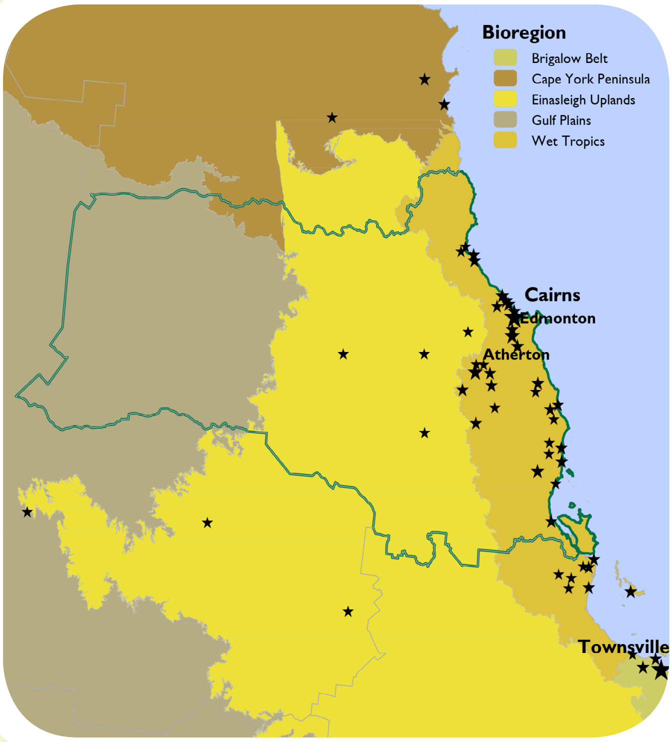

Courtesy of Tourism Queensland

Impacts and adaptation strategies for a variable and changing climate in the **Far North Queensland Region**



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

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Regional Profile

The Far North Queensland (FNQ) region extends from the Wujal Wujal Aboriginal Shire Council in the north to Cassowary Coast Regional Council in the south, and west to include the Atherton Tablelands. The region includes most of the Wet Tropics of Queensland's World Heritage Area and parts of the Great Barrier Reef World Heritage Area, making it one of the most bio-diverse regions on the planet.

The region has a tropical hot and humid climate with an average annual minimum temperature of 20.7°C and an average annual maximum temperature of 28.8°C in Cairns. Rainfall predominantly occurs in the wet season which is from December to March. The average historical annual rainfall (1882-2015) is 2115 mm around Cairns.

Major Primary Industries

Dairy, beef production, cropping, tropical horticulture, aquaculture, fisheries and mining are the major industries in the region and sugarcane farming also represents a major land-use. The wet tropics and the World Heritage-listed properties in this region attract millions of visitors each year and tourism is a major contributor to the economy. The gross value of production (GVP) in 2014-15 of agricultural commodities in the Wet Tropics region was $1.1 B or 9% of the state total GVP for agricultural commodities ($11.9 B, ABS 2016a).

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Climate Trends and Projections

Historical changes in the key climate variables relevant to agricultural production including temperature, evaporation, rainfall, sea surface temperature, hot days and duration of warm periods are summarised in Table 1. Table 2 provides information on the historical means for the key variables and the projected changes for 2030.

