-89.
- Carroll N, Fritjers P and Shields MA (2007) Quantifying the costs of drought: new evidence from life satisfaction data. *Journal of Population Economics* 20:445-461.
- Che N, Grafton Q, Feldman D and Pham T (2011) Energy productivity analysis of the Australian grain industry. *Resources and Energy Quarterly—December quarter*, Bureau of Resources and Energy Economics, Canberra. Accessed at <http://www.industry.gov.au/industry/Office-of-the-Chief-Economist/Publications/Documents/req/resources-and-energy-quart-dec-2011.pdf>.
- Cheung WWL, Lam VWY, Sarmiento JL. et al. (2010) Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. *Global Change Biology* 16: 24-35.
- Chum H, Faaij A, Moreira J, et al. (2011) Bioenergy. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [Edenhofer O, Pichs-Madruga R, Sokona Y, et al. (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Clarke H, Lucas C, Smith P (2013) Changes in Australian fire weather between 1973 and 2010. *International Journal of Climatology* 33: 931-944.
- Clean Energy Council (2015) Bioenergy. Accessed at <http://www.cleanenergycouncil.org.au/technologies/bioenergy.html>.
- Cline W (2007) Global Warming and Agriculture: Impact Estimates by Country, Center for Global Development and Peterson Institute for International Economics, Washington.
- Cocklin C and Dibden J (2009) Systems in peril: climate change, agriculture and biodiversity in Australia. *IOP Conference Series: Earth and Environmental Science* 8: 012013.
- Collet J (2014) Climate change and Australian food security. Future Directions International. Strategic Analysis Paper. Accessed at http://www.futuredirections.org.au/files/sap/Climate_Change_and_Australian_Food_Security.pdf.
- CoA (Commonwealth of Australia) (2014) Agricultural Competitiveness Green Paper, Canberra. Accessed at <http://agwhitepaper.agriculture.gov.au/supporting-information/key-documents>.
- CoA (2015) Agricultural Competitiveness White Paper, Canberra. Accessed at <http://agwhitepaper.agriculture.gov.au/>.
- Connell D and Grafton Q (eds.) (2011) Basin futures: water reform in the Murray- Darling Basin. The Australian National University (ANU) E-Press, Canberra, ACT, Australia, 477 pp.
- Crimp SJ, Flood NR, Carter JO (2002) Evaluation of the Potential Impacts of Climate Change on Native Pasture Production: Implications for livestock carrying capacity. Report for the Australian Greenhouse Office.
- Crimp S, Howden M, Stokes C et al (2014) Climate change challenges for low input cropping and grazing systems – Australia. pp. 31-68 In Climate change impact and adaptation in agricultural systems. (Führer J, Gregory P eds.) CABI.
- Crimp SJ, Stokes CJ, Howden SM et al. (2010) Managing Murray–Darling Basin livestock systems in a variable and changing climate: challenges and opportunities *The Rangeland Journal* 32: 293–304.
- CSIRO (Commonwealth Scientific and Industrial Research Organisation) (2006) Climate change in the Murrumbidgee catchment. Report by CSIRO to the NSW Government. Accessed at http://archive.ils.nsw.gov.au/_data/assets/pdf_file/0007/495268/archive-climate-change-in-the-murrumbidgee-catchment_detailed.pdf.
- CSIRO (2009) Northern Australia Land and Water Science Review 2009. Accessed at http://www.regional.gov.au/regional/ona/nalwt_files/337388_NLAW_Review_2009.pdf.

