Impacts and adaptation strategies for a variable and changing climate in the SOUTH EAST QUEENSLAND REGION

This summary describes the likely impacts of a variable and changing climate on the major primary industries of the South East Queensland (SEQ) region including grazing, dairy, cropping, horticulture, sugar, fisheries and aquaculture, and the potential adaptation strategies, which can be implemented to minimise climate risks.

Courtesy of Tourism Queensland

Regional Profile

South East Queensland (SEQ) is Australia's fastest growing region and includes 11 regional and city councils including Brisbane, the Gold and Sunshine Coasts, Ipswich, and the Lockyer Valley. In 2012, the region's population was 3.2 M and is projected to be above 4.1 M by 2026.

The region has a sub-tropical climate (i.e. hot wet summers with cooler dry winters) and the key climate systems affecting this region include the tropical systems from the north and the sub-tropical high pressure ridges to the south. Temperatures have an average historical annual minimum of 13.5°C and an average annual maximum of 25.6°C at Nambour on the Sunshine Coast; and 14.4°C and 27.4°C at Ipswich. The average historical annual rainfall is 1714 mm at Nambour (1894-2015) and 866 mm at Ipswich (1870-2015). The fast growing population and coastal location make SEQ particularly vulnerable to extreme events associated with a more variable and changing climate.

Major Primary Industries

Land use is very diverse in this region, with urban and industrial areas, forestry in native and plantation forests, national parks and conservation areas. The area supports production of dryland and irrigated sugar, as well as dairy, beef, broadacre crops, fruit and vegetables. The majority of the region's agricultural area is used for grazing of beef cattle, with some dairy farming located on productive grazing land. The rich alluvial soils along the valleys in the west and south of the region including the Brisbane, Lockyer, Fassifern and the Albert-Logan valleys support a vast array of cropping industries. Close to the coast, horticulture and cropping industries thrive in the Gold Coast, Redlands and Sunshine Coast districts. The gross value production (GVP) in 2014-15 of agricultural commodities in the region was $1.4 B or 11% of the state total GVP for agricultural commodities ($11.9 B, ABS 2016a).

Courtesy of Tourism Queensland

Climate Trends and Projections

Historical changes in the key climate variables relevant to agricultural production including temperature, evaporation, rainfall, sea surface temperature, hot days, duration of cold periods and growing season length are summarised in Table 1. Table 2 provides information on the historical means for the key variables and the projected changes for 2030. Projections of rainfall changes are less clear than those of temperature. In SEQ changes by 2030 are within the bounds of existing natural climate variability, and by 2090 models show either little change or a slight decrease in rainfall (Dowdy et al 2015).

Table 1: Historical Climate Trends (Interpreted and summarised from BOM 2016)

Variable	***Trend Since* (year)**	***Change per decade***		
		Annual	Summer	Winter
Maximum Temperature (°C)	1950	+0.05 to +0.20	+0.05 to +0.15	0.15 to +0.30
Minimum Temperature (°C)	1950	+0.10 to +0.15	+0.10 to +0.30	+0.20 (north) to +0.10 (south)
Mean Temperature (°C)	1950	+0.10 (east) to +0.20 (west)	+0.10 to +0.15	+0.15 to +0.20
Pan Evaporation (mm)	1970	-5 to -2.5	-2.5 to NSC	-2.5 to NSC
Rainfall (mm)	1950	-60 (east) to -20 (west)	-20 (east) to -5 (west)	-20 (east) to -10 (west)
Sea Surface Temperature (°C)	1950	+0.08 to +0.12	+0.08 to +0.12	+0.08 to +0.12
Number of Hot Days	1970	+2.5 days		
Cold Spell Duration	1970	0 days		
Growing Season Length	1970	+8 days		

NSC - No significant change | Unknown Growing Season Length | Pan Evaporation = the amount of water evaporated from an open pan per day **| Hot Days** = annual count of days with maximum temperature >35°C **| Cold Spell Duration** = Annual count of nights with at least 4 consecutive nights when daily minimum temperature < 10th percentile **| Growing Season Length =** Annual (01 July to 30 June) count between first span of 6 or more days with daily mean temperature >15°C and first span of 6 or more days with daily mean temperature <15°C

Additional climate projections for Queensland

- Global atmospheric **carbon dioxide concentration** (CO_2) is rapidly increasing. In March 2015, the monthly global average carbon dioxide concentration exceeded 400 ppm, well above the natural historical range from the last 800,000 years of 172 ppm to 300 ppm (CSIRO and BOM 2012a). Global CO_2 levels are projected to reach 540 ppm by 2050 and 936 ppm by 2100 (RCP8.5 high emissions) (IPCC 2013).
- Queensland can expect **longer dry periods** interrupted by **more intense rainfall** events. The frequency of both extreme El Niño and extreme La Niña events are likely to nearly double in response to greenhouse warming (Cai et al. 2014, 2015).
- Although there is some uncertainty about future **tropical cyclone** potential in Queensland, there is confidence in the projections of a future decrease in the number of tropical cyclones, an increase in the proportion of high intensity tropical cyclones and a decrease in the proportion of mid-range intensity storms: more than 50% of models project a decrease in the frequency of tropical cyclones of between 15 to 35% by 2090 (CSIRO and BoM 2015).
- Along the Queensland Coast, **sea level** is expected to rise 13 cm (the model range is 8 – 18 cm) by 2030 and 65 cm by 2090 under the highest emissions (CSIRO and BoM 2015). The Statutory erosion prone areas are declared under section 70 of the *Coastal Protection and Management Act 1995* (Coastal Act) and include the effect of a projected 80 cm sea level rise. An 80 cm rise in sea level is expected to inundate about 1.25 Mha of Queensland (which is 173 Mha in size); or about 65,825 ha (3%) of the SEQ region land (2.23 Mha) consisting mainly of existing marsh/wetland/rivers/lakes (1%), dryland cropping (0.45%), nature conservation areas (0.4%), natural grazing (0.3%) and residential land (0.2%) (DSITIA 2012, Witte et al. 2006).
- Since 1750, atmospheric **CO_2** dissolving in the **oceans** has lowered the global average **ocean pH** by 0.1 units, representing a 30% increase in hydrogen ion (acid) concentration (Howard et al. 2012). Ocean pH is expected to decrease a further 0.2-0.5 units by 2100 lowering rates of calcification for shelled marine organisms (Caldeira and Wickett 2005).
- **Ocean circulations** are expected to change, including a possible intensification and strengthening of the East Australian Current by a further 20% by 2100 (Poloczanska et al. 2009, Cai et al. 2005). However, a more recent study showed differences in strengthening between regions with most of the strengthening likely to occur south of the Great Barrier Reef (Sun et al. 2012).
- **Sea surface temperature** off the Queensland coast is most likely going to be between 0.4-1°C warmer in 2030 and 2.5-3.0°C warmer by 2090 than the 1986-2005 baseline (CSIRO and BOM 2015).
- The amount of time spent in **extreme drought** will increase in the highest emission scenarios (CSIRO and BOM 2015).

Table 2: Historical means for the period 1986-2005 and climate projections for 2030 (2020-2039) under the RCP8.5 emissions scenario relative to the model base period of 1986-2005

Variable		Annual	Summer	Autumn	Winter	Spring
Temperature (°C)	Historical mean	**19.4**	**23.9**	**20.1**	**14.0**	**19.6**
	Projections for 2030	**+0.9** **+0.6 to +1.3**	**+0.9** **+0.6 to +1.3**	**+0.9** **+0.6 to +1.2**	**+0.8** **+0.6 to +1.2**	**+0.9** **+0.6 to +1.4**
Rainfall (mm)	Historical means	**1135**	**431**	**317**	**148**	**227**
	Projections for 2030	**-3%** **-11% to +5%**	**0%** **-10% to +9%**	**-3%** **-14% to +10%**	**-5%** **-15% to +4%**	**-5%** **-15% to +6%**
Potential Evaporation (mm)	Historical mean	**1553**				
	Projections for 2030	**+3%** **+2% to +5%**				
Relative Humidity	Projections for 2030	**0%** **±0.5%**				
Wind Speed	Projections for 2030	**0%** **±2%**				

Historical means from 1986-2005

Projections for 2030 (20-year period centred on 2030)
Best Estimate
Range of Change (5th - 95th)
For more information, including projections for 2050 and 2070, please refer to http://www.climatechangeinaustralia.gov.au/en/ or Moise et al. 2015.

Impacts of a variable and changing climate in the South East Queensland Region

Whilst a more variable and changing climate will impact the key primary industries in the region, the population and natural environment will also feel the effects.

Human Well-Being

The variable and changing climate of the region will have both direct and indirect impacts on health, location and living arrangements.

Likely Impacts	***Potential Strategies for Adaptation***
Extremes of weather and climate (drought, flood, cyclones, heatwaves etc.) on human well-being (Smith et al. 2014, TCI 2011, Hughes and McMichael 2011, NCCARF 2011a)	
• Direct effects of extremes of weather include injury and death during floods and cyclones, heat stress during heatwaves, and a reduction of cold-related deaths. • Indirect effects of extremes of weather could include an increase in the: o number of bushfires due to extreme heat and aridity; o risk of mosquito-borne, water-borne and food-borne diseases; o number of infectious and contagious diseases with an increase in the number of injuries; and o incidence of disease from microbial food poisoning with an increase in temperature. • Increases in extreme events can lead to increased pressure on health systems, including an increased demand for health professionals, ambulance and hospital workers. • Rural, regional and remote communities are particularly exposed in a changing climate compounding the chronic difficulties and inequities that already face many communities. Many parts of the country already find it hard to recruit dedicated health care and social service professionals. A changing climate will also increase the demand for social support and mental health services, and, at the same time, make it harder to recruit and retain staff in affected areas. • Infrastructure assets along the Queensland coast and islands are at risk from the combined impact of sea level rise, inundation, shoreline recession, coastal erosion and extreme events (DCCEE 2011). • Severe weather events can destroy places and disrupt livelihoods and communities leading to long-term mental health effects. According to Bonanno et al. (2010), a significant part of the community, as many as one in five, will suffer the debilitating effects of extreme stress, emotional injury and despair. • The emotional and psychological toll of disasters can linger for months, even years, affecting whole families, the capacity for people to work and the wellbeing of the community. • Evidence is beginning to emerge that drought and heatwaves lead to higher rates (by about 8%) of self-harm and suicide (Doherty and Clayton 2011). • Those most vulnerable to extremes of weather and climate include children, the elderly, Indigenous communities and people with pre-existing diseases and disabilities.	• Adapt existing buildings and plan any new infrastructure to take into account climate impacts and extreme events such as flooding, tropical cyclones and sea level rise. • Implement control measures to reduce the impact of bushfires, heatwaves, mosquitoes, water-borne and food-borne diseases, infectious and contagious diseases and injuries. • Continue to obtain information on the expected effects of a changing climate. • Develop agreements with your workers on how to manage extreme hot days, or identify periods of time where weather and climate affect working conditions. • Develop social support networks. • Contact your local council or relevant government department to find information on social and health support programs.

