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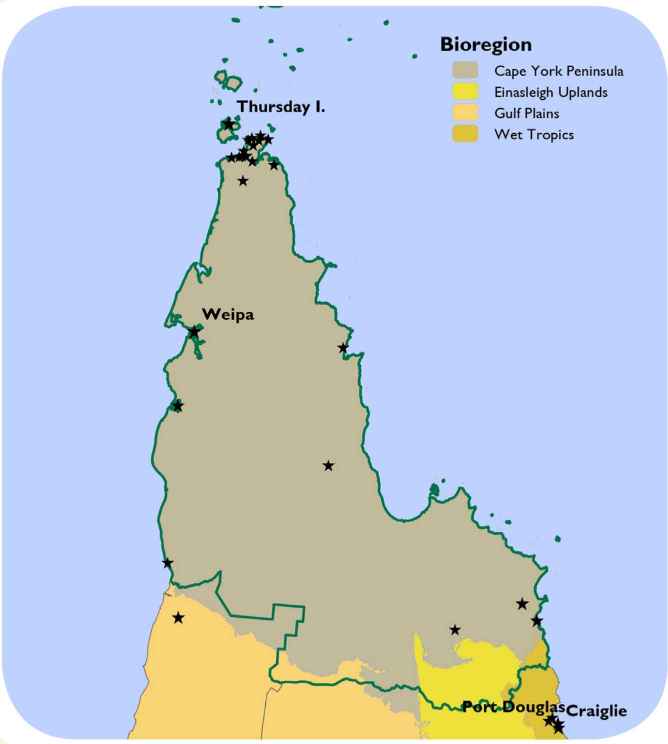
Impacts and adaptation strategies for a variable and changing climate in the CAPE YORK REGION



This summary describes the likely impacts of a variable and changing climate on the major primary industries of the Cape York (CY) region including grazing, fisheries, and aqua-culture, and the potential adaptation strategies which can be implemented to minimise climate risks.

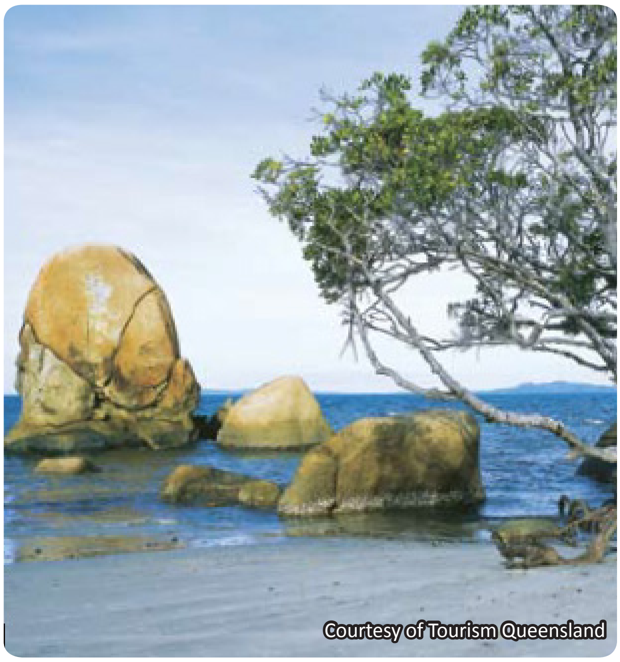
Regional Profile

The Cape York (CY) region covers an area of 137,000 km^2 which includes the Torres Strait Islands and the towns of Weipa, Cooktown and Laura. It is bounded by the Gulf of Carpentaria to the west, the Torres Strait to the north and the Coral Sea to the east.

The region has a typical tropical and monsoonal climate with hot to very hot temperatures experienced throughout the year. The annual average minimum and maximum temperatures are 24.1°C and 29.3°C for Thursday Island, and 19.3°C and 32.8°C for Palmerville. Rainfall is highly seasonal, with most rain falling during the wet season from October to March as heavy thunderstorms generated by monsoonal lows or tropical cyclones. Average historical annual rainfall is 1740 mm on Thursday Island (1888-2015) and 1042 mm in Palmerville (1890-2015). The region contains some exceptional conservation assets including relatively intact and extensive coastal dune-fields, wetlands, rainforests, heathlands and river systems which support a high level of unique biodiversity (COC 2011).