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	NSC to +0.15 (coast)	+0.05 (north) to +0.1 (south)	0 (west) to +0.15 (east)
Minimum Temperature (°C)	1950	+0.1 (west) to +0.30 (east)	+0.1 to +0.20	+0.10 to +0.30
Mean Temperature (°C)	1950	+0.05 to 0.20	+0.05 to +0.1	+0.05 to +0.20
Pan Evaporation (mm)	1970	0 to 5	-2.5 to +2.5	0 to 2.5
Rainfall (mm)	1950	-40 (south) to +20 (north)	-30 (south) to +20 (north)	0 to +5
Sea Surface Temperature (°C)	1950	+0.08 to +0.16	+0.08 to +0.12	+0.08 to +0.12
Number of Hot Days	1970	+2.5 days		
Cold Spell Duration	1970	-1.5 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 2012). 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 frequency 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 61,589 ha (0.8%) of the Far North Queensland region land (7.35 Mha) which consists mainly of existing nature conservation land (0.4%) and marsh/wetland (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, repre-senting 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	**24.2**	**27.1**	**24.2**	**20.2**	**25.3**
	Projections for 2030	**+1** **+1 to +1.4**	**+1** **+0.5 to +1.5**	**+1** **+0.4 to +1.4**	**+1** **+0.4 to +1.4**	**+1** **+0.5 to +1.3**
Rainfall (mm)	Historical means	**1085**	**642**	**272**	**60**	**112**
	Projections for 2030	**-5%** **-14% to +12%**	**-4%** **-29% to +26%**	**-3%** **-21% to +20%**	**-5%** **-52% to +18%**	**-6%** **-46% to +25%**
Potential Evaporation (mm)	Historical mean	**1821**	**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 McInnes et al. 2015.*			
	Projections for 2030	**+3%** **+2% to +6%**				
Relative Humidity	Projections for 2030	**-1%** **-3% to +1%**				
Wind Speed	Projections for 2030	**1%** **0 to +6%**				

Impacts of a variable and changing climate in the Far North 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 (Marshall 2014).

Likely Impacts	*Potential Strategies for Adaptation*
Extremes of weather and climate (drought, flood, cyclones, heatwaves etc.) on human well-being (TCI 2011, Hughes and Mc-Michael 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:
  ◦ number of bushfires due to extreme heat and aridity;
  ◦ risk of mosquito-borne, water-borne and food-borne diseases;
  ◦ number of infectious and contagious diseases with an increase in the number of injuries; and
  ◦ 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 bush-fires, 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

Portions of the Gulf Plains (GP), Wet Tropics (WT) and Einasleigh Uplands (EU) bioregions are located within the Far North Queensland region. The GP bioregion is dominated by vast plains vulnerable to increased flooding over large areas and is an important bioregion for waterbirds such as Brolgas. This bioregion has very few threatened species. The WT is one of Australia's most diverse and significant bioregions as it has the most extensive and species-rich rainforests. The western boundary is made up of tall wet eucalypt forests. High altitude species in this bioregion face serious risks from a changing climate, with invertebrates being the highest risk. The EU region has a high species diversity and level of endemism associated with diverse topography, high elevations and extensive vegetation. The impacts of climate change on biodiversity in the region will introduce new stressors to species and ecosystems, and in some regions, impacts are already evident (Reside et al. 2014, Williams et al. 2014).

Likely Impacts	***Potential Strategies for Adaptation***
Extremes of weather and climate (drought, flood, cyclones, heatwaves etc.) on Biodiversity (Low 2011)	
Impacts in the Gulf Plains • Long dry spells, followed by heavier precipitation events could lead to increased flooding events on the GP. This may result in cattle and wildlife loss, widespread pasture death and weed invasion (Parkinsonia aculeta). • Ground dwelling reptile species, including common skinks, geckoes and dragons, may disappear in the GP due to more severe flood events. Only those species who can survive in trees, such as the gecko (Heteronotia binoei) and the skink (Carlia munda), are likely to survive the increase in flood severity. • More severe flooding events in the GP may also affect kangaroo and wallaby populations, which can get stranded and die from starvation and exposure, and reduce populations of birds and centipedes. • The vulnerable purple-crowned fairy wren (Malurus coronatus) is an example of a species susceptible to population decline during drought due to increased trampling by cattle of the riparian vegetation they are dependent on and increased fire intensity in its restricted habitat. **Impacts in the Wet Tropics** • Rainforests within the WT bioregion, along the coastline, may be threatened by rising temperatures, altered rainfall patterns and carbon dioxide fertilisation altering competitive relationships, and cyclones causing disturbances. • Sea level rise, cyclones and associated storm surges threaten regional ecosystems on low lying land near the sea and rare plants within these ecosystems such as the ant plant (Myrmecodia beccarii). • increase of gamba grass, a highly invasive, very tall pasture grass, in this region may cause repeated intensive fires which can kill eucalypt forests. **Impacts in the Einasleigh Uplands** • Biodiversity losses in the EU bioregion should be less than the rest of the state due to its high, rocky vegetation. • Gamba grass can provide up to 12 times the fuel load of native grasses and cause fires intense enough to kill tress (Rossiter et al. 2003 in Low 2011). Gamba grass is a serious threat within the EU. • *Altered survival habits* - The EU bioregion has seven endem- and three near-endemic reptile species that may survive a changing climate by retreating deeper into the ground during hot dry periods and becoming more active during spring and autumn.	• Fire management. • Manage weeds and flammable invasive pasture grasses, such as buffel grass and gamba grass, in and near conservation areas. • Control pests and feral animals (goats, horses) to reduce losses and protect rare plants. • Protect refugia habitats. • Replant upland rainforests to increase the chances of montane animals surviving varying climates. • Control pigs to prevent the spread of *Phytophthora cinnamomi* and to help rainforest lizard, frog and invertebrate populations.