Biodiversity

The South East Queensland (SEQ) bioregion covers the entire SEQ region and is rich in biodiversity with many species vulnerable to a changing climate, including some that reach their northern limits on mountains and plateaus, and some with very small populations (Williams et al. 2014). Genera endemic to the SEQ bioregion include the satinay sand skink (*Coggeria sp.*), the amorous skink (*Eroticoscincus sp.*), the Nangur spiny skink (*Nangura sp.*) and the Australian lung fish (*Neoceratodus sp.*). Wallum vegetation found on the coastal sandmarshes is also rich in endemic plants and animals such as crustaceans, insects, fish, frogs and reptiles. The region is very rich in eucalypts. The degree of ecological change caused by climate change is more likely to be greater in the plant biological group than that of mammals, amphibians or reptiles (Williams et al. 2014).

Likely Impacts	***Potential Strategies for Adaptation***
Extremes of weather and climate (drought, flood, cyclones, heatwaves etc.) on Biodiversity (Low 2011)	
• *Extended distributions* – Within the bioregion, dominant eucalypts have distributions extending far to the north and west into drier regions. This suggests good prospects for survival under a changing climate. • *Threats to flora* – Under a scenario of more extreme droughts, fires or flooding killing native plants, weeds may take their place. • *Altered mangrove area* – There may be an increase in mangroves due to large areas of saltmarsh available for colonisation and due to sea level rise and sedimentation, enhanced atmospheric carbon dioxide, increased rainfall and nutrient enrichment promoting plant growth (Low 2011). Other factors, such as increased temperature, aridity, increased storm intensity and infrastructure barriers may reduce growth. • *Threats to fauna* – Changed climate conditions will increase the risk of further damage from hot fires. Droughts of greater intensity may decrease seepage flows and food for the frogs and increase pig wallowing and grubbing. Higher temperatures may directly disadvantage the frogs. • *Threats to fauna* – More severe droughts and declining food quality from rising carbon dioxide levels will contribute to ongoing declines in koala and greater glider numbers. • *Threats from increased temperatures* – Rising temperatures will benefit exotic fish in south-eastern waters. Most aquarium fish prefer high temperatures, and several escaped exotic species present in the bioregion are probably limited in numbers by cool temperatures.	• Fire management. • Weed management including community education, nursery liaison and restrictions on weedy plants grown and sold are needed to reduce weed invasion due to escape from home gardens. • Pig control to protect ground dwelling species. • Pollinator conservation. • Reduce development around coastal wetlands to ensure fauna and flora can migrate upslope in response to rising sea level. • Increase conservation of forests on fertile soil for koala, sugar glider and other foliage-feeding fauna.

Courtesy of Tourism Queensland

Grazing Industry

Cattle, sheep and wool are important primary industries in Queensland. In 2014-15 their combined GVP was $5.2 B (44% of the total Queensland GVP of agricultural commodities, ABS 2016a) which is made up of the production and marketing of beef cattle ($5.1 B), sheep and lambs ($66.4 M) and wool ($66.2 M).

Cattle numbers in SEQ were 355,000 in 2014-15 which was 3% of the total cattle numbers for Queensland (ABS 2016b). In 2014-15 the GVP for cattle, sheep and wool for SEQ was $158 M (ABS 2016a) or 1% of state and 12% of the value of SEQ agricultural commodities.

The majority of beef, sheep and wool production come from native pastures which cover about 85% of Queensland. The main pasture communities in SEQ are Black spear grass (40% of region) and Blady grass (3%) (Tothill and Gillies 1992). The soil fertility is good (Black spear grass) to poor (Blady grass) and growth of pastures is usually limited by inadequate rainfall (Black spear grass) or low nitrogen availability (Blady grass).

Case Study - Impacts in the South East Queensland Region

The impacts of a changing climate are complex because of interacting and opposing forces operating within the biophysical system (McKeon et al. 2009). The process of assessing the impacts of a changing climate often involves deriving the 'best estimate' projections of future climate, simulating the grass growth and grazing strategies under changing climate conditions using well-calibrated grass/grazing system models, and combining the simulation output with successful producer and researcher experience in regional Queensland. A good example of a proven process of assessing the impacts, adaptive responses, risks and vulnerability associated with a changing climate is the 'risk matrix' approach (http://www.longpaddock.qld.gov.au/products/matrix/index.html, Cobon et al. 2009, 2016) which is customised for primary industries and is based on the Australian and New Zealand Risk Management Standards (Standards Australia 2004).

There are many gaps in knowledge, for example, the future climate projections are uncertain (particularly for rainfall) and in some cases the projected changes in rainfall and temperature appear smaller than to year-to-year variability. Nonetheless, a risk-averse approach to grazing management based on the 'best estimate' projections in combination with short-term management of climate variability is likely to take advantage of any opportunities and reduce the risk of adverse impacts. There are major known uncertainties in identifying the impacts of a changing climate in the grazing industry in relation to:

1) carbon dioxide and temperature effects on pasture growth, pasture quality, nutrient cycling and competition between grass, trees and scrubs;

2) the future role of woody plants including the effects of fire, climatic extremes and management of stored carbon (see McKeon et al. 2009 for more detail); and

3) carbon dioxide effects on diet quality and liveweight gain of cattle (Stokes 2011).

Modelling analyses of native pasture grasses (C4 tropical and sub-tropical grasses) for the SEQ region were undertaken for the Laidley, Kilcoy and Beaudesert areas (Cobon et al. 2012 *unpublished data*, Table 3). The average impacts of future climate scenarios from the three locations were examined for pasture growth, pasture quality (% nitrogen of growth), liveweight gain of cattle (LWG kg/ha), frequency of burning and frequency of green pasture growing days (GPGD). The baseline climate period was 1960-1990 and carbon dioxide concentration was 350 ppm. Improvements in water and nitrogen use efficiency resulting from doubling of carbon dioxide levels were accounted for in the modelling as per Stokes 2011. The impacts were either positive or negative, and as a guide were also classified as being of either High (>20% change from baseline, H), Medium (5%-20%, M) or of little or no impact (5 to -5%, LC). The soils were of average fertility (20 kgN/ha) and the density of trees (16.73 m^2/ha tree basal area) resembled that of open woodland.

Table 3: Matrix showing potential opportunities and risks associated with the average impacts of future climate scenarios from Laidley, Kilcoy and Beaudesert for modelled pasture growth (kg/ha), pasture quality (% nitrogen in growth), liveweight gain of cattle (LWG kg/ha), frequency of burning and green pasture growing days (GPGD) (Source: Cobon et al. 2012 *unpublished data*).

Future climate	Growth	Quality	LWG	Burning	GPGD
+3°C	LC	LC	+M	+M	+M
2xCO_2	+M	-M	+M	+H	LC
+3°C, 2xCO_2	+M	-M	+H	+H	+M
+3°C, 2xCO_2, +10% rainfall	+H	-H	+H	+H	+M
+3°C, 2xCO_2, -10% rainfall	+M	-M	+M	+H	+M

H= high, M= medium, LC = little change
Shading indicates positive and negative impacts
Positive impacts showing either High or Medium opportunities
Negative impacts showing either High or Medium risks

This study found that there are likely to be:

- positive impacts of a changing climate including increased pasture growth and liveweight gain, a higher frequency of burning providing more opportunity for prescribed burning to control weeds, regrowth and dry vegetation, and more green pasture growing days; and
- negative impacts including a reduction in pasture quality with doubled carbon dioxide and the combined impacts of a 3°C rise in temperature, doubled carbon dioxide and either 10% more or less rainfall.

Opportunities for the Grazing Industry

Many of the impacts and opportunities of a changing climate for the grazing industry in SEQ are detailed in Taylor et al. 2015a. Selected opportunities include:

- Increased production of biomass will result from rising carbon dioxide levels as plants use water, nutrients and light resources more efficiently (Nowak et al. 2004).
- Improved plant water use efficiency will allow pastures to produce more biomass using the same amount of water (Stokes et al. 2011).
- Elevated carbon dioxide will increase the efficiency of water and nitrogen use by the pastures (Stokes et al. 2008), but this increase in growth of pastures is likely to be offset by a reduction in overall pasture quality (lower protein and lower digestibility) (Stokes et al. 2011).

Case Study - Using past records to help understand future impacts

Projected changes in rainfall of the order of ±10% appear low compared to year-to-year variability, or even in the difference between the average of El Niño and La Niña years (-20% and 20% rainfall respectively in eastern Australia) (McKeon et al. 2004). However, when the historical range of variation is analysed for a 25-year (climate change time-scale) moving average then a change in rainfall of ±10% is relatively high. For example, the 25-year moving average of rainfall at Laidley has fluctuated between -11 and +13% compared with the long-term average since 1890 (Figure 1). The extended periods of lower rainfall (1920s to 1950s, 1990s to 2000s) have been associated with extensive droughts, degradation events, reduced profits and greater debt and human hardship. It is likely that under drier climatic conditions these circumstances will become more familiar with shorter and less frequent recovery periods.