Major Primary Industries

The main sectors of primary industry include cattle grazing and fisheries. The region has an established and rapidly expanding mining industry as well as an emerging tourism industry. Aquaculture industries, such as pearling and sponge farming, also occur within the Torres Strait. The gross value production (GVP) in 2014-15 of agricultural commodities in the region was $49 M or 0.4% of the state total GVP for agricultural commodities ($11.9 B, ABS 2016a).



Climate Trends and Projections

Historical changes in the key climate variables relevant to agricultural production including temperature, evaporation, rainfall, sea surface temperature, hot days, duration of warm periods and length of growing season 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 (south) to +0.10	NSC to +0.10	+0.05 to +0.15
Minimum Temperature (°C)	1950	+0.10 (north) to +0.20 (south)	+0.05 to +0.30	+0.05 to +0.15
Mean Temperature (°C)	1950	+0.05 to +0.15	+0.05 to +0.15	+0.05 to +0.15
Pan Evaporation (mm)	1970	0 to 5 mm/year	-2.5 to +2.5 mm/year	-2.5 to 0.0 mm/year
Rainfall (mm)	1950	0 to +30	+5 to +30	0 to +5
Sea Surface Temperature (°C)	1950	+0.12 to +0.18	+0.08 to +0.16	+0.12 to +0.16
Number of Hot Days	1970	+2.5 (south) to 12.5 (north) 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

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).
- The minimum height that structures need to be raised in order to maintain the present likelihood of flooding is approximately 0.14 m in 2030 for most of the Queensland coast. By 2090 there is more variation along the coast with values ranging between 0.65 m to 0.85 m in the scenario of highest CO_2 emissions (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 27,929 ha (0.2%) of the Cape York region land (12.6 Mha) consisting mainly of existing marsh/wetland (0.1%) and nature conservation land (0.03%) (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	**26**	**28**	**26**	**23.0**	**26.9**
	Projections for 2030	**+1** **+0.5 to +1.2**	**+1** **+0.5 to +1.4**	**+1** **+0.5 to +1.3**	**+1** **+0.5 to +1.2**	**+1** **+0.5 to +1.2**
Rainfall (mm)	Historical means	**1305**	**849**	**346**	**20**	**92**
	Projections for 2030	**-5%** **-12% to +8%**	**-1%** **-22% to +16%**	**-3%** **-19% to +14%**	**-2%** **-51% to +35%**	**-9%** **-44% to +82%**
Potential Evaporation (mm)	Historical mean	**1856**	**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 +5%**				
Relative Humidity	Projections for 2030	**-1%** **-3% to 0%**				
Wind Speed	Projections for 2030	**-2%** **-1% to +5%**				

Impacts of a variable and changing climate in the Cape York 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 (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 foodborne 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 Cape York Peninsula (CYP) bioregion covers the entire Cape York region and faces lower impacts of climate change than most of the state. It is a flat region dominated by Sclerophyll woodland (Eucalyptus/Corymbia and Melaleuca) but supports small areas of rainforest, moist sclerophyll forests, heathland, and substantial wetlands, mangroves and saltmarshes. The CYP is rich in endemic species, which occur in a range of habitats including reptiles, amphibians, mammals and some vegetation. There are low levels of diversity and endemism in the rainforest habitats compared to the neighbouring Wet Tropics bioregion. 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 Cape York Paninsula • Some trees are susceptible to drought so that even slight reductions in water availability will increase the natural rate of drought deaths, influencing woodland composition. • Woodland composition could be altered due to an increase in fire risk. • The endangered rodent species, the Bramble Cay melomys, may face a greater threat from a changing climate than any other Queensland species. Restricted to a tiny sand cay in the Torres Strait, with a population of less than 100, waves and storm surges associated with cyclones threaten the survival of this species (Van Dyck and Strahan 2008; Latch 2008 in Low 2011). • Cyclones may promote the spread of gamba grass and other weeds, fuelling fires. • Fauna will be seriously threatened if taller, vigorous growing exotic grasses (i.e. gamba grass, grader grass) and other highly flammable grasses benefit from a changing climate by invading large areas. • Sea level rise will inundate freshwater mangroves, saltmarshes and freshwater wetlands. This may lead to mangroves expanding into saltmarshes.	• Invest in fire management to protect rainforest remnants, wet sclerophyll remnants, and the habitat of the endangered golden-shouldered parrot. • Prevent further spread of introduced pastures grasses, such as gamba grass and grader grass, to reduce fire risk. • Control of feral cattle to improve fire management and to reduce habitat destruction. • Control feral pigs to reduce habitat destruction.

