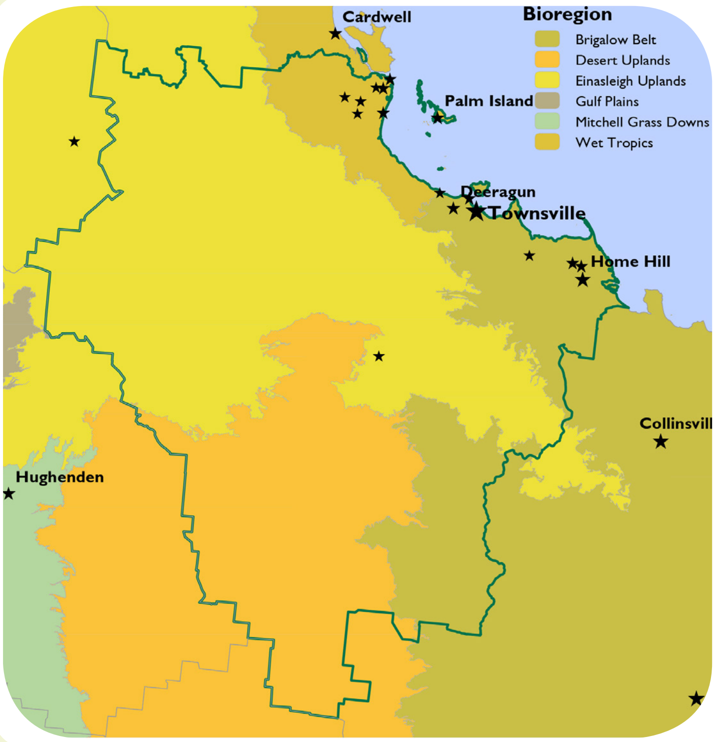
Impacts and adaptation strategies for a variable and changing climate in the TOWNSVILLE - THURINGOWA REGION



This summary describes the likely impacts of a variable and changing climate on the major primary industries of the Townsville-Thuringowa (TT) region including grazing, horticulture, sugar, fisheries and aquaculture, and the potential adaptation strategies which can be implemented to minimise climate risks.

Courtesy of Tourism Queensland

Regional Profile

The Townsville Thuringowa (TT, or Burdekin) region is located in the tropics on Queensland's east coast, covering an area of about 133,400 km^2. The main urban area is the twin city complex of Townsville and Thuringowa. Charters Towers is also within this region. The region has a diversity of landscapes including the interspersed wet tropical rainforests of Paluma including Crystal Creek, the drier sub-catchment area of the Burdekin River and the very wet coastal plains of the lower Burdekin River. Major water systems in the catchment include the Burdekin and Cape Rivers and Lake Dalrymple, created by the Burdekin Falls Dam. The main vegetation types in the region are eucalypt-dominated savannah woodlands and grasslands, interspersed with acacia forests and vine thickets.

The region has a humid, tropical climate with relatively high temperatures and pronounced wet and dry seasons. Rainfall occurs primarily between November and April mostly in the form of short duration but high intensity tropical storms. Temperatures range from an average annual minimum of 19.7°C to an average annual maximum of 28.7°C around Townsville (1871-2015), and 17.3°C to 30.1°C further west around Charters Towers (1882-2015). The average historical annual rainfall is 1146 mm around Townsville and 658 mm around Charters Towers. The region is affected by cyclones, strong winds, storm surges and flooding.