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 the Wet Tropics were 174,000 in 2014-15 which was 1.5% of the total cattle numbers for Queensland (ABS 2016b). In 2014-15 the GVP for cattle, sheep and wool for the Wet Tropics was $77 M (ABS 2016a) or 9% of state and 7% of the value of the Wet Tropics 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 FNQ are Black Spear Grass (50% of region), Aristida-Bothriochloa (30%) and Sparse land (12%) (Tothill and Gillies 1992). The soil fertility is average to very poor and growth of pastures is usually limited by low nitrogen availability.

There are climate change impacts specific to the Wet Tropics region and regionally specific adaptation options some of which will offset negative impacts and other that will enable opportunities to be had (Langston and Turton 2014).

Case Study – Impacts in the Far North 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 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 FNQ region were undertaken for the Mt Molloy, Wrotham Park and Mt Garnet 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 (10.40 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 Mt Molloy, Wrotham Park and Mt Garnet 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	+M	LC	-M	LC
2xCO_2	+M	-M	+M	LC	LC
+3°C, 2xCO_2	+M	-M	+M	LC	LC
+3°C, 2xCO_2, +10% rainfall	+M	-M	+M	LC	+M
+3°C, 2xCO_2, -10% rainfall	+M	-M	+M	LC	LC

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:

- the quality of native pasture grasses is likely to decrease due to doubled carbon dioxide and the combined effects of a 3°C rise in temperature, doubled carbon dioxide and either ±10% rainfall;
- pasture growth and liveweight gain are likely to increase with doubled carbon dioxide and the combined effects of a 3°C rise in temperature, doubled carbon dioxide and either ±10% rainfall;
- green pasture growing days are expected to increase with the combined effect of a 3°C rise in temperature, doubled carbon dioxide and 10% more rainfall; and
- overall, it is unlikely that changes in the climate shown here will affect the frequency of burning and green pasture growing days in this region.

Cattle Muster, Nebo, Queensland

Courtesy of Tourism Queensland

Opportunities for the Grazing Industry

- 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 – Impacts in nitrogen-limited areas

Although the carbon dioxide effects on forage production in nitrogen limited land types are uncertain, it is likely that elevated carbon dioxide will lead to improved nitrogen use efficiency in forage growth and lower minimum nitrogen concentrations in the forage, which is likely to reduce liveweight gain of livestock, increase the risk of wildfires and increase the importance of prescribed burning (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 Chillagoe has fluctuated between -12 and +8% compared with the long-term average since 1902 (Figure 1). The extended periods of lower rainfall (1920s to 1950s) 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.