- CSIRO (2012a) What is Coal Seam Gas? Factsheet. Accessed at <http://www.csiro.au/news/coal-seam-gas#FactSheets>.
- CSIRO (2012b) Climate and water availability in south-eastern Australia – A synthesis of findings from Phase 2 of the South Eastern Australian Climate Initiative (SEACI). CSIRO, September.
- CSIRO and BoM (2015) Climate change in Australia: projections for Australia's NRM regions. Australia Government. Accessed at <http://www.climatechangeinaustralia.gov.au/en/publications-library/technical-report/>.
- Cullen BR, Johnson IR, Eckard RJ et al. (2009) Climate change effects on pasture systems in south-eastern Australia. *Crop & Pasture Science* 60: 933–942.
- DAFF (2011) Issues paper to inform development of a national food plan. Canberra: DAFF. Accessed at http://www.agriculture.gov.au/SiteCollectionDocuments/ag-food/food/national-food-plan/nfp_-_final.pdf.
- DAFF (Department of Agriculture, Forestry and Fisheries) (2012) Australia's Agriculture, Fisheries and Forestry at a Glance 2012. Accessed at <http://www.agriculture.gov.au/about/publications/glance2012>.
- Dairy Australia (2015) Accessed at <http://www.dairyaustralia.com.au/Markets-and-statistics/Production-and-sales/Milk.aspx>.
- Daly J, Anderson K, Ankeny R et al. (2015) Australia's agricultural future. Report for the Australian Council of Learned Academies. Accessed at <http://www.acola.org.au/index.php/projects/securing-australia-s-future/7-australia-s-agricultural-future>.
- Davidson B (1972) The Northern Myth: Limits to Agricultural and Pastoral Development in Tropical Australia. 3rd ed. (first published 1965). Melbourne University Press: Melbourne.
- Department of Environment (2015) Quarterly Update of Australia's National Greenhouse Gas Inventory: September 2014. Accessed at <http://www.environment.gov.au/climate-change/greenhouse-gas-measurement/publications/quarterly-update-australias-national-greenhouse-gas-inventory-sept-2014>.
- Deuter P (2008) Defining the impacts of climate change on horticulture in Australia. In Garnaut R, *Garnaut Climate Change Review* Accessed at <http://www.garnautreview.org.au/2008-review.html>.
- DFAT (Department of Foreign Affairs and Trade) (2014) Australia's agricultural exports (2012–2013), DFAT. Accessed at <http://www.dfat.gov.au/trade/topics/pages/agriculture.aspx#aee>.
- D'Odorico P, Carr JA, Laio F et al. (2014) Feeding humanity through global food trade. *Earth's Future* 2: 458–469. Accessed at <http://onlinelibrary.wiley.com/doi/10.1002/2014EF000250/abstract>.
- Dowd AM, Marshall N, Fleming A et al. (2014) The role of networks in transforming Australian agriculture. *Nature Climate Change* 4: 558–563.
- Drought Policy Review Expert Social Panel (2008) It's about people: changing perspective. A report to Government by an expert social panel on dryness, Report to the Minister for Agriculture, Fisheries and Forestry, Canberra, Accessed at http://www.agriculture.gov.au/SiteCollectionDocuments/ag-food/drought/publications/dryness_report.pdf.
- Dunlop M, Foran B, Poldy F and Turner G (2002) Decision Points for Land and Water Futures. Resource Futures Program Working Document 2002/08, CSIRO Sustainable Ecosystems, Canberra, Australia. Final Report to Land & Water Australia.
- Duus S (2013) Coal contestations: Learning from a long, broad view. *Rural Society* 22: 96–110.
- Edwards F, Dixon J, Hall G et al. (2011) Climate change adaptation at the intersection of food and health. *Asia-Pacific Journal of Public Health* Supplement to 23(2) 91S–104S.
- EIU (Economist Intelligence Unit) (2014) Global food security index 2014: An annual measure of the state of global food security. Accessed at <http://foodsecurityindex.eiu.com>.
- Ericksen P (2007) Conceptualizing food systems for global environmental change research. *Global Environmental Change* 18: 234–245.
- FAO (Food and Agriculture Organization) (1996) Rome Declaration and World Food Summit Plan of Action. Food and Agricultural Organization of the United Nations (FAO) World Food Summit, Rome, Italy, 13–17 November 1996, FAO, Rome, Italy. Accessed at www.fao.org/docrep/003/w3613e/w3613e00.HTM.
- FAO (2008) Soaring food prices: facts, perspectives, impacts and actions required. In High Level Conference on World Food Security: the challenges of climate change and bioenergy. April 2008, HLC/08/ INF/1. (FAO: Rome). Accessed at http://www.fao.org/fileadmin/user_upload/foodclimate/HLCdocs/HLC08-inf-1-E.pdf.
- FAO (2009) Global agriculture towards 2050. In High Level Expert Forum: How to feed the world in 2050. Rome 12–13 October 2009. Accessed at http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf.
- FAO (2015) Climate change and food systems: global assessments and implications for food security and trade. Food Agriculture Organization of the United Nations (FAO). Accessed at <http://www.fao.org/documents/card/en/c/2d309fca-89be-481f-859e-72b27a3ea5dc/>.
- FAOSTAT (2013) Crop production Statistics. Food and Agriculture Organization: Rome. Accessed at www.faostat.fao.org.
- Farine DR, O'Connell DA, Raison RJ et al. (2012) An assessment of biomass for bioelectricity and biofuel, and for greenhouse gas emission reduction in Australia. *Global Change Biology: Bioenergy* 4: 148–175.
- Fernando N, Panozzo J, Tausz M et al. (2015) Rising CO₂ concentration altered wheat grain proteome and flour rheological characteristics. *Food Chemistry* 170: 448–454.