Major Primary Industries

In the Townsville-Thuringowa region, the land uses are predominantly irrigated sugar-cane farming which is mainly concentrated in the Burdekin River delta, horticulture, cropping, and beef cattle grazing. Mining has made a significant contribution to the regional economy for over 100 years. Aquaculture and fisheries industries also occur in this region. The gross value of production (GVP) in 2014-15 of agricultural commodities in the region was $1.2 B or 10% 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 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. In the Burdekin Region rainfall changes by 2030 are within the bounds of existing natural climate variability, and by 2090 there is still little confidence in rainfall projections with the exception of spring rainfall for which a slight decrease is suggested (Moise 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 (west) to +0.20 (east)	0 (north) to +0.20 (south)
Minimum Temperature (°C)	1950	+0.10 to +0.30	+0.10 (north) to +0.30	+0.10 (north) to +0.40
Mean Temperature (°C)	1950	+0.10 (north) to +0.30 (south)	+0.10 to +0.20	+0.05 (north) to +0.30 (south)
Pan Evaporation (mm)	1970	-5 to +10 (north)	+2.5 to +2.5	+2.5 to -2.5
Rainfall (mm)	1950	-60 (northeast) to -10 (southeast)	-30 (northeast) to 0 (west)	-5 to +5
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	0 to +2.5 days		
Cold Spell Duration	1970	0 - 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 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 107,259 ha (1.4%) of the Townsville Thuringowa region land (7.96 Mha) consisting mainly of existing marsh/wetland (0.6%), nature conservation areas (0.4%) and natural grazing land (0.14%) (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	**23.4**	**27.5**	**23.5**	**18.1**	**24.5**
	Projections for 2030	**+1** **+0.5 to +1.5**	**+1** **+0.5 to +1.6**	**+1** **+0.3 to +1.5**	**+1** **+0.5 to +1.5**	**+1** **+0.4 to +1.3**
Rainfall (mm)	Historical means	**661**	**371**	**147**	**51**	**92**
	Projections for 2030	**-8%** **-23% to +9%**	**-6%** **-31% to +24%**	**-6%** **-28% to +14%**	**-9%** **-51% to +25%**	**-9%** **-46% to +19%**
Potential Evaporation (mm)	Historical mean	**1748**	**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.*			
	Projections for 2030	**+3%** **+2% to +5%**				
Relative Humidity	Projections for 2030	**-1%** **-4% to +2%**				
Wind Speed	Projections for 2030	**2%** **0% to +9%**				

Impacts of a variable and changing climate in the Townsville - Thuringowa 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. Resilience is the ability to manage and adapt to change; regional community resilience can be enriched through increased skills and knowledge and also a range of NRM planning processes. (Marshall et al. 2015).

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 Brigalow Belt (BB), Wet Tropics (WT), Einasleigh Uplands (EU) and Desert Uplands (DU) bioregions are present within the Townsville-Thuringowa region. The BB is the largest bioregion in Queensland and is very rich in species, including large numbers of plants and animals with small ranges. This bioregion has endemic and near-endemic eucalypt, wattle and invertebrate 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 DU is dominated by a large sand sheet, has fewer endemic species than the adjoining bioregions and lacks large numbers of species with vulnerability to a changing climate. The degree of ecological change caused by climate change is more likely to be greater in the plant biological group than that in the mammals, amphibians or reptiles group (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 Brigalow Belt • Severe drought in the BB may result in deaths of many trees including Brigalow and Cypress pines. • Buffel grass invasion is of particular concern within the BB. Invasion of this species may displace groundcover plants and significantly increase fire risk. **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*). • An 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** • The EU bioregion has seven endemic and three near-endemic reptile species (one blind snake species and skinks) that may survive a changing climate by retreating deeper into the ground during hot dry periods and becoming more active during spring and autumn. • An increase in fire size and temperature may threaten many species including the northernmost populations of the rufous bettong (*Aepyprymnus rufescens*). • 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. **Impacts in the Desert Uplands** • Buffel grass invasion is of particular concern within the DU. Invasion of this species may displace groundcover plants and increase the risk of intensive fires. • As higher temperatures increase heat stress for cattle and sheep, more producers may farm goats or encourage feral goats. Higher goat numbers could seriously threaten rare and endemic shrubs in the region.	• Fire management. • Manage weeds and invasive pasture grasses, such as buffel grass, gamba grass and guinea grass, to prevent spread into conservation areas and the habitats of rare species. • Control pests and feral animals (goats, horses) to reduce losses and protect rare plants. • Control feral pigs to reduce damage of amphibian habitats and to reduce the spread of phytophthora root rot. • Protect refugia habitats. • Replant rainforest in the WT bioregion to assist species populations. • Prevent further clearing, fragmentation and degradation to protect the remaining lowland habitats in the WT and to increase survival of mahogany gliders and other lowland fauna. • Increase control of parkinsonia weeds to reduce the threat to seasonal wetlands used by water birds. • Reduce grazing around lakes to protect habitat for ground animals and nesting birds.