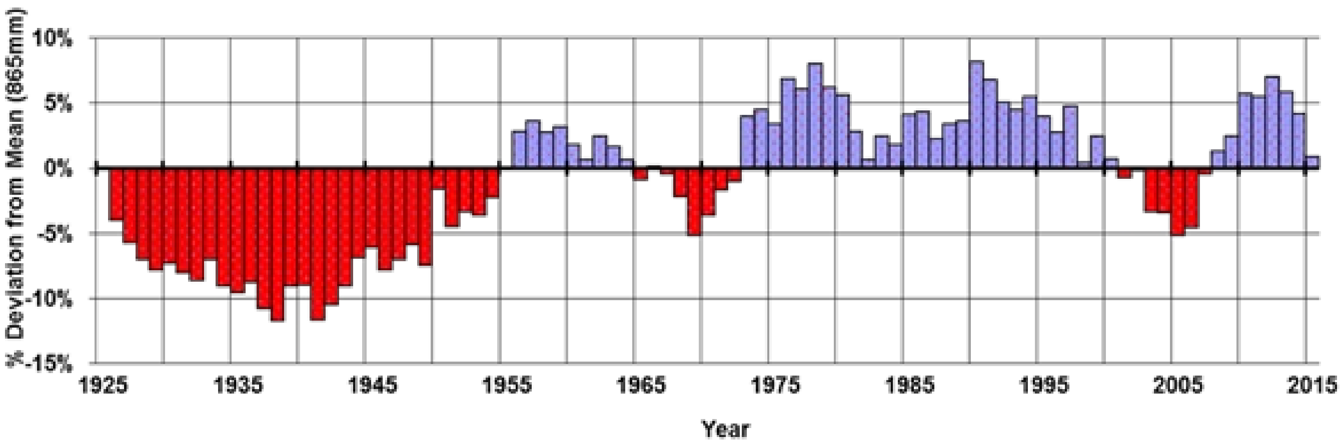

Figure 1: 25-year moving average rainfall (12 months, April in year 1 to March in year 2) at Chillagoe, Qld

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.

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). • 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.