Cape York, Queensland

Courtesy of Tourism Queensland

Grazing Industry

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

Cattle numbers in CY were 90,740 in 2014-15 which was 0.8% of the total cattle numbers for Queensland (ABS 2016b). In 2014-15 the GVP for cattle, sheep and wool for CY was $41 M (ABS 2016a) or 0.4% of state and 86% of the value of CY 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 the CY region are Monsoon tallgrass (50% of region), Aristida-Bothriochloa (10%) and sparse land with little grass cover (10%) (Tothill and Gillies 1992). Their growth is driven by high, relatively reliable summer and autumn rainfall, but limited by poor soil fertility (plant growth is often limited by available nitrogen, Mott et al. 1985) and competition for limited nutrients from woody vegetation.

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 Cape York 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 CY region were undertaken for the Laura, Coen and Merluna 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 (7.57 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 Laura, Coen and Merluna for modelled pasture growth (kg/ha), pasture quality (% nitrogen in growth), liveweight gain of cattle (LWG kg/ha), frequency of burning and green pasture growing days (GPGD) (Source: Cobon et al. 2012 *unpublished data*).

Future climate	Growth	Quality	LWG	Burning	GPGD
+3°C	LC	LC	LC	LC	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	LC
+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:

- there is expected to be little or no impact on pasture growth with a 3°C rise in temperature;
- the quality of native pasture grasses is expected to decline in all future climate scenarios, apart from a 3°C rise in temperature;
- the combined effects of higher temperature, doubled carbon dioxide and 10% more or less rainfall is likely to increase pasture growth and liveweight gain; and
- the frequency of burning and green pasture growing days is not expected to change with the future climate shown here.

Coastline near Cooktown, Queensland

Courtesy of Tourism Queensland

Opportunities for the Grazing Industry

- Warmer conditions in a wet environment will increase growth of pasture and allow more frequent use of prescribed burning to control woody weeds (Burrows et al. 1990).
- Warmer conditions in a wet environment may increase soil fertility by increasing plant decomposition and nitrogen availability (Robbins et al. 1989).
- 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 low digestibility) (Stokes et al. 2011).

Case Study - Climate effects on Monsoon Tallgrass

The combination of reliable rainfall, poor soil fertility and competition for limited nutrients results in high pasture yields of poor quality, low stocking rates and the need for prescribed burning and supplementation to maintain beef production. Control of weeds and feral animals is important for productivity and the ecological integrity of the resource.

Carbon dioxide effects on pasture growth in regions where availability of nutrients (particularly nitrogen) are a major limitation to pasture growth are highly uncertain (e.g. monsoonal northern Queensland) (McKeon et al. 2009).

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 Coen has fluctuated between -14 and +11% compared with the long-term average since 1887 (Figure 1). Extended periods of lower rainfall (1930s to 1970s) 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.

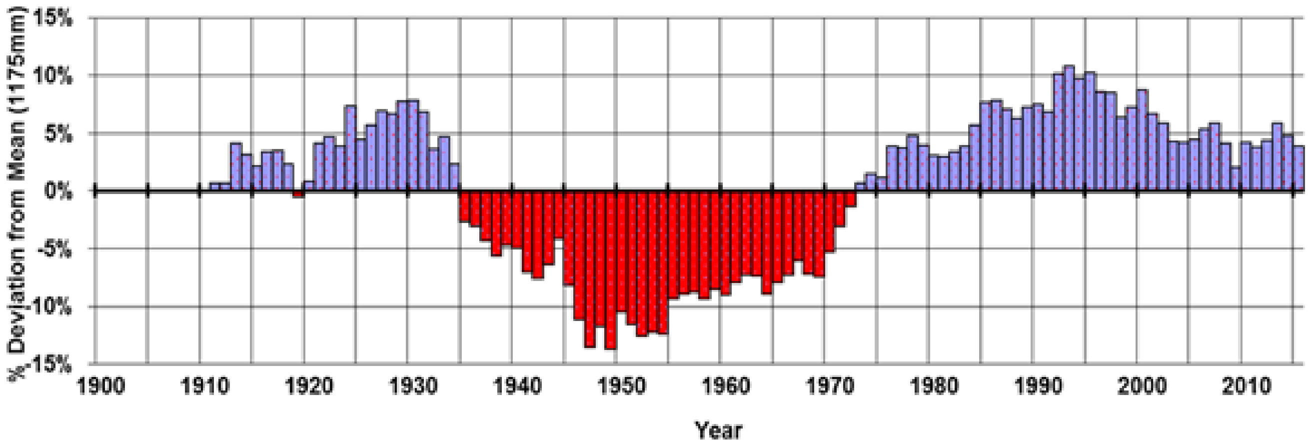


Figure 1: 25-year moving average rainfall (12 months, April in year 1 to March in year 2) at Coen, Cape York Peninsula (Source: Clewett et al. 2003).