- Finlay KJ, Yen AL, Aurambout JP et al. (2009) Consequences for Australian biodiversity with establishment of the asiatic citrus psyllid, *Diaphorina citri*, under present and future climates. *Biodiversity* 10: 25-32.
- Fleming A, Hobday AJ, Farmery A et al. (2014) Climate change risks and adaptation options across Australian seafood supply chains – A preliminary assessment. *Climate Risk Management* 1: 39-50.
- Foley W, Ward P, Carter P et al. (2010) An ecological analysis of factors associated with food insecurity in South Australia, 2007. *Public Health Nutrition* 13: 215-21.
- Friel S, Berry H, Dinh H et al. (2014) The impact of drought on the association between food security and mental health in a nationally representative Australian sample. *BMC Public Health* 14: 1102.
- Fuglie K, Rada N (2014) International Agricultural Productivity. United States Department of Agriculture. Accessed at <http://www.ers.usda.gov/data-products/international-agricultural-productivity.aspx>.
- Fulton EA (2011) Interesting times: winners, losers, and system shifts under climate change around Australia. *ICES Journal of Marine Science* 68: 1329-1342.
- Gallant AJE and Karoly D (2010). A combined climate extremes index for the Australian region. *American Meteorological Society* 23: 6153-6165.
- Garnaut R (2008) The Garnaut climate change review. Cambridge University Press: Melbourne. Accessed at: www.garnautreview.org.au.
- Garnaut R (2010) Climate change and the Australian agricultural and resource industries. *The Australian Journal of Agricultural and Resource Economics* 54: 9-25.
- Garnaut R (2011a) Transforming rural land use. Update Paper 4. Garnaut Climate Change Review Update 2011, Canberra, ACT.
- Garnaut R (2011b) Transforming rural land use. Update 5 of the 2008 Garnaut Report, Canberra, ACT.
- Garnett T (2014) What is a sustainable healthy diet? Food Climate Research network. Accessed at http://www.fcrn.org.uk/sites/default/files/fcrn_what_is_a_sustainable_healthy_diet_final.pdf.
- Geoscience Australia (2015) Bioenergy. Accessed at <http://www.ga.gov.au/scientific-topics/energy/resources/other-renewable-energy-resources/bioenergy#heading-2>.
- Gerland P, Raftery AE, Sevcikova H et al. (2014) World population stabilization unlikely this century. *Science* 346: 234-237.
- Ghahramani A and Moore AD (2015) Systemic adaptations to climate change in southern Australian grasslands and livestock: Production, profitability, methane emission and ecosystem function. *Agricultural Systems* 133:158-166.
- Global Food Security Programme (2015) Extreme weather and resilience of the global food system. Final Project Report from the UK-US Taskforce on Extreme Weather and Global Food System Resilience, The Global Food Security programme, UK. Accessed at <http://www.ilsa.org/ResearchFoundation/Publications/extreme-weather-resilience-of-global-food-system.pdf>.
- Godfray HCJ, Beddington JR, Crute IR et al. (2010) Food Security: The challenge of feeding 9 billion people. *Science* 327: 812.
- Godfray HCJ, Garnett T (2014) Food security and sustainable intensification *Philosophical Transactions of the Royal Society B* 5 369: no. 1639 20120273.
- Goss K (2014) Sustainable mallee jet fuel: sustainability and life cycle assessment for supply to Perth airport, Western Australia. Future Farm Industries CRC for Airbus. Accessed at <http://www.futurefarmonline.com.au/research/new-woody-crops/sustainable-jet-fuel.htm>.
- Gregory PJ, Ingram JSI and Brklacich M (2005) Climate change and food security. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 360: 2139-2148.
- Growcom (2011) Food security issues for the Australian horticultural industry. A report prepared for HAL project AH09009. Accessed at http://www.growcom.com.au/_uploads/171320food_security_report.pdf.
- Gunasekera D, Kim Y, Tulloh C and Ford M (2007) Climate Change: impacts on Australian agriculture. *Australian Commodities* 14: 657-676.
- HAL (Horticulture Australia Limited) (2009) Climate change and the Australian horticultural industry. HAL and Climate Change Research Strategy for Primary Industries (CCRSPI). August 2009. Accessed at http://ausveg.com.au/enviroveg/CCRSPI_PDF.pdf.
- Hanna EG, Bell E, King D and Woodruff R (2011) Climate change and Australian agriculture: a review of the threats facing rural communities and the healthy policy landscape. *Asia Pacific Journal of Public Health* 10S5-18.
- Hanslow KD, Gunasekera BR, Cullen B, and Newth D (2013) Economic impacts of climate change on the Australian dairy sector. *Australian Journal of Agricultural and Resource Economics* 58: 60-77.
- Harle KJ, Howden SM, Hunt and Dunlop M (2007) The potential impact of climate change on the Australian wool industry by 2030. *Agricultural Systems* 93: 61-89.
- Haug A, Brand-Miller J, Christophersen OA et al. (2007) A food "lifeboat": food and nutrition considerations in the event of a pandemic or other catastrophe. *Medical Journal of Australia* 187: 674-676.
- Hayman P, Rickards L, Eckard R, and Lemerle D (2012) Climate change through the farming systems lens: challenges and opportunities for farming in Australia. *Crop and Pasture Science* 63: 203-214.
- Heimann M and Reichstein M (2008) Terrestrial ecosystem carbon dynamics and climate feedbacks. *Nature* 451: 289-292.