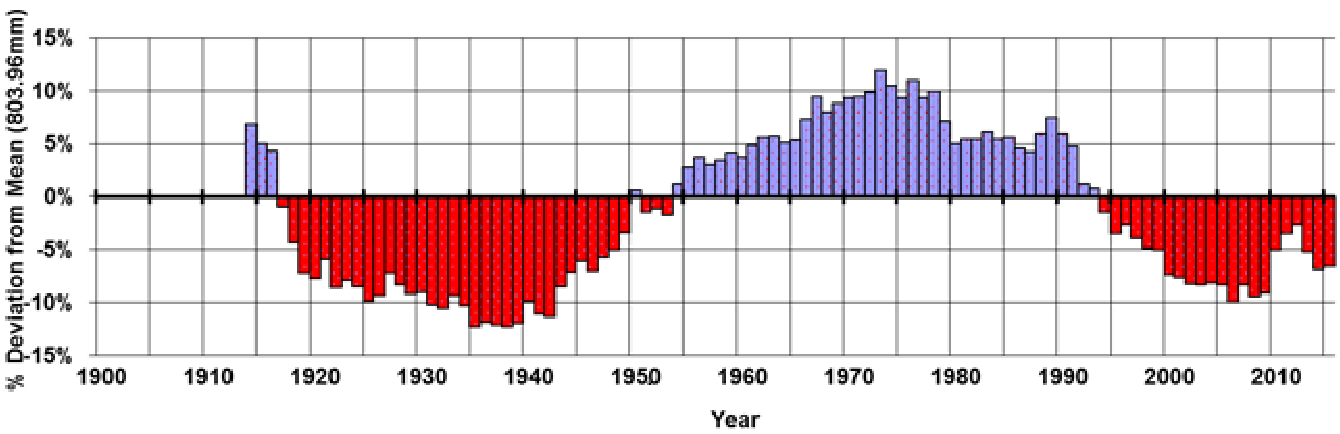

Figure 1: 25-year moving average rainfall (12 months, April in year 1 to March in year 2) at Laidley, Qld (Source: Clewett et al. 2003).

Likely Impacts	*Potential Strategies for Adaptation*
Changed rainfall patterns	

• Longer and more frequent droughts associated with more extremes of climate, fewer recovery events, changes in decadal rainfall variability and ENSO will decrease forage production, surface cover, livestock carrying capacity, animal production and cause major changes in plant and animal species composition (Cobon et al. 2009, McKeon et al. 2009).
• Erosion risks are likely to increase due to greater year-to-year variability in rainfall.
• Rising tree densities and declining pasture condition raise the sensitivity of pastures to climate induced water stress.
	• Manage perennial grass cover using 'best management practice' for the pasture community. For example, set the annual stocking rate at the end of each growing season to utilise a safe proportion (10-20%) of available pasture and make adjustments accordingly for beneficial or spoiling rainfall in winter or spring, early breaks to the dry season, locust plagues and forecasts of rainfall for the coming summer.
	• Monitor trends in rainfall.
	• Use climate indicators to make early adjustments in animal numbers.
	• Manage non-domestic grazing pressure.
	• Use wet season spelling of pastures.
	• Manage invasive plant species.
	• Maintain refugia especially around wetlands (Cobon et al. 2009).
	• Manage climate variability and change by using forecasts of rainfall (and temperature) in decision making.
	• Manage intra-seasonal (MJO, 30-60 day cycle), inter-annual (ENSO, 2-7 year cycle) and decadal rainfall variability (PDO/IPO, 20-30 year cycle) using indicators of MJO, ENSO (SOI, SST) and PDO, and climate analysis tools to adjust animal numbers commensurate with past and projected climate trends, such as:
	  ○ LongPaddock (http://www.longpaddock.qld.gov.au);
	  ○ AussieGRASS (http://www.longpaddock.qld.gov.au/about/researchprojects/aussiegrass/index.html);
	  ○ ClimateArm http://www.armonline.com.au/ClimateArm
	  ○ Bureau of Meteorology Website http://www.bom.gov.au, http://reg.bom.gov.au/climate/mjo
	• Use supplementary feeding, early weaning and culling animals at risk to reduce mortalities in dry conditions (Fordyce et al. 1990).
	• Increase or maintain *Bos indicus* content in herd to increase cattle tick and buffalo fly resistance/resilience.
	• Monitor spread of pests, weeds and disease.
	• Introduce more species of dung fauna (control of buffalo fly larvae).
	• Promote greater use of traps and baits (buffalo and sheep blowflies) and vaccines (cattle ticks and worms).
	• Use fire to control woody thickening.

Crows Nest - Landscape, Toowoomba, Gold Coast, Queensland

Courtesy of Tourism Queensland

Likely Impacts	*Potential Strategies for Adaptation*
Increased temperatures	
• Warming will be greatest toward the interior of the continent away from the moderating influence of the ocean. Each 1°C increase in temperature will cause a warming that would be roughly equivalent to moving about 145 km (or about 2° in latitude) closer to the equator (Stokes et al. 2011). For example, Clermont under warming of 3°C is likely to receive temperatures currently experienced at Kowanyama (Figure 2). • Grazing suitability is predicted to shift and contract south and east (Hosking et al. 2014) • Livestock will be exposed to a greater risk of heat stress. They are unlikely to travel as far to water which concentrates grazing pressure and increases the risk of adverse pasture composition changes and soil degradation (Howden et al. 2008). • Increased day time temperatures increases water turn-over and evaporative heat loss resulting in reduced rate of passage and forage intake in livestock (Daly 1984). • Increased night time temperatures can reduce recovery time of livestock and increase the effects of heat stress during the day. • Increased heat stress reduces fertility, conception, peri-partum survival and follicle development in sheep. • Warmer conditions favour vectors and the spread of animal disease (White et al. 2003). • Pastures could cure earlier under warmer climates shifting the timing of fires to earlier in the season. • Warmer drier conditions with higher frequency of storms could increase the risk of wildfires.	• Arrange water points to reduce distance to water and even out grazing pressure. • Select the time of mating to optimise nutritional requirements and reduce the risk of mortality in new-borns. • Select cattle lines with effective thermoregulatory controls, efficient feed conversion and lighter coat colour (Finch et al. 1984, King 1983). • Proactively control disease by targeting known sources of disease and vectors (Sutherst 1990). • Maintain high standards of animal welfare to build domestic and export meat and fibre markets (Mott and Edwards 1992). • Incorporate greater use of prescribed burning to reduce the risk of wildfires and control woody thickening. • Rotate paddocks of heavier grazing for use as fire breaks. • Maintain or improve quarantine capabilities, monitoring programs and commitment to identification and management of pests, disease and weed threats. • Develop species resistant to pests and disease, and use area-wide improved management practices.

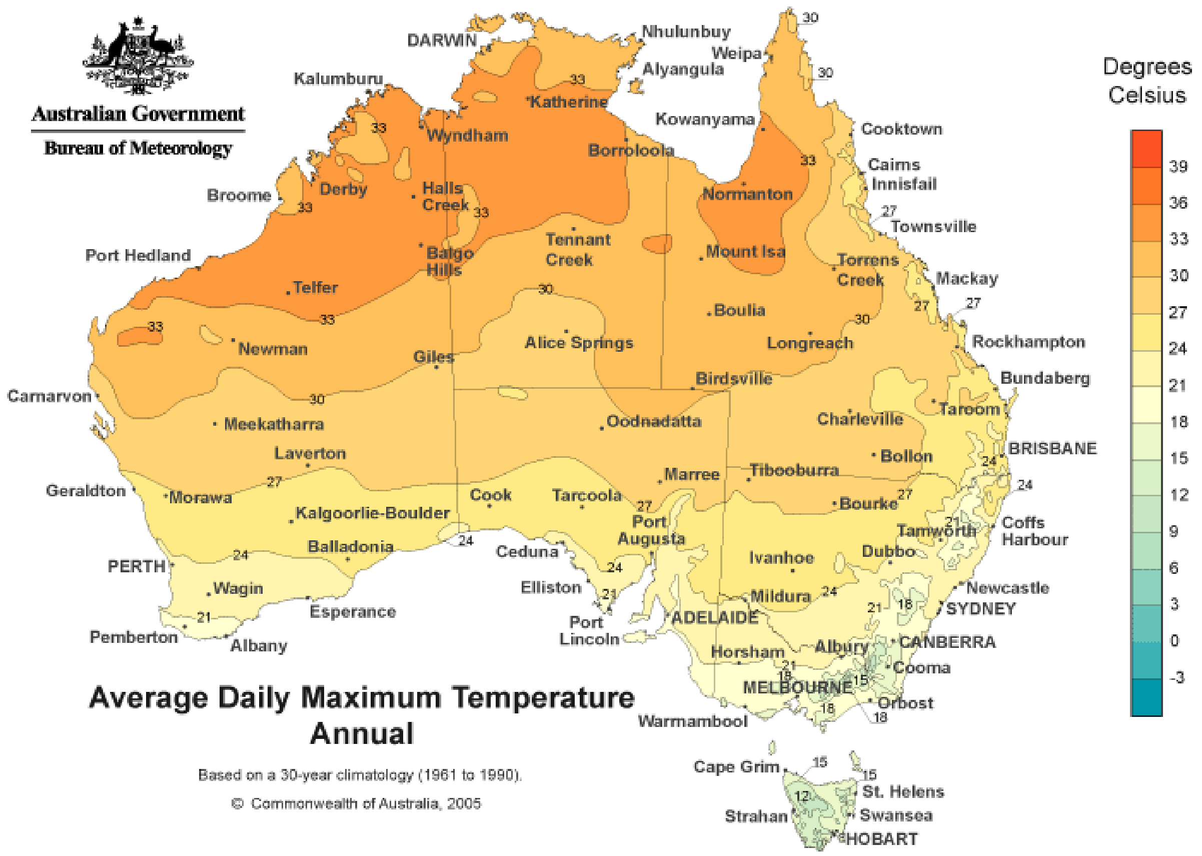

Figure 2: Annual average temperature in Australia (Source: Bureau of Meteorology). One degree of warming is roughly equivalent to moving 145 km toward the equator.

Likely Impacts	*Potential Strategies for Adaptation*
Increased temperature, higher carbon dioxide concentration and changed rainfall	
• Pastures growing under a climate characterised by consistent water stress appear to benefit most from increased plant water use efficiency under elevated carbon dioxide. • The fertilisation effects of doubled carbon dioxide (700 ppm) were found to offset declines in forage production under 2°C warming and a 7% decline in rainfall (Webb et al. 2011). • The combined effects of elevated carbon dioxide (650 ppm), higher temperature (3°C) and lower rainfall (10%) resulted in 10-20% lower forage production (McKeon et al. 2009). In this study increased temperature and declining rainfall outweigh the conservatively represented benefits of increasing carbon dioxide. • Rising carbon dioxide will result in a reduction in overall pasture quality (lower protein and lower digestibility) (Stokes et al 2011).	• Maintain land in good condition to reduce potential declines in forage production under a warmer drier climate. • To compensate for declining forage quality, increase the use of supplements (N, P and energy) and rumen modifiers. • Destock earlier in the season to make greater use of feedlots to finish livestock. • Explore alternative land use in marginal areas. • Apply safe carrying capacity of ~10-15% utilisation of average long-term annual pasture growth. • Undertake risk assessments to evaluate needs and opportunities for changing species, management of land and land use. • Support assessments of the benefits and costs of diversifying property enterprises. • Introduce pasture legumes to improve nitrogen status.
More intense storms	
• Rainfall intensity is expected to increase as temperature and moisture content of the atmosphere increase. • A 1°C increase in temperature may result in an increase in rainfall intensity of 3-10% (SAG 2010). • More intense storms are likely to increase runoff, reduce infiltration, reduce soil moisture levels and pasture growth, and increase the risk of soil erosion.	• Maintain pasture cover for optimal infiltration of rainfall. • Adjust livestock numbers to maintain good coverage of perennial pastures during the storm season.
Higher temperature humidity index (combination of maximum temperature and dewpoint temperature)	
• Temperature humidity index (THI) is an indicator of heat stress. Heat stress in beef cattle is significant at a THI of over 80. Frequency of days per year above this level is shown in Figure 3 for historical and projected climate. Rising temperature by 2.7°C increases the occurrence of heat stress by about 30% points (Howden et al. 1999). • Heat stress reduces liveweight gain and reproductive performance in beef cattle, and increases mortality rates (see Howden et al. 1999). • Heat stress reduces the development of secondary wool follicles in sheep, reducing lifetime wool production in sheep (Hopkins et al. 1978).	• Select cattle lines with effective thermoregulatory controls, efficient feed conversion and lighter coat colour (Finch et al. 1984, King 1983).