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 Burdekin were 1.14 M in 2014-15 which was 10% of the total cattle numbers for Queensland (ABS 2016b). In 2014-15 the GVP for cattle, sheep and wool for TT was $511 M (ABS 2016a) or 10% of state and 42% of the value of TT 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 TT are Black Spear grass (63% of region), Spinifex grass (12%) and Aristida-Bothriochloa (10%) (Tothill and Gillies 1992). The soil fertility is good (Black spear grass) to poor (Spinifex and Aristida-Bothriochloa) and growth of pastures is usually limited by inadequate rainfall (Black spear grass) or low nitrogen availability (Spinifex and Aristida-Bothriochloa). A review of the beef industry in the Monsoonal North is provided by Crowley 2015.

Case Study - Impacts in the Townsville-Thuringowa 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 TT region were undertaken for the Mingela, Clarke River and Mt McConnel 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 (7.22 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 Mingela, Clarke River and Mt McConnel 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	-M	+M	-M	-M	LC
2xCO_2	+M	-M	+H	+H	LC
+3°C, 2xCO_2	+M	-M	+M	+M	+M
+3°C, 2xCO_2, +10% rainfall	+M	-M	+H	+M	+M
+3°C, 2xCO_2, -10% rainfall	LC	LC	LC	-M	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 there are likely to be:

- the benefits of doubled carbon dioxide and the combined effect of a 3°C rise in temperature doubled carbon dioxide and 10% more rainfall associated with pasture growth, liveweight gain and frequency of burning outweighed the disadvantages caused by a 3°C rise in temperature;
- doubled carbon dioxide and the combined effect of a 3°C rise in temperature, doubled carbon dioxide and 10% more rainfall is likely to reduce pasture quality; and
- green pasture growing days are likely to increase with the combined effects of a 3°C rise in temperature and doubled carbon dioxide; and a 3°C rise in temperature, doubled carbon dioxide and 10% more rainfall.


Rural Scene, Charters Towers, Queensland

Courtesy of Tourism Queensland

Opportunities for the Grazing Industry

- Increased production of biomass will result from rising carbon dioxide concentration 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).

Modelling studies at Charters Towers showed the combined effects of a 2°C rise in temperature, 7% lower rainfall and doubling carbon dioxide are likely to result in little change in forage production (Webb 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 Charters Towers has fluctuated between -13 and +13% compared with the long-term average since 1882 (Figure 1). The extended periods of lower rainfall (mid 1910s to 1950s, late 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.

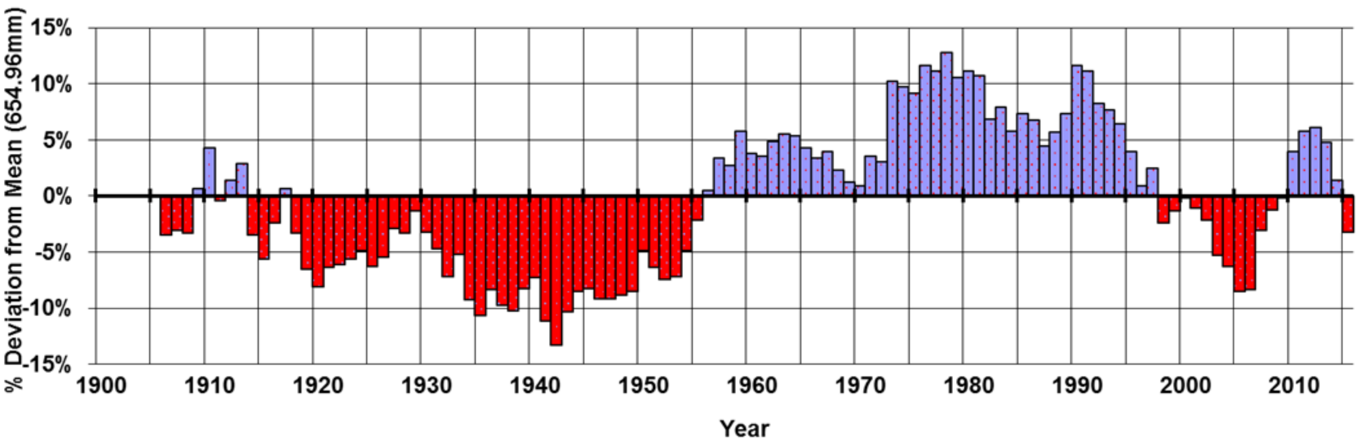


Figure 1: 25-year moving average rainfall (12 months, April in year 1 to March in year 2) at Charters Towers, Qld (Source: Clewett et al. 2003).