- Hennessey K, Fawcett R, Kirono D, et al. (2008) An assessment of the impact of climate change on the nature and frequency of exceptional climatic events. CSIRO and BoM. Accessed at <http://www.oisaweb.es/documents/10148/30643/Impact+of+climate+change+on+the+nature+of+excepcional+climatic+events.pdf>.
- Henry B, Charmley E, Eckard R, Gaughan JB, and Hegarty R (2012) Livestock production in a changing climate: adaptation and mitigation research in Australia. *Crop and Pasture Science* 63: 191–202.
- Herr A and Dunlop M (2011) Bioenergy in Australia: an improved approach for estimating spatial availability of biomass resources in the agricultural production zones. *Biomass and Bioenergy* 35: 2298–2305.
- Hertzler G, Sanderson T, Capon T et al (2013) Will primary producers continue to adjust practices and technologies, change production systems or transform their industry? An application of real options, National Climate Change Adaptation Research Facility, Gold Coast, 93 pp.
- Heyhoe E, Kim Y, Kokic P et al. (2007) Adapting to climate change. *Australian Commodities* 14: 167–78.
- Hobday AJ and Poloczanska ES (2011) Marine fisheries and aquaculture. In *Adapting agriculture to Climate Change* (Stokes C and Howden M eds) pp 205–228. CSIRO Publishing, Australia.
- Hogan A, Berry HL, Ng SP and Bode A (2011) Decisions made by farmers that relate to climate. Rural Industries Research and Development Corporation (RIRDC) Publication No. 10/208. Accessed at file:///Users/lesley/Downloads/10-208.pdf.
- Homer-Dixon T, Walker B, Biggs R et al. (2015) Synchronous failure: the emerging causal architecture of global crisis. *Ecology and Society* 20: 6.
- Houston P (2005) Re-valuing the fringe: some findings on the value of agricultural production in Australia's peri-urban regions. *Geographical Research* 43: 209–223.
- Howden SM (2002) Potential global change impacts on Australia's wheat cropping systems. In: *Effects of climate change and variability on agricultural production systems*. (Eds OC Doering, JC Randolph, J Southworth, RA Pfeifer) pp. 219–247. (Springer: The Netherlands).
- Howden SM, Reyenga PJ and Meinke H (1999) *Global Change Impacts on Australian Wheat Cropping: CSIRO Wildlife & Ecology Working Paper 99/04*, report to the Australian Greenhouse Office, Canberra.
- Howden SM, Schroeter S and Crimp S (2014) Agriculture in an even more sunburnt country. In *Four Degrees of Global Warming: Australia in a hot world*. (Ed P Christoff). Earthscan, Routledge, Oxford and New York. Pages 101–120.
- Howden SM, Crimp S and Nelson RN (2010) Australian agriculture in a climate of change. In 'Managing Climate Change: Papers from GREENHOUSE 2009 Conference'. (Eds I Jubb, P Holper, W Cai) pp. 101–112. (CSIRO Publishing: Melbourne).
- IEA (International Energy Agency) (2010) Energy technology perspectives. Scenarios & strategies to 2050. Executive summary. Paris: OECD/IEA; p. 16.
- IME (Institute of Mechanical Engineers) (2013) Global food: waste not, want not. Accessed at http://www.imeche.org/docs/default-source/reports/Global_Food_Report.pdf?sfvrsn=0.
- IPCC (Intergovernmental Panel on Climate Change) (2013) Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp. Accessed at <http://www.ipcc.ch/report/ar5/wg1/>.
- IPCC (2014) Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field C, Barros V, Mach K, Mastrandrea M (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp 485–533.
- IPSOS (2015) Climate change report 2015. Accessed at http://ipsos.com.au/Ipsos_docs/CC2015/Ipsos_Climate_Change_Report_2015.pdf.
- IRRI (The International Rice Research Institute) (2014) Rice and Climate Change. Accessed at <http://irri.org/news/hot-topics/rice-and-climate-change>.
- Keating BA and Carberry PS (2010) Emerging opportunities and challenges for Australian broadacre agriculture. *Crop & Pasture Science* 61: 269–278.
- Kharas H (2010) The Emerging Middle Class in Developing Countries, Working Paper No. 285, OECD Development Centre, Organisation for Economic Co-operation and Development, Paris.
- Kiem AS and Austin EK (2012) Limits and barriers to climate change adaptation for small inland communities affected by drought, National Climate Change Adaptation Research Facility, Gold Coast, 36 pp.
- Kiem AS, Austin EK (2013a) Drought and the future of rural communities: Opportunities and challenges for climate change adaptation in regional Victoria, Australia. *Global Environmental Change* 23: 1307–1316.
- Kiem AS and Austin EK (2013b) Disconnect between science and end-users as a barrier to climate change adaptation. *Climate Research* 58: 29–41.
- Kingwell, R, Anderton, L, Islam, N, et al. (2013) Broadacre farmers adapting to a changing climate, National Climate Change Adaptation Research Facility, Gold Coast, 171 pp.
- Koehn JD, Hobday AJ, Pratchett MS, Gillanders BM (2011) Climate change and Australian marine and freshwater environments, fishes and fisheries: synthesis and options for adaptation. *Marine and Freshwater Research* 62: 1148–1164.
- Kraxner F, Nordström EM, Havlik P et al. (2013). Global bioenergy scenarios—future forest development, land-use implications, and trade-offs. *Biomass and Bioenergy* 57: 86–96.
- Lal R (2004) Soil carbon sequestration to mitigate climate change. *Geoderma* 123: 1–22.