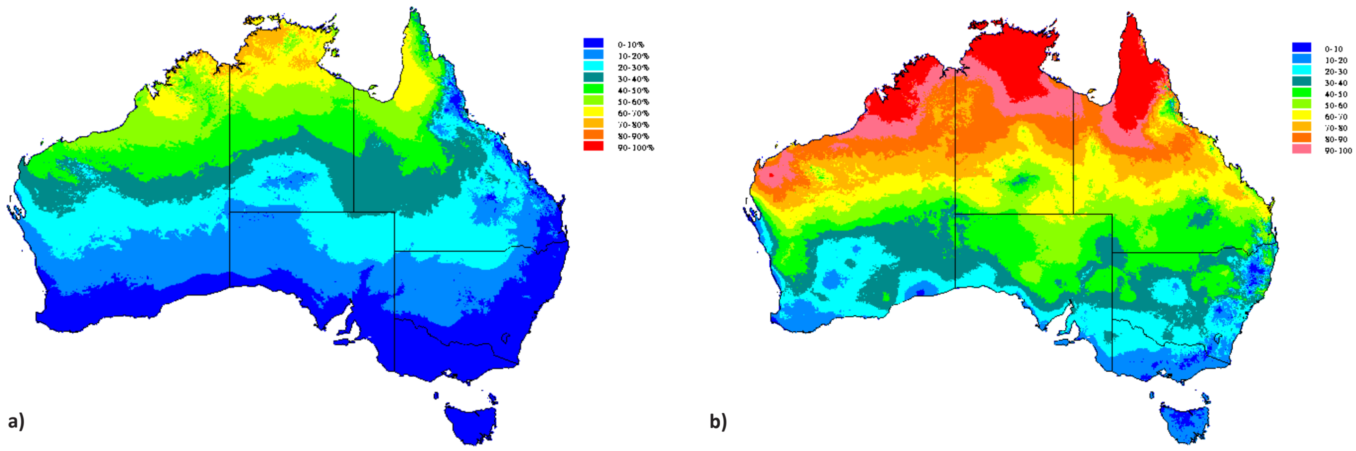

Figure 3: Frequency of days per year that the THI>80 for a) 1957-97 and b) a future climate scenario of +2.7°C. Thermal stress is significant in beef cattle when the THI exceeds 80 (Source: Howden et al. 1999).

Dairy Industry

In 2014-15 the Queensland dairy industry had a herd of about 168,000 dairy cattle of which 91,000 are cows in milk (ABS 2016b). The Queensland dairy industry produced 411 million litres of milk from 448 farms, which was 4.2% of Australia's milk production (Dairy Australia 2015). In 2014-15 SEQ produced nearly 21% of the value of Queensland's whole milk ($236 M, ABS 2016a).

Much of the information below on the impacts of a changing climate for the dairy industry is drawn from Dairy Australia (2011).

Opportunities for the Dairy Industry

- Increased plant photosynthesis and associated increased production with increases in carbon dioxide.
- Increased pasture growth during cooler months due to increased minimum temperatures and less frosts.
- Lower water availability will favour short rotation pasture systems.

Case Study - The effects of increased temperature on dairy cows.

Cows have the ability to off-load heat; however, prolonged periods of heat, particularly above 25°C, may lead to heat stress. Heat stress reduces the cows' ability to produce milk and get in calf. There may also be health and welfare problems.

Management and adaptation tools to minimise the risk of heat stress include increased provisions of shade, active cooling sprays and breed selection.

Likely Impacts	*Potential Strategies for Adaptation*
Increased temperatures	
• Rising temperatures may cause an increase in the incidence of heat stress to dairy cows. Impacts include reduced milk yield, reduced conception rates, and increased mortality rates. • Lower pasture growth and quality. • Higher temperatures may make C4 pasture species more competitive at the expense of nutritious C3 species, however higher carbon dioxide is expected to favour C3 species more than C4. • Water and irrigation requirements may be increased with higher temperatures.	• Provide more cooling mechanisms for dairy cows e.g. shade and active cooling sprays. • Selectively breed stock, pasture and feedstock for their ability to withstand higher temperatures. • Switch to pasture species that will adapt to changing conditions. • Sow pastures earlier to match warmer conditions. • Use nitrogen fertiliser during winter months. • Use short rotation pasture systems and winter fodder crops.
Decreased rainfall	
• There may be associated lower runoff and reduced soil moisture. • Less water will be available causing more competition for water. • Lower growth of rain-fed pastures and crops.	• Decrease evaporation rates in water storage and in the soil. • Install more efficient irrigation systems and improve water use efficiency. • Change feed system. • Apply more emphasis to crops. • Switch to pasture species that will adapt to changing conditions.
More intense and frequent storms with increased seasonal variability	
• Livestock could be injured by more intense storms and hail, particularly in intensive production systems where animals are concentrated. • Extreme wet seasons can negatively impact milk production, herd health and property infrastructure.	• Use summer housing for dairy cows. • Develop and implement a risk management plan when long range weather forecasts indicate a higher than average probability for either a wet or dry season ahead.

Cropping Industry

Broadacre cropping in Queensland produces a range of cereal, oilseed and legume crops, including wheat, maize, barley, sorghum, chickpea, mungbean, soybean, sunflowers and peanuts (QFF 2012). In Queensland the most commonly grown winter crop is wheat (1 M tonnes in 2014-15, ABS 2016b) and summer crop is sorghum (1.6 M tonnes in 2009-10, ABS 2016b). In 2014-15 the value of broadacre crops, excluding crops harvested for hay, cotton and sugar was $1.1 B (ABS 2016a) in Queensland and $6 M in SEQ (ABS 2016a). In 2014-15 the value of pasture and cereal crops cut for hay was $40 M in SEQ (ABS 2016a)

Much of the information below on the impacts and opportunities of a changing climate on the cropping industry are drawn from Taylor et al. (2015b) and Stokes and Howden (2010) and references therein.

Opportunities for the Cropping Industry

- Increased carbon dioxide may result in higher crop yields and biomass due to increased carbon dioxide fertilisation and photosynthesis.
- C3 plants (cereal grain crops like wheat) respond better to increased carbon dioxide than C4 plants (tropical-origin crops such as sugar cane and maize).
- The effect of increased temperature may, however, have the opposite effect due to increased water stress. Therefore, the net results remain uncertain (NCCARF 2011b).
- In cooler months, increased temperatures may reduce frost risk.

Likely Impacts	*Potential Strategies for Adaptation*
Increased temperatures and carbon dioxide concentration	
• Rising carbon dioxide may increase biomass production and grain yields which will in turn reduce both the average nitrogen level of grain and the frequency of achieving key nitrogen thresholds. • Warmer temperatures and increased rainfall are likely to favour the slower-maturing cultivars (greater thermal time requirements) that could benefit from an earlier date of flowering and a longer period of photosynthesis (with adequate moisture). • Heat stress during the summer months is likely to cause poor seed set in summer grain crops, such as mung bean, sunflower and maize because higher temperatures lead to earlier flowering crops and poor pollination. • Heat stress during spring may decrease yield of winter crops (e.g. wheat). • Warmer temperatures in spring may allow earlier planting of summer crops with lower frost risk. • Decreased frost incidence may benefit winter crops because of less chance of frost at flowering, however, this will be complicated by the fact that they will flower earlier.	• Adjust planting times of summer crops (e.g. mung beans, sunflower and maize) so that they are not flowering during the hottest months. • To maintain grain nitrogen content at historical levels, there will be a need to increase fertiliser application rates by up to 50% depending on the yield expectations. Therefore, increase nitrogenous fertiliser application or increase use of pasture legume rotations may be needed to maintain grain yields and protein content. • Increase application rates of other crop nutrients (e.g. P, K).
Changed rainfall patterns and increased storm frequency	
• Increased risk of storm damage and erosion. • Increased occurrence of some pests and diseases. • Heavy rainfall can increase leaching of nutrients and movement of salts, although total rainfall is likely to decline. • Decreased yields as a result of increased crop water stress.	• Optimise availability of all resources (e.g. through precision agriculture). • Adopt efficient irrigation technology to control water table, monitor water table position and improve catchment vegetation distribution and ground cover to increase infiltration rate. • Apply fungicides to wheat crops to decrease leaf disease (Meinke and Hochman 2000 in Stokes and Howden 2010). • Reduce soil moisture loss by: o increasing residue cover by minimal or no-tillage; o establishing crop cover in high loss periods; o weed control; and o maximising capture and storage of excess rainfall on-farm. • Establish a higher percentage of summer crops relative to winter crops as rainfall changes point towards the largest decreases being in winter and spring. • In mixed farming systems, where cropping is marginal and may become more so, consider incorporating a greater proportion of livestock into the farm business for profitability.