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: o LongPaddock (http://www.longpaddock.qld.gov.au); o AussieGRASS (http://www.longpaddock.qld.gov.au/about/researchprojects/aussiegrass/index.html); o ClimateArm http://www.armonline.com.au/ClimateArm o 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). • 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.

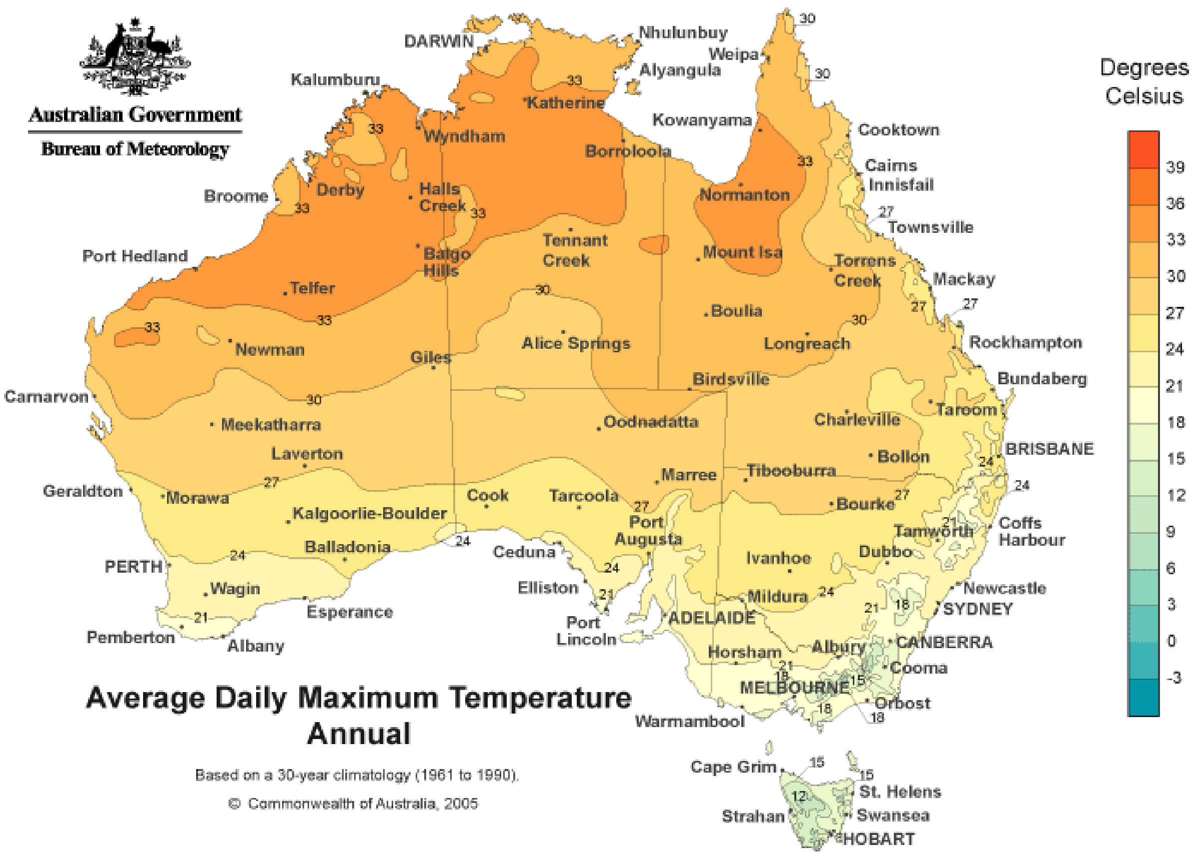


Figure 2: Annual average temperature in Australia (Source: Bureau of Meteorology). One degree of warming is roughly equivalent to moving 145 km toward the equator.

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).