- Lam SK, Chen D, Mosier AR and Roush R (2013) The potential for carbon sequestration in Australian agricultural soils is technically and economically limited. *Scientific Reports* 3 : 2179 DOI: 10.1038/srep02179.
- Last PR, White WT, Gledhill DC et al. (2011) Long-term shifts in abundance and distribution of a temperate fish fauna: a response to climate change and fishing practices. *Global Ecology and Biogeography* 20: 58–72.
- Lawrence G, Richards C and Lyons K (2013) Food security in Australia in an era of neoliberalism, productivism and climate change. *Journal of Rural Studies* 29: 30–39.
- Lough JM and Hobday AJ (2011). Observed climate change in Australian marine and freshwater environments. *Marine and Freshwater Research* 62: 984–999.
- Luo Q, Bellotti W, Williams M and Wang E (2009) Adaptation to climate change of wheat growing in South Australia: analysis of management and breeding strategies. *Agriculture, Ecosystems & Environment* 129: 261–267.
- Luo Q, Bange M and Clancy L (2014) Cotton crop phenology in a new temperature regime. *Ecological Modelling* 285: 22–29.
- Marangos J and Williams C (2005) The effect of drought on uncertainty and agricultural investment in Australia. *Journal of Post Keynesian Economics* 27: 575–594.
- Marshall NA, Dowd A-M, Fleming A et al. (2014) Transformational capacity in Australian peanut farmers for better climate adaptation Agronomy and Sustainable Development 34:583–591.
- McCarthy BL (2014) Sustainable food systems in Northern Queensland. *Journal of Economic and Social Policy* 16: Article 4.
- McGovern M (2015) Free trade agreements fail to boost Australian agriculture and food manufacturing. The Conversation 17th September, 2015. Accessed at https://theconversation.com/free-trade-agreements-fail-to-boost-australian-agriculture-and-food-manufacturing-47576?utm_medium=email&utm_campaign=Latest+from+The+Conversation+for+September+17+2015+.
- McKenzie F and Williams J (2015) Sustainable food production: constraints, challenges and choices by 2050. *Food Security* DOI 10.1007/s12571-015-0441-1 published online 12th March 2015.
- McKeon GM, Stone GS, Syktus JI et al. (2009) Climate change impacts on northern Australian rangeland livestock carrying capacity: a review of issues. *The Rangeland Journal* 31: 1–29.
- MDBA (Murray Darling Basin Authority) (2011) Proposed Basin Plan, Water Act 2007. MDBA Publication No. 192/11, Draft plan prepared for the purpose of consultation for the Commonwealth of Australia by the Murray-Darling Basin Authority (MDBA), MDBA, Canberra 210 pp.
- MDBA (2012a) The proposed groundwater baseline and sustainable diversion limits: Methods report. MDBA publication no: 16/12, Murray-Darling Basin Authority, Canberra.
- MDBA (2012b) Proposed Basin Plan – A Revised Draft. MDBA Publication No. 57/12, Prepared by Murray-Darling Basin Authority (MDBA), as required by subsection 43A(2) of the Water Act 2007, MDBA, Canberra 215 pp.
- MDBA (2013) (Murray Darling Basin Authority) Irrigated Agriculture in the Basin - Facts and Figures Accessed at <http://www.mdba.gov.au/about-basin/irrigated-agriculture-in-the-basin>.
- MDBA (2014a) The Murray Darling Basin Overview brochure. Accessed at <http://www.mdba.gov.au/sites/default/files/pubs/MDBA-Overview-Brochure.pdf>.
- MDBA (2014b) Annual Report 2013-14. Accessed at <http://www.mdba.gov.au/media-pubs/publications/annual-report-2013-14>.
- MDBC (2008) Murray system drought update, Issue 16. Accessed at http://www.mdba.gov.au/sites/default/files/archived/mdbc-drought-updates/Drought_Update_Issue_16_-_November_2008.pdf.
- Michael DT and Crossley RL (2012) Food security, risk management and climate change, National Climate Change Adaptation Research Facility, Gold Coast, 152 pp.
- Millar J and Roots J (2012) Changes in Australian agriculture and land use: implications for future food security. *International Journal of Agricultural Sustainability* 10: 25–39.
- Miller, E, K van Megen and L Buys (2012) Diversification for sustainable development in rural and regional Australia: How local community leaders conceptualise the impacts and opportunities from agriculture, tourism and mining. *Rural Society* 22: 2–16.
- MLA (Meat and Livestock Association) (2013) Australian Beef Industry. Accessed at www.mla.com.au/cattle-sheep-and-goat-industries/Industry-overview/Cattle.
- Moore AD and Ghahramani A (2014) Climate change and broadacre livestock production across southern Australia. 3. Adaptation options via livestock genetic improvement. *Animal Production Science* 54: 111–124.
- Mosley LM, Palmer D, Leyden E et al. (2014) Acidification of floodplains due to river level decline during drought. *Journal of Contaminant Hydrology* 161: 10–23.
- Mu J and Khan S (2009) The effect of climate change on the water and food nexus in China. *Food Security* 1:413–430.
- Mullen J, Tester M, Goddard M et al. (2012) Assessing the opportunities for achieving future productivity growth in Australian agriculture. Australian Farm Institute pp1–82.
- Mullen J and Keogh M (2013) The future productivity and competitiveness challenge for Australian agriculture. Contributed paper prepared for presentation at the 57th AARES Annual Conference, Sydney, New South Wales, 5th–8th February, 2013.
- Myers SS, Zanolletti A, Kloog I et al. (2014) Increasing CO₂ threatens human nutrition. *Nature* 510: 139–142.