Likely Impacts	*Potential Strategies for Adaptation*
Increased temperatures and decreased rainfall	
• Warmer temperatures and a significant decrease in rainfall are likely to favour winter crop varieties (e.g. wheat and barley) with earlier-flowering characteristics which allow grainfill to occur in the cooler, wetter parts of the year in dry areas. Varieties with characteristics such as higher response to elevated carbon dioxide conditions, rapid germination, early vigour and increased grain set in hot/windy conditions may also be favoured. • Increased temperatures and evaporation may reduce the yield of dryland crops like wheat and sorghum (Potgieter et al. 2004); however, this may be offset by increased carbon dioxide. • Irrigated crops may be adversely affected due to a reduction in supply of irrigation water. • There will be more pressure and challenges for managing groundcover, crop choice (winter or summer), soil nutrient requirements, pest and weed control, soil carbon etc., especially from higher temperature, increased soil moisture stress and higher rainfall variability. • Lower rainfall may reduce deep drainage in dryland cropping systems. • In general, in the SEQ region, areas currently suitable for cropping are predicted to remain suitable, with the highest suitability remaining the central SEQ (Hosking et al. 2014).	• Incorporate 'best practice' farm management by constantly varying crops and inputs based on the availability of limited and variable resources and signals from the operating environment (Rodriguez et al. 2011a, Rodriguez et al. 2011b). • Use varieties that incorporate the traits of appropriate thermal time (degree days) and vernalisation (exposure to cold temperatures required for flowering) requirements and with increased resistance to heat shock and drought. • Diversify the farm enterprise (e.g. using opportunistic planting). • Increase the use of legume-based pastures and leguminous crops or further increase nitrogen fertiliser application to maintain grain quality, especially protein content. • Adjust planting times to cater for changes in crop maturity and the duration and timing of heatwaves. • Adopt efficient irrigation technology. • Increase use of supplementary water. • Optimise irrigation scheduling. • Use more effective irrigation water delivery technologies (i.e. trickle tape). • Construct on-farm water storage facilities. • Use drought-tolerant or more water efficient varieties. • Modify row spacing. • Minimise tillage. • Use cover crops. • Manage water resources and improve efficiency of irrigation systems. • Integrate cropping into regions of higher rainfall. • Make crop planting decisions based on seasonal climate forecasting, soil tests and other climate related information obtained from tools such as Rainman, Whopper Cropper and APSIM. • Use adaptive crop management techniques such as: o zero-tillage practices, minimum disturbance planting techniques (e.g. seed pushing); o controlled traffic; o responding to planting opportunities when they occur; o widening row spacing or skip-row planting; o lowering plant populations; o using efficient on-farm irrigation management with effective scheduling, application and transfer systems; and o assessing fertiliser inputs. • Reduce surface soil erosion by: o increasing residue retention; o maintaining erosion control infrastructure (e.g. contour banking); and o using controlled traffic systems. • Control pests and diseases.

Farm Crops, Boonah, Queensland

Courtesy of Tourism Queensland

Horticulture Industry

Horticulture is Queensland's second largest primary industry (QFF 2012). Queensland grows approximately one third of Australia's horticulture produce, with more than 120 different types of fruit and vegetables being grown in 16 defined regions covering a total area of 100,000 hectares and 2800 farms (QFF 2012, HAL 2012). In 2014-15 the value of production for Queensland was about $2.5 B which was made up of $1 B for vegetables, $1.2 B for fruit and nuts and $290 M for nurseries, cut flowers and turf (ABS 2016a).

In 2014-15 SEQ produced about 27% of the total value of the state's horticulture, including 35% of the value of vegetables, 14% of the value of fruit and nuts, and 49% of the value of nurseries, cut flowers and turf (ABS 2016a). The region is a major producer of Queensland's pineapples, strawberries and a variety of vegetables (HAL 2012).

Much of the information below on the impacts and opportunities of a changing climate for the horticulture industry is drawn Taylor et al. (2015c) and from reports commissioned for the Garnaut Review (Deuter 2008).

Opportunities for the Horticulture Industry

- Increased minimum temperature, reduced frost frequency and shortened frost period during the growing season may increase the area climatically suitable to optimum growth of frost sensitive sub-tropical crops such as avocado.
- Vegetable growers producing summer crops in temperate regions will have the additional option of planting earlier, and later, therefore extending the production season.
- Increased runoff (from higher intensity rainfall events) may provide opportunities for growers to capture more water for irrigation.

Case Study – Adaptable Cultivars

More adaptable cultivars for lettuce and brassica are needed as the winter season (mid-April to October) will be shortened by 2030 (Deuter 2008). In the case of iceberg lettuce, about two weeks before harvest the heart starts developing but mean maximum temperatures above 28°C will produce soft hearts and reduce quality. The climate projections for 2030 suggest that mean maximum temperatures in the Lockyer Valley are expected to exceed 28°C from early October to mid-April, which is likely to shorten the lettuce season by 3-4 weeks.

Likely Impacts	***Potential Strategies for Adaptation***
Increased temperatures	
• Changes to the suitability and adaptability of some crops. • Potential shift in the optimum growing regions from the current hotter producing areas towards areas currently regarded as too cool. Avocado production in SEQ will shift and contract eastwards and southwards (Hosking et al. 2014). • Change the timing and reliability of plant growth, flowering, fruit growth, fruit setting, ripening and product quality; fruit size, quality and pollination. • Change harvesting times for different areas. • Reduce the time to reach maturity (earlier in the season). • Change the occurrence and distribution patterns of fruit fly, *Helicoverpa* and diamond back moth. • Potentially downgrading product quality. • Result in pollination failures. • Increase active soil-borne diseases and insect infestation for longer periods during the year. • May cause fruit yellowing of tomatoes, and affect the post-harvest processing for some crops such as beans, melons and strawberries that are required to be cooled quickly. • May induce fruit abscission in citrus during the bloom or early fruit set period. • Potential influence on fruit quality and pollination of some sub-tropical crops e.g. avocado. • Reduced diurnal temperature range will potentially reduce the overlap between open stages of male and female flower parts thus decreasing the chances for pollination and resulting in more pollination failures, fruit drop and sunburn to fruit. • Increased minimum temperatures and reduced occurrence of frost may benefit the growth of pineapples and negatively impact vegetable growers in tropical and sub-tropical regions producing winter crops as the winter production season will be shortened. • Changes in disease and pest distribution ranges.	• Select for, or change to, cultivars which are more adaptable to a changing and variable climate. • Select and review growing site/location to avoid unsuitable climate factors through identifying threshold temperatures or other climate conditions for crops. • Choose optimal timing of planting. • Use chemical treatments such as hydrogen cyanamide to induce bud break to manage the variable and non-uniform budburst and to protract full bloom of pip, stone fruit and nut trees if dormancy is affected. • Start breeding programs for heat tolerant, low chill, and more adaptable varieties of various horticultural crops. Varieties with higher quality under enhanced carbon dioxide and elevated temperatures will need to be evaluated then considered in breeding programs. • Apply the latest research results and best management techniques to maintain product quality. • Use crop protection treatments including solar radiation shading and evaporative cooling through overhead irrigation to maintain fruit quality. • Use tools/models associated with managing climate variability to improve both quality and quantity of horticulture products. • Plant varieties with chilling requirements below 1000 hours.

Likely Impacts	*Potential Strategies for Adaptation*
Changed rainfall patterns	
• Increased risk to crops reliant on irrigation where irrigation water availability is reduced especially during dry periods. • Changes to the reliability of irrigation supplies, through impacts on recharge to surface and groundwater storages.	• Adopt more efficient irrigation monitoring and scheduling technologies which provide further water-use efficiencies. • Apply the latest research results and best management techniques to maintain product quality, including fertiliser timing and amounts according to crop requirements. • Use tools/models associated with managing climate variability to improve both quality and quantity of horticulture products.
More intense storms	
• Increased runoff may provide opportunities for growers to capture more water for irrigation. • Lead to conditions favouring foliar diseases and some root invading fungi, for example, the fungus Phytophthora cinnamomi, which affects avocado. • Increase the likelihood of damage and waterlogging, de-creasing quality and production. • Affect the timing of cultural practices and ability to harvest, as well as negative effects on yield and product quality. • Increase the risk of the spread and proliferation of soil borne diseases; soil erosion and off-farm effects of nutrients and pesticides; affected water quality and impacts on other ecosystems.	• Improve Integrated Pest and Disease Management practices to adapt to a changing climate and encourage disease suppressive soil techniques. • Improve on-farm water storage linked to drainage and water harvesting systems. • Improve sediment runoff protection via grassed waterways and erosion control structures. • Improve plant nutrition management. • Improve all-weather access to cropping areas.

Mushrooms, Eumundi Markets, Queensland — Courtesy of Tourism Queensland

Sugar Industry

Australian sugarcane is grown in Queensland and northern New South Wales and the industry consists of 4000 cane farming businesses, 24 mills and six bulk storage ports (Canegrowers 2011). Ninety-five percent of Australian sugarcane is grown in Queensland and 85% is exported (QLDDAFF 2010). In 2014-15, 30 M tonne of cane was produced in Queensland (ABS 2016b) with a value of $1.2 B of which $10 M was produced in SEQ (ABS 2016a).

Much of the information below on the impacts of a changing climate on the sugar industry is drawn from Stokes and Howden (2010) and references therein.

Opportunities for the Sugar Industry

- Increased temperatures and carbon dioxide are likely to lead to accelerated crop development, increased yield and an extended growing season.

Case Study – The delayed impact of the 2010 (extremely) wet season on sugarcane

In September 2011, canefarmers were starting to feel the full impact of the 2010 wet season. The 2010 wet conditions meant that a large amount of cane was unable to be crushed and was left in the field as standover. As a result, the overall tonnage for 2011 was 23 M tonnes, about 10 M tonnes less than average.