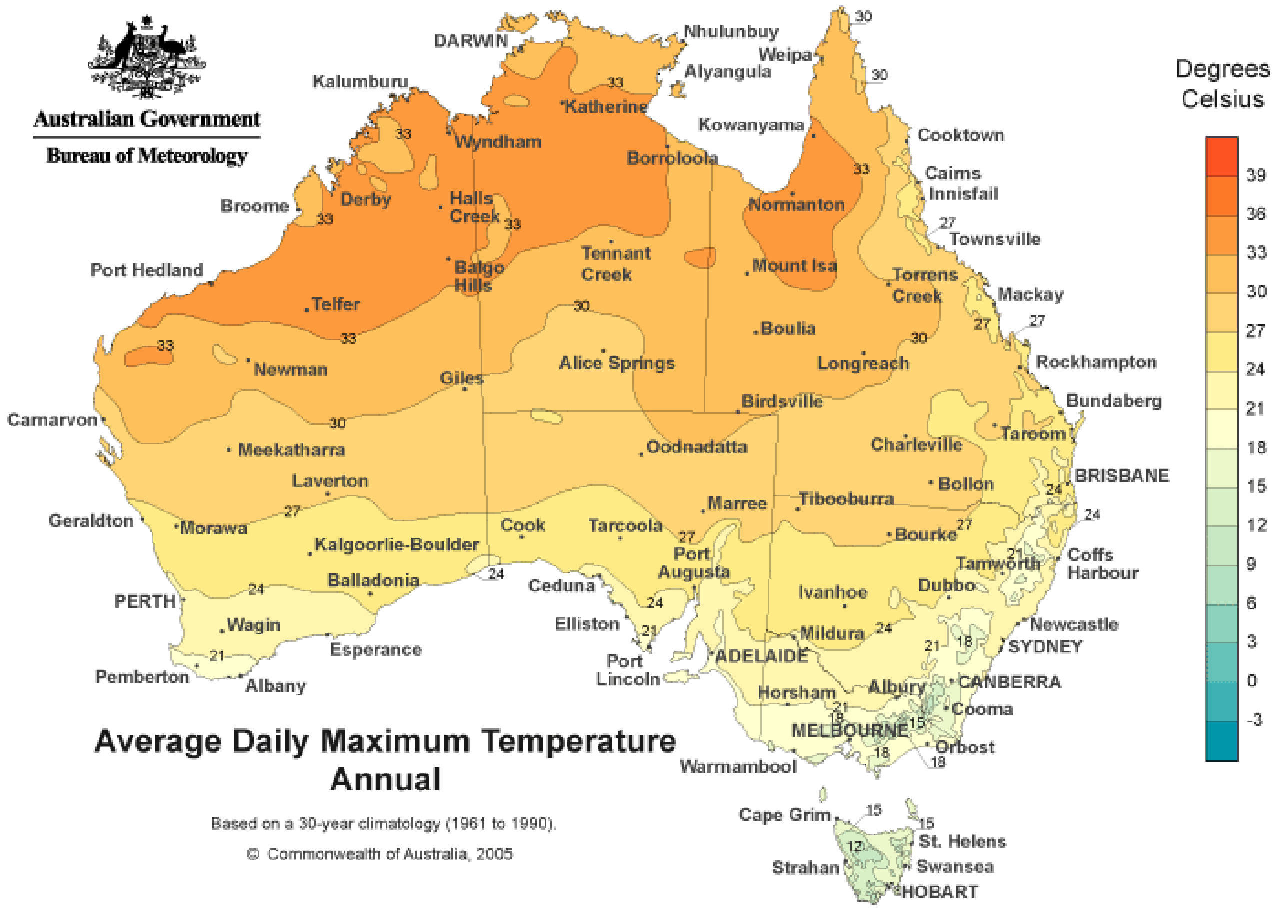

Figure 2: Annual average temperature in Australia (Source: Bureau of Meteorology). One degree of warming is roughly equivalent to moving 145 km toward the equator.

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).

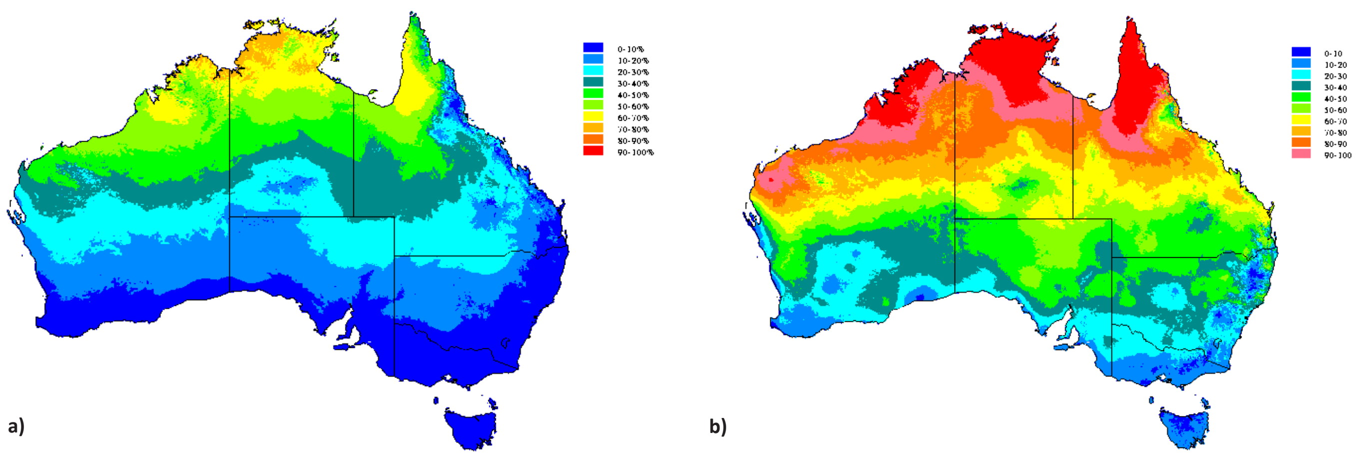

Figure 3: Frequency of days per year that the THI>80 for a) 1957-97 and b) a future climate scenario of +2.7°C. Thermal stress is significant in beef cattle when the THI exceeds 80 (Source: Howden et al. 1999).