- NAIF (Northern Australia Irrigation Futures) (2007) National Program for Sustainable Irrigation, CSIRO Land and Water. Northern Australia Land and Water Taskforce (2009) Sustainable development of northern Australia. Accessed at <http://www.regional.gov.au/regional/ona/files/NLAW.pdf>.
- NAILSMA (North Australian Indigenous Land and Sea Management Alliance) (2012) WALFA – West Arnhem Land Fire Abatement project. Accessed at <http://www.nailsma.org.au/walfa-west-arnhem-land-fire-abatement-project>.
- National Irrigators Council (2009) Irrigation Facts. Accessed at <http://www.irrigators.org.au/?page=facts>.
- Natural Resources Defense Council (2012) Wasted: how America is losing up to 40 percent of its food from farm to fork to landfill. Accessed at <http://www.nrdc.org/food/files/wasted-food-IP.pdf>.
- Nelson R, Kokic P, Crimp S et al. (2010a) The vulnerability of Australian rural communities to climate variability and change: Part I—Conceptualising and measuring vulnerability. *Environmental Science and Policy* 13: 8–17.
- Nelson R, Kokic P, Crimp S et al. (2010b) The vulnerability of Australian rural communities to climate variability and change: Part II - integrating impacts with adaptive capacity. *Environmental Science and Policy* 13: 18–27.
- Nicholls N (2004) The changing nature of Australian droughts. *Climatic Change* 63: 323–336.
- Nidumolu U, Crimp S, Gobbett D et al. (2014) Spatio-temporal modelling of heat stress and climate change implications for the Murray dairy region, Australia. *International Journal of Biometeorology* 58:1095–1108.
- Nidumolu UB, Hayman PT, Howden SM and Alexander BM (2012) Re-evaluating the margin of the South Australian grain belt in a changing climate. *Climate Research* 51: 249–260.
- Nielsen D and Brock M (2009) Modified water regime and salinity as a consequence of climate change: prospects for wetlands of Southern Australia. *Climatic Change* 95: 523–533.
- NSW Department of Health (2005) New South Wales Population Health Survey 2005: Food insecurity in the last 12 months by socioeconomic disadvantage, persons aged 16 years and over. Sydney: Centre for Epidemiology and Research, NSW Department of Health.
- Nyamdorj NB, Zerihun A, Mpelasoka F et al. (2014a) Responses of grape berry anthocyanin and titratable acidity to the projected climate change across the Western Australian wine regions. *International Journal of Biometeorology* 58:1279–1293.
- Nyamdorj NB, Zerihun A, Gibberd M and Bates B (2014b) Berry composition and climate: responses and empirical models. *International Journal of Biometeorology* 58:1207–1223.
- OECD (Organisation for Economic Cooperation and Development) (2015) Producer and Consumer Support Estimates database. Accessed at <http://www.oecd.org/tad/agricultural-policies/producerandconsumersupportestimatesdatabase.htm#tables>.
- Office of the Chief Scientist (2012) Health of Australian Science. Australian Government, Canberra. Accessed at http://www.chiefscientist.gov.au/wp-content/uploads/OCS_Health_of_Australian_Science_LOWRES1.pdf.
- Park SN, Marshall E, Jakku A et al. (2012) Informing adaptation responses to climate change through theories of transformation. *Global Environmental Change* 22: 115–126.
- Pearce SC, Gabler NK, Ross JW et al. (2013) The effects of heat stress and plane of nutrition on metabolism in growing pigs. *Journal of Animal science* 91: 2108–2118.
- Perkins S and Alexander L (2013) On the measurement of heat waves. *Journal of Climate* 26:4500–4517.
- PMSEIC (Prime Minister's Science, Engineering and Innovation Council) (2010) *Australia and Food Security in a Changing World*, Canberra.
- Porter JR, Xie L, Challinor A, et al. (2014) Food Security and Food Production Systems. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field C, Barros V, Mach K, Mastrandrea M (eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp 485–533.
- Potgieter A, Meinke H, Doherty A, et al. (2013) Spatial impact of projected changes in rainfall and temperature on wheat yields in Australia. *Climatic Change* 117:163–179.
- Potter N, Chiew FHS and Frost AJ (2010) An assessment of the severity of recent reductions in rainfall and runoff in the Murray–Darling Basin. *Journal of Hydrology* 1: 52–64.
- Pretty JN, Ball AS, Lang T and Morison JI (2005) Farm costs and food miles: An assessment of the full cost of the UK weekly food basket. *Food policy* 30: 1–19.
- Productivity Commission (2009) Government Drought Support Inquiry Report: key points. Accessed at <http://www.pc.gov.au/projects/inquiry/drought/report/>.
- PWC (PricewaterhouseCoopers) (2011a) The Australian Dairy Industry: the basics. Accessed at <http://www.pwc.com.au/industry/agribusiness/assets/Australian-Dairy-Industry-Nov11.pdf>.
- PWC (2011b) The Australian Grain Industry: the basics. Accessed at <http://www.pwc.com.au/industry/agribusiness/assets/Australian-Grains-Industry-Nov11.pdf>.
- Quiggin J (2007) Drought, climate change and food prices in Australia. Australian Conservation Foundation. Accessed at https://www.acfonline.org.au/sites/default/files/resources/Climate_change_and_food_prices_in_Australia.pdf.
- Quiggin J, Adamson D, Chambers S and Schrobback P (2010) Climate change, uncertainty, and adaptation: the case of irrigated agriculture in the Murray–Darling Basin in Australia. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie* 58: 531–554.
- Qureshi EM, Hanjra MA and Ward J (2013a) Impact of water scarcity in Australia on global food security in an era of climate change. *Food Policy* 38: 136–145.