Likely Impacts	*Potential Strategies for Adaptation*
Increase in atmospheric carbon dioxide	
• Increased growth of stalk and total biomass. • Increased competitiveness from C3 weeds (e.g. temperate grasses). • Increased growth of vegetative plant parts (i.e. increased volume of trash). • Higher carbon to nitrogen ratio of leaves.	• Optimise supply of all necessary resources to the crop. • Use bio-control agents, cultural practices and expert systems for improved weed and crop management. • Adopt or breed suitable varieties with characteristics of high-partitioning sucrose. • Adopt the integrated pest management system.
Increased temperatures	
• Yields may decrease as a result of increased heat and evaporation, stomatal closure and leaf damage. However, increased carbon dioxide may override these effects. • Sucrose content may decrease as a result of higher temperatures during the harvest season. • Incidence of pests and diseases may increase through better survival of populations during winter periods, the spread of exotic populations into wider climatic windows and altered ecological interactions with natural enemies. • Increased carbon decomposition and soil nitrogen mineralisation. • Increased crop energy diverted into producing trash and fibre. • Limits to crop growth in frost-prone areas in the western districts.	• Lengthen the period of harvest time to increase yield, or grow additional fallow or cash crops. • Reduce excessive biomass accumulation by planting later and emphasising erect growth habit in breeding and variety selection. • Use varieties with greater tolerance to higher temperatures. • Optimise supply of all necessary resources. • Alter the duration of the harvest season to coincide with cooler temperatures. • Use adapted varieties and management practices, i.e. irrigation scheduling in favour of sucrose accumulation and use ripeners to better manage sugar accumulation. • Change cultural practices to reduce pests and disease (e.g. use legume crops to break soil pest and disease cycles) and reduce vegetative growth (e.g. reduce water use from irrigation).
	• Change insecticides, fungal and bacterial bio-pesticides. • Use varieties with improved resistance to pests and diseases. • Use integrated pest management. • Use decision support software. • Revise quarantine boundaries. • Consider implementing pest strategies presently used by more northerly regions. • Review soil carbon and nitrogen management practices. • Use precision agriculture and legume crops to boost soil organic carbon and nitrogen stores. • Use varieties with low vegetative growth habits and stalk fibre content.
Changes in rainfall	
• Limited supply of irrigation water. • Reduced soil anaerobic conditions and nutrient loss through less leaching and erosion. • Increased commercial cane sugar through more effective drying-off period. • Increased traffic-ability for harvest machinery and the timeliness of operating. • Poor crop establishment. • Decreased yields as a result of increased crop water stress. • Reduced quality of supplementary water. • Reduced rate of early leaf area and canopy development. • Reduced photosynthesis, tillering and stalk length.	• Optimise availability of all resources (possibly through precision agriculture). • Adopt efficient irrigation technology to control water table and monitor water table position. • Adopt efficient irrigation technology. • Increase use of supplementary water. • Optimise irrigation scheduling. • Use more effective irrigation water delivery technologies (i.e. trickle tape). • Construct on-farm water storage. • Use drought-tolerant or more water efficient varieties. • Modify row spacing. • Minimise tillage. • Use cover crops. • Improve catchment vegetation distribution and ground cover to increase infiltration rate.

Likely Impacts	*Potential Strategies for Adaptation*
More intense storms, increases in rainfall intensity and rising sea levels	
• Increased physical damage to crops and infrastructure. • Increased soil erosion and nutrients and sediment load to the Great Barrier Reef. • Decreased yield through reduced infiltration of rainfall into the soil. • Increased flooding, land degradation and damage to infrastructure. • Exacerbation of storm and cyclone damage. • Increased intrusion of saltwater into coastal aquifers.	• Plant trees around the paddock to act as a windbreak. • Use harvesting machinery suitable for harvesting a lodged crop. • Use varieties with reduced propensity to lodging and adopt cultural practices to reduce lodging (e.g. hilling up). • Diversify crops with a shorter duration. • Utilise insurance and reinsurance options to offset risk. • Use trash blanketing to intercept rainfall, inhibit lateral movement of water, reduce evaporation, improve soil structure and water infiltration, and increase soil carbon stores. • Use conservation tillage to reduce soil compaction. • Alter row configurations. • Use drainage ditches and laser levelling to control localised flooding and retain surface water, nutrients and sediment. • Increase use of precision farming and adopt conservation tillage methods. • Construct man-made seawater defences. • Restrict groundwater pumping. • Abandon bores already impacted by saltwater intrusion. • Monitor water quality in aquifers. • Investigate new regions to plant sugarcane.

Fish Stall at Morgans Seafood, Scarborough, Queensland — Courtesy of Tourism Queensland

Fishing Industry

The majority of Queensland Fisheries extend the entire length of the east coast, with a few fisheries also located in the Gulf of Carpentaria. The highest value Queensland fishery, the East Coast Otter Trawl Fishery, targets nine prawn species, two bug species, two lobster species, two crab species and a variety of other crustaceans, plus several species of molluscs and fish (Fisheries Queensland 2016). In the 2014 season, the total harvest for this fishery (including recreational, indigenous and charter fishing) was 6,681 tonnes with a gross value of production (GVP) of $86 M. The next highest value fisheries are three line fisheries which cover the entire Queensland coast line, including the Gulf of Carpentaria. These fisheries target a variety of fish species and have an approximate total harvest of 6,300 tonnes and GVP of $38 M.

Much of the information below on the impacts of a changing climate on the fishing industry is drawn from Holbrook and Johnson (2014), Hobday et al. (2008), Johnson and Marshall (2007), and NCCARF (2011c).

Opportunities for the Fishing Industry • Increased nutrient influx, multiple spawning events and participation in fishing. • Increased abundance and catch rates of some target prawn and bug species due to possible biomass and growth increases with rising temperatures.	**Case Study – Climate effects on Prawns in Southern Queensland** The catch rates of Banana Prawns and Greasyback Prawns in Moreton Bay increase as freshwater flow increases, especially from the Brisbane River. Higher temperatures also influence the abundance of prawns: as temperatures increase, the tropical species, Banana Prawn increase, whereas the temperate Eastern King Prawn decreases. (Courtney et al. 2012).

<table>
<tr><th>Likely Impacts</th><th>Potential Strategies for Adaptation</th></tr>
<tr><td>Increased carbon dioxide levels and ocean acidification</td><td rowspan="6">

Incorporate climate risk management into Ecosystem Based Fishery Management including further developments in by-catch reduction and improved targeting practices.
Implement responsive business practices and management amendments including:

improving fishing technology including technology to locate stock and communicate with other boats and people on land;
reviewing sustainable and precautionary harvest levels;
building resilience through improved stock status;
improving spatial management including zoning of fish habitats to minimise unwanted species interactions and closures; and
using predictive models for estimating harvest levels (Hobday et al. 2008).

Make seasonal changes to home port to minimise economic costs associated with transport.
Develop programs to restore and protect fish habitats, breeding grounds, nursery habitats and fish refugia.
Increase environmental flow allocation and water aeration.
Implement operational changes including fleet restructuring, optimising catch per unit effort and diversifying income streams.
Develop a new business model that enables fewer fishing days to increase responsiveness to good weather.

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Degradation of reef habitats may lead to a decrease in small reef fish. This may impact higher trophic level species which may be important for recreational and commercial fisheries (Munday et al. 2008, Pratchett et al. 2008).
Ocean acidification may have impacts on the olfactory cues of some tropical fish species, impacting connectivity and ability to migrate (Booth et al. 2009).

</td></tr>
<tr><td>Increased ocean temperatures</td></tr>
<tr><td>

Changes to reproduction, life history traits, catchability and fish behaviour (Voice et al. 2006).
In freshwater dependent fisheries, impacts may include earlier spawning, skewed sex ratios and decreases in oxygen levels.
In both freshwater and marine fisheries, there may be changes to the distribution of species, range expansions and contractions, and modified tolerance to normal temperature changes.
There may be a southern distribution shift of some species, may increase the risk of competition between resource users.
Established fishing grounds may decrease in size or be replaced with other species leading to changed profitability.

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<tr><td>Changed rainfall patterns</td></tr>
<tr><td>

A decrease in rainfall may lead to an altered nutrient supply in near-coastal habitats, which may lead to changed spawning timing and availability of recruits (Voice et al. 2006).
The penaeid prawn fisheries and other estuarine-dependent fisheries may be sensitive to changes in rainfall and freshwater flow.
Changes to freshwater flow patterns may change nutrient runoff, which may affect productivity.
In freshwater dependent fisheries, decreases in rainfall and subsequent drought may lead to decreased participation in the industry and, therefore, decreased input into the local economy.
There may be decreases in natural recruitment, growth rates and connectivity, and increases in the number of natural fish deaths.
Between January and March in the year immediately following an El Niño event there may be enhanced vulnerability of the reef to coral bleaching reducing fish habitat and health of the reef.

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</table>

Maroochy River, Queensland — Courtesy of Tourism Queensland

Likely Impacts	*Potential Strategies for Adaptation*
More intense storms, rising sea levels and changes to ocean circulation	
• In trawl fisheries, more frequent and intense storms may lead to a decrease in the number of fishing days, fishing opportunity, reduced effort and an increase in the need for more robust equipment. • There may be potential impacts on coastal habitats (e.g. mangrove forests, estuarine and river systems and seagrass beds) which provide important breeding and nursery grounds for prawns, crab and fish. • The extent of mangrove areas and connectivity between habitats may be reduced. • Sea level rise and inundation will impact estuarine species and river fish populations (Voice et al. 2006, Booth et al. 2009). • Changes to ocean circulation may have potential impacts on larval transport among reefs and on the distribution and production of plankton, which may reduce the growth, distribution, reproductive success and survival of larvae, pelagic fishes and reef-associated fishes. • Changes to ocean circulation may change patterns of fish migration taking stocks away from traditional fishing grounds. • An increase in the severity of tropical cyclones will cause increased damage to reefs and negatively impact on reef line fishers' productivity.	


Aquaculture & Seafood, Gold Coast, Queensland
Courtesy of Tourism Queensland

Aquaculture Industry

In 2014-15, the aquaculture industry in Queensland was worth $120 M (Fisheries Queensland 2015). The two largest components include prawns and barramundi. Other species harvested include jade perch, redclaw, silver perch, eels, black tiger and kuruma prawns, mud crabs and rock oysters. In 2014-15, the estimated farm-gate value of the Australian prawn industry was $83 M (4950 tonnes); while the Australian barramundi sector was worth $28 M (Fisheries Queensland 2015).

Much of the information below on the impacts of a changing climate on the aquaculture industry is drawn from Hobday et al. (2008) and Johnson and Marshall (2007).

Opportunities for the Aquaculture Industry

- Rising temperatures may extend the cultivation area suitable for farming these species further south.
- The production systems for native warm water fish and crayfish, which consist of static earthen ponds that re-use fish effluent water, will more easily adapt to more variable temperature and limited future water supplies.

Case Study – The positive impact of increased temperatures on farmed prawn productivity

- Increasing atmospheric temperature and resulting higher water temperature may increase production efficiency of tropical and sub-tropical species of farmed prawns, such as *Penaeus monodon* and *P. merguiensis* (Hobday et al. 2008).
- Studies have shown that during prolonged periods of warmer pond water, growth rates of tiger prawns (*P. monodon*) were observed to be around the maximum (Jackson and Wang 1998 in Hobday et al. 2008).