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 the Wet Tropics produced 18% 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.
- 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. • Higher temperatures may reduce 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 areas. • Selectively breed stock, pasture and feedstock for 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	
• 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.	• 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, cyclones 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.

Dairy Farm, Malanda, Queensland

Courtesy of Tourism Queensland

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 20014-15, 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 $3.2 M in the Wet Tropics (ABS 2016a).

Much of the information below on the impacts of a changing climate on the cropping industry is drawn from 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).

Case Study – Effects of higher temperatures and increased carbon dioxide on crops

Warmer temperatures and rising carbon dioxide are likely to favour:

1. 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);
2. varieties with earlier-flowering characteristics which allow grainfill to occur in the cooler, wetter parts of the year in dry areas; and
3. varieties with characteristics such as higher response to elevated carbon dioxide conditions, rapid germination, early vigour and increased retention of flowers in hot/windy conditions (Stokes and Howden 2010).

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).	• 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:
	  • increasing residue cover by minimal or no-tillage;
	  • establishing crop cover in high loss periods;
	  • weed control; and
	  • 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.

Likely Impacts	*Potential Strategies for Adaptation*
	• 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.
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 grain-fill 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.
	• 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:
	  • zero-tillage practices, minimum disturbance planting techniques (e.g. seed pushing);
	  • controlled traffic;
	  • responding to planting opportunities when they occur;
	  • widening row spacing or skip-row planting;
	  • lowering plant populations;
	  • using efficient on-farm irrigation management with effective scheduling, application and transfer systems; and
	  • assessing fertiliser inputs.
	• Reduce surface soil erosion by:
	  • increasing residue retention;
	  • maintaining erosion control infrastructure (e.g. contour banking); and
	  • using controlled traffic systems.
	• Control pests and diseases.

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 Wet Tropics produced about 23% of the total value of the state's horticulture, including 4% of the value of vegetables, 43% of the value of fruit and nuts, and 8% of the value of nurseries, cut flowers and turf (ABS 2016a). The region is a major producer of Queensland's bananas (97% of $441 M GVP in 2014-15, ABS 2016a) and avocados (39% of $123 M GVP in 2014-15, ABS 2016a).

Much of the information below on the impacts of a changing climate for the horticulture industry is drawn from reports commissioned for the Garnaut Review (Deuter 2008).

Opportunities for the Horticulture Industry

- Increased minimum temperature and reduced frost frequency (in tropical highland areas) during the growing season may increase the area climatically suitable to optimum growth of sub-tropical crops such as avocado.
- Fruit and vegetable growers producing winter crops in tropical regions will experience warmer minimum temperatures in autumn, winter and spring with slightly reduced rainfall.

Case Study – Runoff treatment and best practices on a Banana farm in FNQ

A 2.5 ha wetland was constructed on a banana farm in South Johnstone to treat runoff from the farm and packing sheds. The farm is located 10 km from the GBR World Heritage Area and is surrounded by two creeks. The farm also has best practices including grassed inter-rows, the use of compost to increase organic matter in the soil, application of nutrients through fertigation, minimising soil compaction and monitoring soil moisture and plant nutrition which have reduced the risk of excess nutrient, sediment and chemicals leaving the production area, thereby reducing runoff. As a result, the farm has seen improved plant health, a reduction in pests and disease and has reduced application of granular fertilisers by a third, dramatically reducing costs (Dryden 2009).