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.

Horn Island, Torres Strait, Tropical North Queensland

Courtesy of Tourism Queensland

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

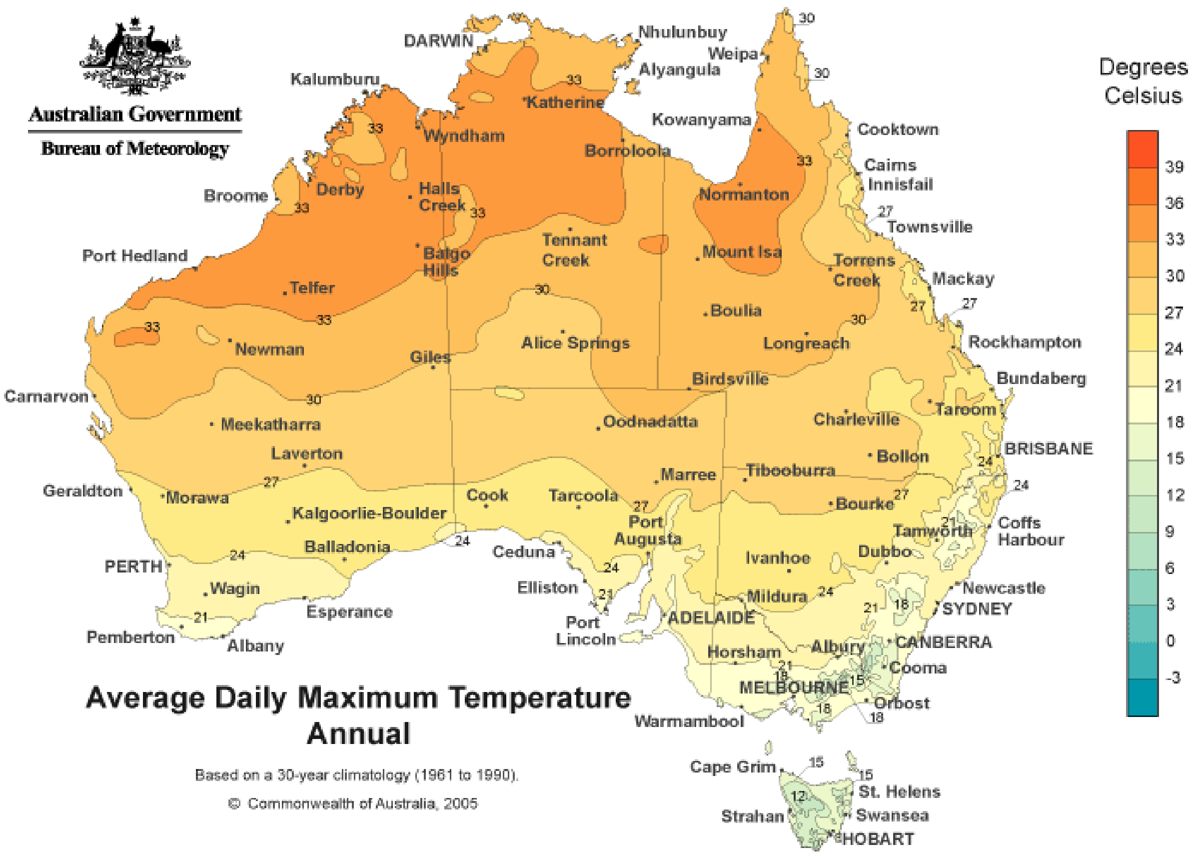


Figure 2: Annual average temperature in Australia (Source: Bureau of Meteorology). One degree of warming is roughly equivalent to moving 145 km toward the equator.

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 out-weigh 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).	• Select cattle lines with effective thermoregulatory controls (e.g. increase *Bos indicus* content), efficient feed conversion and lighter coat colour (Finch et al. 1984, King 1983).