Likely Impacts	***Potential Strategies for Adaptation***
Increased acidification (carbon dioxide and pH)	• Selective breeding for tolerance to, or the use of alternate species that are pre-adapted to, altered temperature, water and salt regimes. • Use of dedicated sedimentation ponds (Jackson et al. 2003). • Relocation of production facilities and associated infrastructure. • Raise bund walls around farms to minimise overflowing.
• Increased acidification and warmer temperatures may adversely impact growth and reproduction although some species may be able to adapt to the change. • Increased acidification may also lead to decreased calcification and growth rates in some species.	
Increased water temperatures	
• Increases in temperature can influence biological systems by modifying the timing of spawning, the tolerance to increased water temperatures, the range and distribution of some species, and composition and interactions within marine communities (Walther et al. 2002). • Pond evaporation rates will be increased and the increased salinity may adversely affect less salt-tolerant species. • Temperature-induced disease outbreaks may increase (Harvell et al. 2002). • Increases in air temperature may lead to a change in the geographic suitability for some pond-based systems (Voice et al. 2006).	
More intense storms, rising sea levels and changes to ocean circulation	
• Changes to rainfall patterns will lead to changes in suspended sediment and nutrient loads. • Alteration of precipitation patterns will alter salinity, nutrients and suspended sediment levels of coastal waters with implications for coastal aquaculture. The viable regions for aquaculture may shift, depending on species. • Decreased rainfall will negatively impact aquaculture industries that rely on rainfall to fill dams and ponds. • Storms may increase flood risk which in turn threaten brackish water ponds reducing farm production. Severe flooding may result in mass mortalities. • Storms may also increase the frequency of physical damage, infrastructure damage and stock losses. This may be exacerbated by rising sea level and storm surges. • Increases in nutrient pulses, algal blooms and storm tides can negatively affect profitability (NCCARF 2011c). • Severe rainfall events may result in loss of stock through potential for escape of stock (e.g. flooding of ponds).	

More Information

For more information, including projections for 2050 and 2070, please refer to http://www.climatechangeinaustralia.gov.au/en/ or Dowdy et al. 2015.

For more information on the varying and changing climate please see the Queensland Government and The Long Paddock websites at http://www.qld.gov.au/environment/climate/climate-change/ and http://www.longpaddock.qld.gov.au, in particular:

- **The Climate Change Risk Management Matrix -** *http://www.longpaddock.qld.gov.au/products/matrix/index.html*
- **Queensland Coastal Hazard Area Maps -** *http://ehp.qld.gov.au/coastal/management/coastal_plan_maps.php#map_layers*

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Acronyms

APSIM, Agriculture Production Simulation Model
ENSO, El Niño Southern Oscillation
IPO, Interdecadal Pacific Oscillation
GVP, Gross Value of Production
MJO, Madden Julian Oscillation or 40 day wave
PDO, Pacific Decadal Oscillation
SOI, Southern Oscillation Index
SST, Sea Surface Temperature

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References

Australian Bureau of Statistics (**ABS**) 2016a, Value of agricultural commodities produced, Australia, 2014-15, Category Number: 7503.0, Australian Burean of Statistics © Commonwealth of Australia, http://www.abs.gov.au

Australian Bureau of Statistics (**ABS**) 2016b, Agricultural Commodities, Australia, 2014-15, Category Number: 71210.0, Australian Burean of Statistics © Commonwealth of Australia, http://www.abs.gov.au

Bonanno, GA, Brewin, CR, Kaniasty, K and La Greca, AM 2010, Weighing the Costs of Disaster: Consequences, Risk, and Resilience in Individuals, Families, and Communities, Psychological Science in the Public Interest, vol. 11, pp. 1-49.

Booth, D, Edgar, G, Figueria, W, Jenkins, G, Kingsford, M, Lenanton, R and Thresher, R 2009, Temperature Coastal and Demersal Fish and Climate Change, A Marine Climate Change Impacts and Adaptation Report Card for Australia 2009.

Bureau of Meteorology (**BoM**) 2016, Australian climate variability and change - Trend Maps, Bureau of Meteorology, http://reg.bom.gov.au/cgi-bin/climate/change/trendmaps.cgi

Cai, W, Shi, G, Cowen, T, Bi, D and Ribbe, J 2005, The response of the Southern Annular Mode, the East Australian Current, and the southern mid-latitude ocean circulation to global warming, Geophysical Research Letters, vol. 32.

Cai, W., Borlace, S., Lengaigne, M., Van Rensch, P., Collins, M., Vecchi, G., Timmermann, A., Santoso, A., McPhaden, M.J., Wu, L. and England, M.H. 2014, Increasing frequency of extreme El Niño events due to greenhouse warming. *Nature climate change*, *4*(2), pp.111-116.

Cai, W., Wang, G., Santoso, A., McPhaden, M.J., Wu, L., Jin, F.F., Timmermann, A., Collins, M., Vecchi, G., Lengaigne, M. and England, M.H. 2015. Increased frequency of extreme La Niña events under greenhouse warming. *Nature Climate Change*, *5*(2), pp.132-137.

Caldeira, K. and M. E. Wickett. 2005,"Ocean model predictions of chemistry changes from carbon dioxide emissions to the atmosphere and ocean." *Journal of Geophysical Research: Oceans* 110.C9.

Canegrowers 2011, Annual Report 2010/11, Queensland Cane Growers Organisation Ltd, Brisbane, Queensland http://www.canegrowers.com.au

Clewett, JF, Clarkson, NM, George, DA, Ooi, SH, Owens, DT, Partridge, IJ and Simpson GB 2003, Rainman StreamFlow version 4.3: a comprehensive climate and streamflow analysis package on CD to assess seasonal forecasts and mangement climate risk, QI03040, Department of Primary Industries, Queensland.

Cobon, D, Stone, G, Carter, J, Scanlan, J, Toombs, N, Zhang, X, Willcocks, J and McKeon, G 2009, The Climate Change Risk Management Matrix for the grazing industry of northern Australia, The Rangeland Journal, vol. 31**,** pp.31-49 http://www.longpaddock.qld.gov.au/about/publications/index.html

Cobon, DH, Williams, AA, Power, B, McRae, D and Davis, P, 2016. Risk matrix approach useful in adapting agriculture to climate change. *Climatic Change*, pp.1-17.

Commonwealth Scientific and Industrial Research Organisation and Bureau of Meteorology (**CSIRO and BOM**) 2012a, State of the Climate 2012, Commonwealth Scientific and Industrial Research Organisation and Bureau of Meteorology http://www.csiro.au/Outcomes/Climate/Understanding/State-of-the-Climate-2012.aspx

CSIRO and Bureau of Meteorology 2015, Climate Change in Australia Information for Australia's Natural Resource Management Regions: Technical Report, CSIRO and Bureau of Meteorology, Australia.

Courtney, AJ, Kienzle, M, Pascoe, S, O'Neill, MF, Leigh, GM, Wang, Y-G, Innes, J, Landers, M, Braccini, M, Prosser, AJ, Baxter, P, Sterling, D & Larkin, J 2012, *Harvest strategy evaluations and co-management for the Moreton Bay Trawl Fishery*, Australian Seafood CRC final report, project 2009/774, Queensland Department of Agriculture, Fisheries and Forestry, Brisbane.

Dairy Australia 2011, Climate Toolkit, Dairy Australia http://www.dairyaustralia.com.au.

Dairy Australia 2015. Australian Dairy Industry in Focus, Dairy Australia Limitied 2015. 2015ISSN 2202-7467 (Online); ISSN 1448-9392 (Print).

Daly, JJ 1984, Cattle need shade trees, Queensland Agriculture Journal, vol. 110**,** pp.21-24.

Department of Climate Change and Energy Efficiency (**DCCEE**) 2011, Change Risks to Coastal Buildings and Infrastructure: A Supplement to the First Pass National Assessment, Commonwealth of Australia (Department of Climate Change and Energy Efficiency), http://www.climatechange.gov.au/~/media/publications/coastline/riskscoastalbuildings.pdf

Department of Climate Change and Energy Efficiency (**DCCEE**) 2012, Climate Change - potential impacts and costs: Queensland, Commonwealth of Australia (Department of Climate Change and Energy Efficiency), http://www.climatechange.gov.au/en/climate-change/impacts/national-impacts/~/media/publications/adaptation/fs-QLD-PDF.pdf

Department of Science, Information Technology, Innovation and the Arts (**DSITIA**) 2012, Queensland's Land Use Innundation of 0.8m Sea level above Highest Astronomical Tide. Base Data: Geoscience Australia 2011. 1 Second SRTM derived hydrological digital elevation model (DEM-H) Version 1.0, Canberra, Brisbane, http://ehp.qld.gov.au/coastal/management/coastal_plan_maps.php#map_layers

Deuter, P 2008, Defining the Impacts of Climate Change on Horticulture in Australia, Reports Commissioned by the Garnaut Climate Change Review, http://www.garnautreview.org.au/CA25734E0016A131/pages/all-reports--resources-commissioned-reports.html

Doherty, TJ and Clayton, S 2011, The Psychological Impacts of Global Climate Change, American Psychologist, vol. 66**,** pp. 265-76

Dowdy, A, Abbs, D, Bhend, J, Chiew, F, Church, J, & Ekström, M 2015, East coast cluster report. *Climate Change in Australia Projections for Australia's Natural Resource Management Regions: Cluster Reports, Australia. CSIRO and Bureau of Meteorology*.

Finch, VA, Bennett, IL and Holmes, CR 1984, Coat colour in cattle - effect on thermal balance, behaviour and growth, and relationship with coat type, Journal of Agriculture Science, vol. 102**,** pp. 141-47.

Fisheries Queensland 2015, "Ross Lobegeiger Report to Farmers Aquaculture Production Summary for Queensland 2014-15." Department of Agriculture and Fisheries, Queensland Government 2015.

Fisheries Queensland 2016, Fisheries Queensland Summary Status Reports, https://www.daf.qld.gov.au/fisheries/monitoring-our-fisheries/data-reports/sustainability-reporting/queensland-fisheries-summary

Fordyce, G, Tyler, R and Anderson, VJ 1990, Effect of reproductive status, body condition and age of Bos indicus cross cows early in a drought on survival and subsequent reproductive performance, Australian Journal of Experimental Agriculture, vol. 30**,** pp. 315-22.

Harvell C.D., Mitchell C.E., Ward J.R., Altizer S., Dobson A.P., Ostfeld R.S. and Samuel M.D. 2002. Climate warming and disease risks for terrestrial and marine biota. Science 296: 2158-2162.

Hobday, AJ, Poloczanska, ES and Matear, RJ (eds) 2008, Implications of Climate Change for Australian Fisheries and Aquaculture: a preliminary assessment, Report to the Department of Climate Change, Canberra.