- Qureshi EM, Whitten SM, Mohammed M, Marvanek S and Elmahdi A (2013b) A biophysical and economic model of agriculture and water in the Murray-Darling Basin, Australia. *Environmental Modelling & Software* 41: 98-106.
- Rabobank (2015) Media release: Unlocking productivity growth in the Australian and New Zealand food & agribusiness sector. Accessed at <http://www.rabobank.com.au/News-and-Events/Media-Releases/2015-News-Archive/Pages/media-release-20150630.aspx>.
- Raymond CM and Spoehr J (2013) The acceptability of climate change in agricultural communities: Comparing responses across variability and change. *Journal of Environmental Management* 115: 69-77.
- RBA (2006) (Reserve Bank of Australia) Statement on Monetary Policy – November 2006, Canberra, ACT, Australia, 59 pp.
- RGA (Rice Growers Association) (2015) The Australian Rice Industry. Accessed at <http://www.rga.org.au/the-rice-industry.aspx>.
- Reisinger, A., R.L. Kitching, F. Chiew, et al. (2014) Australasia. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V.R., C.B. Field, D.J. Dokken, M.D. et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1371-1438.
- Rickards L and Howden SM (2012) Transformational adaptation: agriculture and climate change. *Crop and Pasture Science* 63: 240-250.
- Rodale Institute (2015) Regenerative organic agriculture and climate change. Accessed at <http://rodaleinstitute.org/assets/WhitePaper.pdf>.
- Sapere Research Group (2012) Resilience in the Australian food supply chain. Report for the Australian Government Department of Agriculture, Fisheries and Forestry. Accessed at [QoN_DAFF_Att_resilience-food-supply.pdf](http://www.qon.daff.gov.au/Att_resilience-food-supply.pdf).
- Sarewitz D (2010) Tomorrow never knows. *Nature* 463: 24.
- SEWPaC (Department of Sustainability, Environment, Water, Population and Communities) (2010) National Waste Report 2010, Department of Sustainability, Environment, Water, Population and Communities, Canberra. Accessed at <http://www.scew.gov.au/resource/ephc-archive-waste-management#nwp>.
- SEWPaC (2013) National Water Initiative. Accessed at www.environment.gov.au/water/australia/nwi/index.html.
- Shervall M and Askew LE (2012) Experiencing 'drought and more': local responses from rural Victoria, Australia. *Population and Environment* 33:347-364.
- Sims R, Taylor M, Saddler J, Mabey W (2008) From 1st- to 2nd-generation biofuel technologies: an overview of current understanding and RD&D activities. OECD/IEA. Accessed at https://www.iea.org/publications/freepublications/publication/2nd_Biofuel_Gen.pdf.
- Singh-Peterson L, Shoebridge A, Lawrence G (2013) Food pricing, extreme weather and the rural/urban divide: A case study of Northern NSW, Australia. *Journal of Food Security* 1: 42-48.
- Singh-Peterson L and Lawrence G (2014) Insights into community vulnerability and resilience following natural disasters: perspectives with food retailers in Northern NSW, Australia. *The International Journal of Justice and Sustainability* DOI:10.1080/13549839.2013.873396.
- Slade C and Wardell-Johnson A (2013) Creating a climate for food security: Governance and policy in Australia, National Climate Change Adaptation Research Facility, Gold Coast, 34 pp.
- Smith P, Bustamante M, Ahammad H, et al. (2014) Agriculture, Forestry and Other Land Use (AFOLU). In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer O, Pichs-Madruga R, Sokona Y, et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- SoE (2011) (State of the Environment 2011) Independent Report to the Australian Government Minister for Sustainability, Environment, Water, Population and Communities, Australian State of the Environment (SoE) Committee, Canberra, ACT, Australia, 932 pp.
- Steffen W, Sims J, Walcott J and Laughlin G (2011) Australian agriculture: Coping with dangerous climate change. *Regional Environmental Change* 11 (Suppl 1): S205-S214.
- Stern N (2007) The economics of climate change: The Stern Review. Cambridge: Cambridge University Press.
- Stokes CJ and Howden SM (eds) (2008) An Overview of Climate Change Adaptation in Australian Primary Industries: Impacts, Options, and Priorities. Report prepared for the National Climate Change Research Strategy for Primary Industries. CSIRO Publishing, Canberra.
- Stokes MC and Howden M (eds) (2010) Adapting Agriculture to Climate Change: Preparing Australian Agriculture, Forestry and Fisheries for the Future, CSIRO Publishing.
- Stokes CJ, Crimp S, Gifford R et al. (2010) Broadacre grazing. In Stokes MC and Howden M (eds) (2010) Adapting Agriculture to Climate Change: Preparing Australian Agriculture, Forestry and Fisheries for the Future, CSIRO Publishing.
- Story J, Bristow K and Camkin J (2008) Irrigation Mosaics in Northern Australia, Department of Agriculture, Fisheries and Forestry; Northern Australia Irrigation Futures.
- Sutherst RW (1990) Impact of climate change on pests and diseases in Australasia. *Search* 21: 230-232.
- Sutherst RW, Collyer BS and Yonow T (2000) The vulnerability of Australian horticulture to the Queensland fruit fly, *Bactrocera (Dacus) tryoni*, under climate change. *Australian Journal of Agricultural Research* 51: 467-480.
- TAI (The Australia Institute) (2005) What a waste: an analysis of household expenditure on food. Accessed at <http://www.tai.org.au/node/1580>.