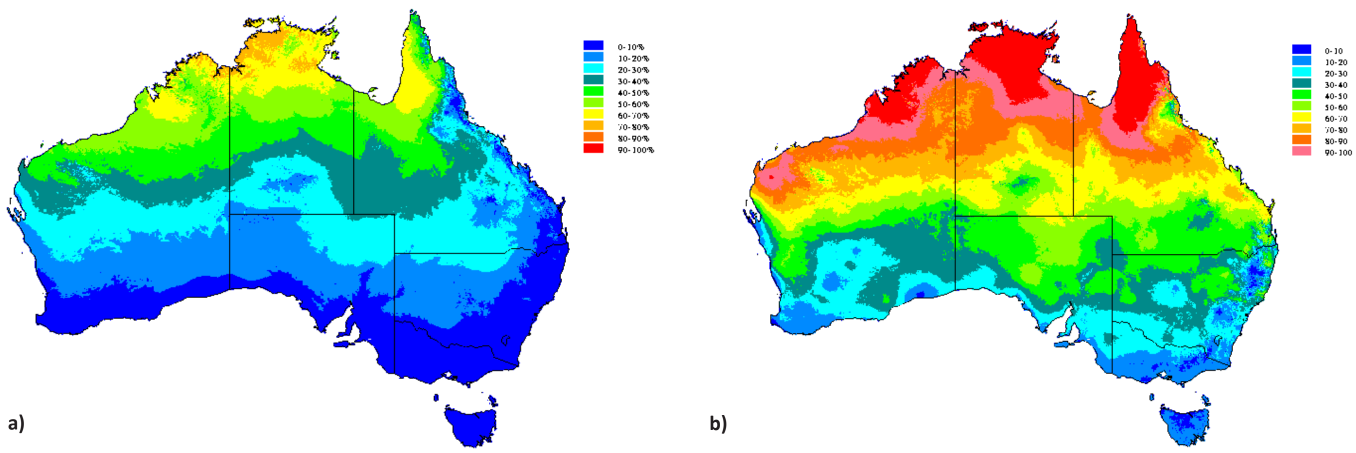


Figure 3: Frequency of days per year that the THI>80 for a) 1957-97 and b) a future climate scenario of +2.7°C. Thermal stress is significant in beef cattle when the THI exceeds 80 (Source: Howden et al. 1999).

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.

The Crayfish and Rock Lobster fishery is located in the Cape York and Gulf regions. In 2014, this fishery had a total harvest of 192 tonnes with a GVP of $7.3 M. The Gulf of Carpentaria Line and Inshore Fin Fish Fisheries target Spanish mackerel, barramundi, threadfins, shark and grey mackerel. In 2014, the line fishery had a total harvest of 191 tonnes with a GVP of $1.3 M, while the fin fish fishery had a total harvest of 1,620 tonnes with a GVP of $9.7 M (Fisheries Queensland 2016).

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 penaeid prawn species in Northern Australia

In both laboratory and field experiments, high temperatures reduce growth and survival of juvenile banana prawns (*Penaeus merguiensis*) and juvenile brown tiger prawns (*P. esculentus*) (Haywood and Staples 1993, Heales 1991 and O'Brien 1994 in Hobday et al. 2008).

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 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.	• 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 (CPUE) and diversifying income streams.

Coconut Island, Torres Strait, Tropical North Queensland

Courtesy of Tourism Queensland

Likely Impacts	*Potential Strategies for Adaptation*
Changed rainfall patterns	• Develop a new business model that enables fewer fishing days to increase responsiveness to good weather.
• 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 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 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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References

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

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

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

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

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

Burrows, W., Carter, J., Scanlan, J., and Anderson, E., 1990, Management of savannas for livestock production in north-eastern Aistralia: contrasts acrosss the tree-grass continuum, Journal of Biogeography, vol. 17, 503-512.

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

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

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

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

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

Caring for our Country (COC) 2011, Cape York - Natural Resource Management region, Caring for Our Country, Australian Government http://www.nrm.gov.au/about/nrm/regions/qld-cyrk.html

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

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

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

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

Commonwealth Scientific and Industrial Research Organisation and Bureau of Meteorology (**CSIRO and BOM**) 2012b, Climate Change in Australia: Queensland Annual Sea surface temperature change, Commonwealth Scientific and Inudstrial Research Organisation and Bureau of Meterology, http://www.climatechangeinaustralia.gov.au/qldsea10.php

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

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

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

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

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

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

Dryden, K 2009, Constructed wetland treating banana farm runoff, Terrain Natural Resource Management, http://www.terrain.org.au/news-for-members/547-constructed-wetland-treating-banana-farm-runoff.html

Ekström, M, 2015. Central Slopes Cluster Report, Climate Change in Australia Projections for Australia's Natural Resource Management Regions: Cluster Reports, eds. Ekström, M. et al.