Holbrook, N. J., & Johnson, J. E.,2014. Climate change impacts and adaptation of commercial marine fisheries in Australia: a review of the science. *Climatic change, 124*(4), 703-715. doi:10.1007/s10584-014-1110-7.

Hopkins, PS, Knight, GI and Le Feuvre, AS 1978, Studies of the environment physiology of tropical Merinos, Australian Journal of Agricultural Research, vol. 29**,** pp. 161-71

Horticulture for Tomorrow (**HAL**) 2012, Horticulture for Tomorrow: For Growers, Your Catchment, Queensland, http://www.horticulturefortomorrow.com.au/for_growers/your_catchments/qld.asp.

Hosking, C., Mills, M. and Lovelock, C. 2014, *Climate Change and Agriculture: a study for the SEQ Catchments NRM,* Global Change Institute, University of Queensland.

Howard, WR et al. 2012, Ocean acidification, In: A Marine Climate Change Impacts and Adaptation Report Card for Australia 2012, Poloczanska, ES, Hobday, AJ and Richardson, AJ (eds.), http://www.oceanclimatechange.org.au.

Howden, S M and McKeon, G M and Reyenga, P J 1999, *Global change impacts on Australian rangelands. Working Paper Series 99/09.* Working Paper. CSIRO Wildlife and Ecology, Resource Futures Program, 1999, Lyneham, A.C.T.

Hughes, L and McMichael, T 2011, The Critical Decade: Climate change and health, Climate Commission, Commonwealth of Australia (Department of Climate Change and Energy Efficiency), http://climatecommission.gov.au/wp-content/uploads/111129_FINAL-FOR-WEB.pef

Intergovernmental Panel on Climate Change (**IPCC**) 2013, **Scenario Process For Ar5**, http://sedac.ipcc-data.org/ddc/ar5_scenario_process/index.html

Jackson C.J., Preston N.P., Burford M.A. and Thompson P. 2003. Managing the development of sustainable shrimp farming in Australia: the role of sedimentation ponds in treatment of farm discharge water. Aquaculture 226: 23-34.

Johnson, JE and Marshall, PA 2007, Climate Change and the Great Barrier Reef, Great Barrier Reef Marine Park Authority and Australian Greenhouse Office.

King, JM 1983, Livestock water needs in pastoral Africa in relation to climate and forage, Addis Ababa, ILCA Research report**,** vol. 94.

Low, T 2011, Climate Change and Terrestrial Biodiversity in Queensland, Department of Environment and Resource Management, Queensland Government, Brisbane.

McKeon, G, Hall, W, Henry, B, Stone, G and Watson, I 2004, Learning from history. Pasture degradation and recovery in Australia's rangelands, Queensland Department of Natural Resources, Mines and Energy, Brisbane.

McKeon, GM, Stone, GS, Syktus, JI, Carter, JO, Flood, NR, Ahrens, DG, Bruget, DN, Chilcott, CR, Cobon, DH, Cowley, RA, Crimp, SJ, Fraser, GW, Howden, SM, Johnston, PW, Ryan, JG, Stokes, CJ and Day, KA 2009, Climate change impacts on northern Australian rangeland livestock carrying capacity: a review of issues, A Climate of Change in Australian Rangelands, The Rangeland Journal, vol. 31**,** pp.1-30.

Montgomery, SS 1990, Possible impacts of the greenhouse effect on commercial prawn population and fisheries in New South Wales, Wetlands (Australia), vol. 10, pp.35-39.

Mott, JJ and Edwards, GP 1992, Beyond beef - a search for a level grazing paddock, Search, vol.7, pp. 223-5.

Munday, P.L., Jones, G.P., Pratchett, M.S., Williams A.J. 2008. Climate Change and the Future for Coral Reef Fishes. *Fish and Fisheries* **9**, 261-285.

Murphy, R and Simpson, G 2011, Balancing dairy production and profits in Northern Australia: QDAS Financial and production trends – 2011, Department of Employment, Economic Development and Innovation, Toowoomba, Queensland.

National Climate Change Adaptation Research Facility (**NCCARF**) 2011a, Climate change impacts factsheet: 8. Human Health, http://www.nccarf.edu.au/sites/default/files/8.Health-Impacts.pdf

National Climate Change Adaptation Research Facility (**NCCARF**) 2011b, Climate change impacts factsheet: 4. Primary Industries, http://www.nccarf.edu.au/sites/default/files/4.Primary-Industries-Impacts.pdf

National Climate Change Adaptation Research Facility (**NCCARF**) 2011c, Climate change impacts factsheet: 1. Marine biodiversity and resources, http://www.nccarf.edu.au/sites/default/files/1.Marine-Impacts.pdf

Nowak, RS, Ellsworth, DS and Smith, DS 2004, Functional responses of plants to elevated atmospheric CO_2 - do photosynthetic and productivity data from FACE experiments support early predictions? New Phytologist, vol. 162**,** pp. 253-80.

Poloczanska, ES, Hobday, AJ and Richardson, AJ 2009, Report Card of Marine Climate Change for Australia, In: Poloczanska, ES, Hobday, AJ and Richardson, AJ (eds.), NCCARF Publication 05/09.

Potgieter, A, Meinke, H and Doherty, A 2004, Likely impact of climate on wheat and sorghum production in central Queensland, 4th International Crop Science Congress, Brisbane.

Pratchett, MS, Wilson, SK, Graham, NAJ, Cinner, JE, Bellwood, DR, Jones, GP, Polunin, NVC, McClanahan, TR, 2008 Effects of climate-induced coral bleaching on coral-reef fishes – ecological and economic consequences**.** *Oceanography and Marine Biology: An Annual Review* **46,** 251-296.

Queensland Department of Agriculture, Fisheries and Forestry (**QLDDAFF**) 2010, Sugar, http://www.daff.qld.gov.au/26_6730.htm

Queensland Farmer's Federation (**QFF**) 2012, Farming in Queensland, Queensland Farmer's Federation, http://www.qff.org.au/farming-in-qld/

Rodriguez, D, deVoil, P, Power, B and Cox, H 2011a, Adapting to change: more realistic quantification of impacts and better informed adaptation alternatives, 5th World Congress of Conservation Agriculture incorporating 3rd Farming Systems Design Conference, September 2011, Brisbane.

Rodriguez, D, deVoil, P, Power, B, Cox, H, Crimp, S and Meinke, H 2011b, The intrinsic plasticity of farm businesses and their resilience to change. An Australian example, Field Crops Research, vol. 124, pp. 157-270.

Scientific Advisory Group (**SAG**) 2010, Increasing Queensland's resilience to inland flooding in a changing climate, Final Scientific Advisory Group report, Department of Environment and Resource Management, Brisbane, http://www.ehp.qld.gov.au/climatechange/pdf/inland-flood-study.pdf

Standards Australia 2004, AS/NZS4360:2004 Risk Management.

Stokes, C 2011, Developing improved industry strategies and policies to assist beef enterprises across northern Australia adapt to a changing and more variable climate, MLA Milestone 3 report, Project No. B.NBP.0617, Meat and Livestock Australia.

Stokes, C and Howden, M 2010, Adapting agriculture to climate change: preparing Australian agriculture, forestry and fisheries for the future, CSIRO.

Stokes, C, Ash, AJ, Scanlan, J and Webb, N 2011, Strategies for adapting to climate change, Proceedings of the Northern Beef Research Conference, Darwin**,** pp. 81-86.

Stokes, CJ, Ash, AJ and Holtum, JA 2008, Savannas face the future: windows into a future CO_2 enriched world, A Climate of Change in the Rangelands, 15th Biennial Conference, Charters Towers, Queensland, Australian Rangeland Society.

Sun, C, Feng, M, Matear, RJ, Chamberlain, MA, Craig, P, Ridgway, KR and Schiller, A, 2012 Marine downscaling of a future climate scenario for Australian boundary currents. *Journal of Climate*, 25(8), pp.2947-2962.

Sutherst, RW 1990, Impact of climate change on pests and diseases in Australia, Search, vol. 21**,** pp. 232.

Taylor, B., Marshall, N., Heyenga, S., Butler, D. and Long, P., 2015a. Grazing and Climate Change in the East Coast Cluster: Impacts and Opportunities. Prepared as part of the East Coast NRM Cluster, CSIRO, Brisbane.

Taylor, B., Marshall, N., Heyenga, S., 2015b. Cropping and Climate Change in the East Coast Cluster: Impacts and Opportunities. Prepared as part of the East Coast NRM Cluster, CSIRO, Brisbane.

Taylor, B., Marshall, N., Heyenga, S., 2015c. Horticulture and Climate Change in the East Coast Cluster: Impacts and Opportunities. Prepared as part of the East Coast NRM Cluster, CSIRO, Brisbane.

The Climate Institute (**TCI**) 2011, A Climate of Suffering: the real cost of living with inaction on climate change (Melbourne and Sydney), The Climate Institute.

Tothill, CJ and Gillies, C 1992, The pasture lands of northern Australia - their condition, productivity and sustainability, Tropical Grassland Society of Australia, Occasional Publication No 5, Brisbane.

Voice, M, Harvey, N and Walsh, K 2006, Vulnerability to Climate Change of Australia's Coastal Zone: Analysis of gaps in methods, data and system thresholds, Report to the Australian Greenhouse Office, Canberra.

Walther, G, Post, E, Convey, P, Menzel, A, Parmesan, C, Beebee, TJC, Hoegh-Guldberg, O and Bairlein, F 2002, Ecological responses to recent climate change, Nature, vol. 146, pp. 389-95.

Webb, NP, Stokes, CJ and Scanlan, JC 2011, Interacting effects of vegetation, soils and managment on the sensitivity of Australian savanna rangelands to climate change, Climate Change, DOI: 10.1007/s10584-011-0236-0.

White, N, Sutherst, R, Hall, W and Whish-Wilson, P 2003, The vulnerability of the Australian beef industry to the impacts of the cattle tick (Boophilus microplus) under climate change, Climatic Change, vol. 61**,** pp. 157-90.

Witte, C, van den Berg, D, Rowland, T, O'Donnell, T, Denham, R, Pitt, G and Simpson, J 2006, Mapping Land Use in Queensland - Technical Report on the 1999 Land Use Map for Queensland, NRMW, Brisbane.

Williams KJ, Prober SM, Harwood TD, Doerr VAJ, Jeanneret T, Manion G, and Ferrier S (2014) Implications of climate change for biodiversity: a community-level modelling approach, CSIRO Land and Water Flagship, Canberra. Available at: www.AdaptNRM.org ISBN 978-1-4863-0479-0.