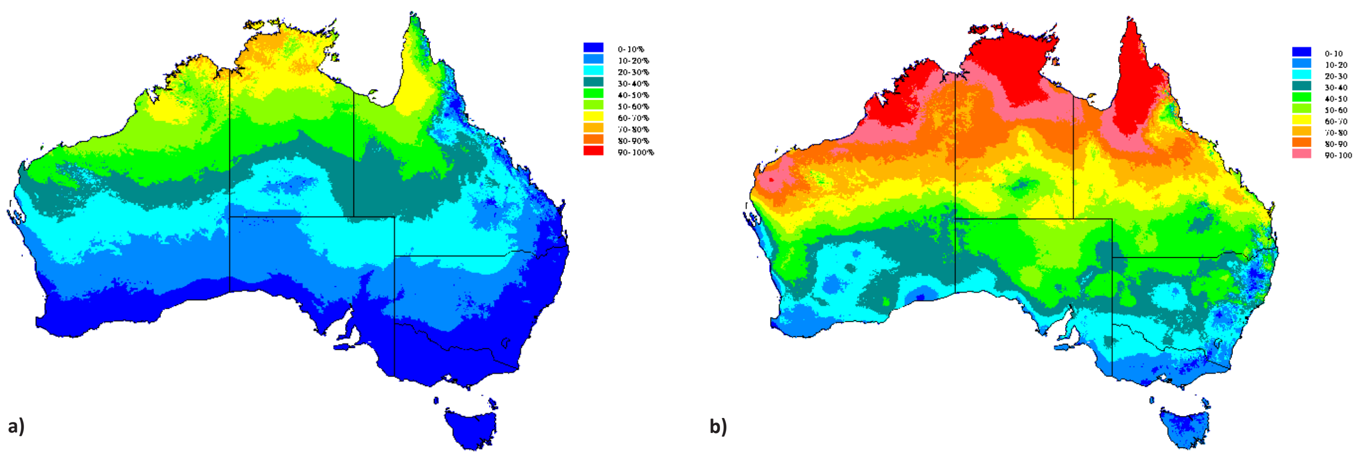


Figure 3: Frequency of days per year that the THI>80 for a) 1957-97 and b) a future climate scenario of +2.7°C. Thermal stress is significant in beef cattle when the THI exceeds 80 (Source: Howden et al. 1999).

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 the Burdekin produced about 12% of the total value of the state's horticulture, including 27% of the value of vegetables, 2% of the value of fruit and nuts, and 2% of the value of nurseries, cut flowers and turf (ABS 2016a). The region is a major producer of Queensland's tomatoes, beans, capsicums, mangoes, sweet corn and melons.

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, 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.
- Fruit and vegetable growers producing winter crops in tropical regions will experience warmer minimum temperatures in autumn, winter and spring with slightly reduced rainfall.

Likely Impacts	***Potential Strategies for Adaptation***
Increased temperatures	
• Changes to the suitability and adaptability of some crops. • Potential shift in the period for winter vegetable production. • 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 *Helicoverpa*. • Potentially downgrading product quality. • Result in pollination failures. • Increase active soil-borne diseases and insect infestation for longer periods during the year. • May affect the post-harvest quality for horticultural crops that are required to be cooled so as to remove field heat quickly. • 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 some crops, e.g. grapes, 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. • 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 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. • 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, avocados, bananas and pecan nuts. • Plant varieties with chilling requirements below 1000 hours.
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.

Likely Impacts	*Potential Strategies for Adaptation*
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, 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.

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 29% was produced in the Burdekin (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 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. • 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).

Likely Impacts	*Potential Strategies for Adaptation*
	• 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.

Sugar Cane burning, Ayr, Queensland

Courtesy of Tourism Queensland

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.

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 (2011b).

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 reduce as temperature increases (Johnson and Marshall 2007).

Jupiters Casino, Townsville, Queensland

Courtesy of Tourism Queensland

<table>
<tr><th>Likely Impacts</th><th>Potential Strategies for Adaptation</th></tr>
<tr><td>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 acidification 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, 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.
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.</td>
<td>• 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:
o improving fishing technology including technology to locate stock and communicate with other boats and people on land;
o reviewing sustainable and precautionary harvest levels;
o building resilience through improved stock status;
o improving spatial management including zoning of fish habitats to minimise unwanted species interactions and closures; and
o 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.</td></tr>
</table>

The Strand, Townsville, Bundaberg, 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.	


The Strand, Townsville, Bundaberg, 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 cray-fish, which consist of static earthen ponds that reuse 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).

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 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).	• 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.
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 2011b). • 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
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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