- Tan PL, George D and Comino M (2015) Cumulative risk management, coal seam gas, sustainable water, and agriculture in Australia. *International Journal of Water Resources Development* (ahead-of-print): 1-19.
- Taub DR, Miller B and Allen H (2008) Effect of elevated CO₂ on the protein concentration of food crops: a meta-analysis. *Global Change Biology* 14: 565-575.
- Taylor RG, Scanlon B, Döll P et al. (2014) Groundwater and climate change. *Nature Climate Change* 3: 322-329.
- Temple JB (2008) Severe and moderate forms of food insecurity in Australia: Are they distinguishable? *Australian Journal of Social Issues* 43: 649-668.
- The Age (2010) Climate drives big wine deal. August 17 2010. Accessed at <http://www.theage.com.au/business/climate-drives-big-wine-deal-20100816-1272s.html>.
- The Guardian (2015) Battle for Liverpool Plains: Chinese coal project tears at fabric of rural NSW by Tom Morton, 26 February 2015. Accessed at <http://www.theguardian.com/environment/2015/feb/26/battle-for-liverpool-plains-chinese-coal-project-tears-at-fabric-of-rural-nsw>.
- Thomson G, McCaskill M, Goodwin I et al. (2014) Potential impacts of rising global temperatures on Australia's pome fruit industry and adaptation strategies, *New Zealand Journal of Crop and Horticultural Science* 42: 21-30.
- Thornton P (2012) Recalibrating food production in the developing world: global warming will change more than just the climate. CCAFS Policy Brief no. 6. (CGIAR Research Program on Climate Change, Agriculture and Food Security, 2012).
- Thornton P and Cramer L (eds) (2012) Impacts of climate change on the agricultural and aquatic systems and natural resources within the CGIAR's mandate. CCAFS Working Paper 23. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). p. 13.
- TIA (2012) (Tasmanian Institute of Agriculture) Projected impact of climate change in wine grape production opportunities for growers. Accessed at <http://dpiwwe.tas.gov.au/Documents/Wine-Production-V8---31-May-FINAL.pdf>.
- Tubiello FN, Salvatore M, Rossi S et al. (2013) The FAOSTAT database of greenhouse gas emissions from agriculture. *Environmental Research Letters* 8:015009.
- Turner NC, Molyneux N, Yang S et al. (2011) Climate change in south-west Australia and north-west China: challenges and opportunities for crop production. *Crop and Pasture Science* 62: 445-456.
- UN (United Nations) (2015) World population projected to reach 9.7 billion by 2050. Accessed at <http://www.un.org/en/development/desa/news/population/2015-report.html>.
- van Dijk AIJM, Beck HE, Crosbie RS et al. (2013) The Millennium Drought in southeast Australia (2001-2009): Natural and human causes and implications for water resources, ecosystems, economy, and society. *Water Resources Research* 49:1040-1057.
- Vermeulen SJ, Campbell BM and Ingram JSI (2012) Climate Change and Food Systems. *Annual Review of Environment and Resources* 37: 195-222.
- WA Department of Agriculture and Food (2013) Carbon farming in WA: Fact Sheet 9. Accessed at <https://www.agric.wa.gov.au/sites/gateway/files/CFWANO%209web%202015.pdf>.
- Webb L, Whetton P and Barlow EWR (2007) Modelled impact of future climate change on the phenology of winegrapes in Australia. *Australian Journal of Grape and Wine Research* 13: 165-175.
- Webb L, Whetton P and Barlow EWR (2008) Climate change and wine grape quality in Australia. *Climate Research* 36: 99-111.
- Webb LB, Whetton PH, Bhend J, et al. (2012). Earlier winegrape ripening driven by climatic warming and drying and management practices. *Nature Climate Change* 2: 259-264.
- Webster T, Morison J, Abel N et al. (2009) Irrigated agriculture: development opportunities and implications for northern Australia. In: Northern Australia Land and Water Science Review 2009. Report to the Northern Territories Land and Water Task Force coordinated by the Commonwealth Scientific and Industrial Research Organization (CSIRO) Sustainable Agriculture Flagship, Department of Infrastructure, Transport, Regional Development and Local Government, Canberra, ACT, Australia.
- Wentworth Group of Concerned Scientists (2014) Blueprint for a Healthy Environment and a Productive Economy. Accessed at <http://wentworthgroup.org/wp-content/uploads/2014/11/Blueprint-for-a-Healthy-Environment-and-a-Productive-Economy-November-2014.pdf>.
- Wheeler T and von Braun J (2013) Climate change impacts on global food security. *Science* 341: 508-513.
- White N, Sutherst RW, Hall N and Whish-Wilson P (2003) The vulnerability of the Australian beef industry to impacts of the cattle tick (*Boophilus microplus*) under climate change. *Climatic Change* 61: 157-190.
- Whittaker J, Handmer J and Mercer D (2012) Vulnerability to bushfires in rural Australia: A case study from East Gippsland, Victoria. *Journal of Rural Studies* 28: 161-173.
- Wilson P, Ringrose-Voase A, Jacquier D et al. (2009) Land and Soil Resources in Northern Australia, CSIRO Land and Water.
- Wittwer G and Griffith M (2011) Modelling drought and recovery in the southern Murray-Darling basin. *Australian Journal of Agricultural and Resource Economics* 55: 342-359.
- World Bank (2015) Annual freshwater withdrawals, agriculture (% of total freshwater withdrawal. Accessed at <http://data.worldbank.org/indicator/ER.H2O.FWAG.ZS>.
- Ziska LH, Bunce JA, Shimono H et al. (2012) Food security and climate change: on the potential to adapt global crop production by active selection to rising atmospheric carbon dioxide. *Proceedings of the Royal Society B* 279: 4097-410.

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EXTREME WEATHER CAN DRIVE UP FOOD PRICES



Extreme weather events such as droughts and storms **affect food prices in Australia** and these events are expected to become **more intense and frequent**.



Food prices during the **2005-2007 drought** **increased at twice the rate** of the Consumer Price Index (CPI).

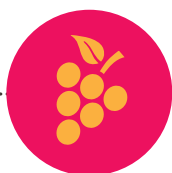


Fresh fruit and vegetables **worst hit during 2005-2007 drought** - prices increasing 43% and 33% respectively.

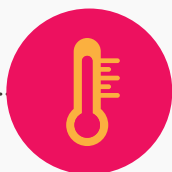


Cyclone Larry destroyed **90% of the North Queensland banana crop** in 2006, affecting supply for nine months and **increasing prices by 500%**.

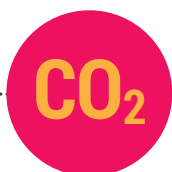
CLIMATE CHANGE AFFECTS THE QUALITY & AVAILABILITY OF FOOD



Up to 70% of Australia's wine-growing regions (including iconic areas like the Barossa Valley and Margaret River) will be less suitable for grape growing by 2050.



Higher temperatures cause earlier ripening and reduced grape quality.



Many foods produced by plants growing at elevated CO₂ have reduced protein and mineral concentrations, **reducing their nutritional value.**



Heat stress reduces milk yield by **10-25% and up to 40%** in extreme heatwave conditions.

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