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

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

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

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

Hardy, T, Mason, L, Astorquia, A and Harper, BA 2004, Queensland Climate Change and Community Vulnerability to Tropical Cyclones: Ocean Hazards Assessment Stage 3, Report to the Queensland Department of Natural Resources and Mines, Brisbane.

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

Haywood, M. D .E., and Staples, D. J. 1993. Field estimates of growth and mortality of juvenile banana prawns (Penaeus merguiensis). Marine Biology 116, 407-16.

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

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

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

Howden, SM, Crimp, SJ and Stokes, CJ 2008, Climate change and Australian livestock systems: impacts research and policy issues, Australian Journal of Experimental Agriculture, vol. 48, pp.780-88.

Howden, SM, Hall, WB and Bruget, D 1999, Heat stress and beef cattle in Australian rangelands: recent trends and climate change, People and Rangelands, Building the Future, Proceedings of the 6th International Rangelands Conference, pp. 43-44.

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

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

Jackson CJ and Wang Y-G 1998, Modelling growth rate of Penaeus monodon Fabricus in intensively managed ponds: effects of temperature, pond age and stocking density. Aquaculture Research, 29: 27-36.

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

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

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

Langston, J, and Turton, S M 2014, Industry-adaptation pathways and opportunities in the Wet Tropics cluster In: Moran, C, Turton, S M., and Hill, R, (eds.) Adaptation Pathways and Opportunities for the Wet Tropics NRM Cluster Region: volume 2: infrastructure, industry, indigenous peoples, social adaptation, emerging planning frameworks, evolving methodologies and climate adaptation planning in practice. James Cook University, Cairns, QLD, Australia, pp. 128-143.

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

McInnes, K. et al., 2015, Wet Tropics Cluster Report, Climate Change in Australia Projections for Australia's Natural Resource Management Regions: Cluster Reports, eds. Ekström, M. et al., CSIRO and Bureau of Meteorology, Australia.

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

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

Marshall, NA, 2014. Social adaptation: minimising impacts through enhancing adaptive capacity. In: Moran, C, Turton, S M., and Hill, R, (eds.) Adaptation Pathways and Opportunities for the Wet Tropics NRM Cluster Region: volume 2: infrastructure, industry, indigenous peoples, social adaptation, emerging planning frameworks, evolving methodologies and climate adaptation planning in practice. James Cook University, Cairns, QLD, Australia, pp. 168-178.

Marshall, NA, Capon, S, Curnock, M, Edgar, B, Race, D & Scherl, LM 2015, A handbook for enhancing social resilience in the Monsoonal North of Australia. CSIRO Land and Water, Townsville.

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

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

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

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

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

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

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

Reef Catchments 2010, Reef Rescue 2010: Wet Season Cover Crop, Reef Catchments, <www.reefcatchments.com.au>

Reside, AE, Ceccarelli, DM, Isaac, JL, Hilbert, DW, Moran, C, Llewelyn, J, Macdonald, S, Hoskin, CJ, Pert, P, and Parsons, J 2014 Biodiversity: adaptation pathways and opportunities. In: Moran, C, Turton, S M., and Hill, R, (eds.) Adaptation Pathways and Opportunities for the Wet Tropics NRM Cluster Region: volume 1: introduction, biodiversity and ecosystem services. James Cook University, Cairns, QLD, Australia, pp. 11-74.

Robbins, G.B., Bushell, J.J. and McKeon, G.M. 1989. Nitrogen immobilization in decomposing litter contributes to productivity decline in ageing pastures of green panic (Panicum maximum var. trichoglume). The Journal of Agricultural Science, 113(03), pp.401-406.

Rossiter NA, Douglas MM, Setterfield SA and Hutley LB 2003. Testing the Grass-Fire Cycle: Alien Grass Invasion in the Tropical Savannas of Northern Australia. Diversity and Distributions 9: 169-176.

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

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

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

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

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

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

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

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

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

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

Van Dyck, S and Strahan, R 2008, The mammals of Australia, Reed New Holland, Sydney.

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

Walsh, KJE, Nguyen, KC and McGregor, JL 2004, Finer resolution regional climate model simulations of the impact of climate change on tropical cyclones near Australia, Climate Dynamics, vol. 22.

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

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

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

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

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