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 hotter producing areas towards areas currently regarded as too cool. • 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 and other pests. • Potentially downgrading product quality. • Result in pollination failures. • Increase active soil-borne diseases and insect infestation for longer periods during the year. • May induce fruit abscission 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 may result in the winter production season being shortened. • Changes in disease and pest distribution ranges.	• Select for, or change to, available 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 crop protection treatments including solar radiation shading and evaporative cooling through overhead irrigation to maintain fruit quality. • Start breeding program for heat tolerant, low chill, and more adaptable varieties of various horticultural crops. Varieties with higher quality under enhanced carbon dioxide and elevated then 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 tools/models associated with managing climate variability to improve both quality and quantity of horticulture products. • Consider growing frost-sensitive fruit in regions previously considered unsuitable due to frost risk, e.g. expansion of areas for growth of tropical and sub-tropical crops such as citrus and avocados. • 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 and several other crops. • Increase the likelihood of crop damage and waterlogging, decreasing 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 (e.g. Great Barrier Reef).	• 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.


Rusty's Markets - Mangoes, Cairns, 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 the 2014-15 season, 30 M tonne of cane was produced in Queensland (ABS 2016b) with a value of $1.2 B of which 30% was produced in the Wet Tropics (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 Cyclone Yasi on sugarcane

In September 2011, canefarmers were starting to realise the full impact of Cyclone Yasi, which hit land in early February 2011. Due to cane damage by the cyclone, a large amount of cane could not reach full growth, thus reducing cane supply. As a result, the overall tonnage for 2011 was 23 M tonnes, about 10 M tonnes less than average (Hunt 2011).

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. • Use or breed suitable varieties with improved future climate yield characteristics (high sugars). • Adopt an 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.	• 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.

Likely Impacts	*Potential Strategies for Adaptation*
Reduced 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.	• 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. • Optimise availability of all resources (possibly through precision agriculture). • Adopt efficient irrigation technology to control water table. • Monitor water table position. • Improve catchment vegetation distribution and ground cover to increase infiltration rate.
More intense storms, increases in rainfall intensity and rising sea levels	
• Increased physical damage to crops and infrastructure. • Increased flooding, land degradation and damage to infrastructure. • Exacerbation of storm and cyclone damage. • Increased soil erosion and nutrients and sediment load to the Great Barrier Reef Marine Park. • Increased intrusion of saltwater into coastal aquifers. • Decreased yield through reduced infiltration of rainfall into soil.	• 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. • 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, adopt conservation tillage methods. • Construct man-made seawater defences and investigate new regions to plant sugarcane. • Restrict groundwater pumping. • Abandon bores already impacted by saltwater intrusion. • Monitor water quality in aquifers. • Investigate new regions to plant sugarcane.

Road between cane fields, Tully, 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 – The impacts of increased temperatures on redthroat emperor in the Great Barrier Reef

Sweetlip or redthroat emperor (Lethrinus miniatus) appears to be restricted to south of 18°S due to its apparent upper thermal limit of about 28°C. Its longevity of about 20 years means it is unlikely to adapt quickly to environmental change. The distribution of L. miniatus on the GBR is therefore expected to be reduced as temperature increases (Johnson and Marshall 2007).

Likely Impacts	*Potential Strategies for Adaptation*

Increased carbon dioxide levels and ocean acidification
• 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 acid-ification may have impacts on the olfactory cues of some tropical fish species, impacting connectivity and ability to migrate (Booth et al. 2009).
Increased ocean temperatures
• 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, which 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.
	• 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.
	• 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.

Fishing Trawler, Low Isles, Queensland

Courtesy of Tourism Queensland

Likely Impacts	*Potential Strategies for Adaptation*
Changed rainfall patterns	
• 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.	
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 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 (4,950 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 temperatures and limited future water supplies.

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

Increasing atmospheric temperature and the 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).

Likely Impacts	*Potential Strategies for Adaptation*
Increased acidification (carbon dioxide and pH) • 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 lead to decreased calcification and growth rates in some species.	• 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 in Hobday et al. 2008). • Relocation of production facilities and associated infrastructure. • Raise bund walls around farms to minimise overflowing.
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).	
Changed rainfall patterns and more frequent and intense storms • 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 McInnes 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
GVP, Gross Value of Production
IPO, Interdecadal Pacific Oscillation
MJO, Madden Julian Oscillation or 40 day wave
PDO, Pacific Decadal Oscillation
SOI, Southern Oscillation Index
SST, Sea Surface Temperature

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