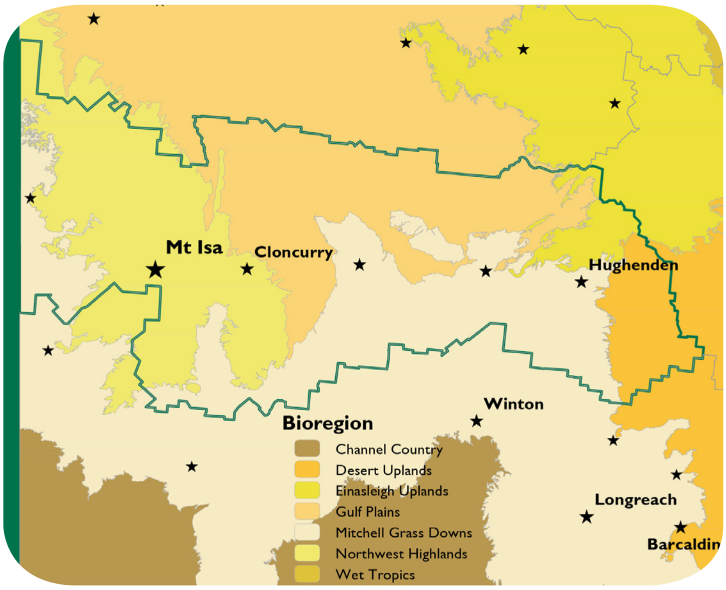
Climate Impact and Adaptation Series

Scenic vista, Carisbrook Station, near Winton

Courtesy of Tourism Queensland

Impacts and adaptation strategies for a variable and changing climate in the NORTH WEST QUEENSLAND REGION



This summary describes the likely impacts of a variable and changing climate on the major primary industries of the North West Queensland (NWQ) region, most notably grazing, and the potential adaptation strategies which can be implemented to minimise climate risks

Courtesy of Tourism Queensland

Regional Profile

The North West Queensland (NWQ) region covers more than 200,500 km^2, stretching from the Northern Territory border in the west to the Great Dividing Range in the east, including the towns of Mt Isa, Cloncurry, Julia Creek, Richmond and Hughenden.

The region has a semi-arid climate, varying between warm and dry from May to October, and hot and wet from November to April. Within the region, average temperatures are from an annual average minimum of 18°C to an annual average maximum of 33°C. Rainfall in the NWQ region is highly seasonal and irregular, with most rain falling during the monsoon lows or summer 'wet' season (December-March) either as heavy thunderstorms or rain depressions from decayed cyclones. Average historical annual rainfall (1894-2015) in Mount Isa is 422 mm. NWQ is the source of numerous river systems and has five bioregions which are home to endangered flora and fauna.

Major Primary Industries

The NWQ region has a long history of pastoral beef, sheep and wool production. However, the region is also well known for its globally significant mineral resources (e.g. iron-oxide, copper, gold, uranium, silver-lead-zinc deposits), including over one-quarter of the world's known lead and zinc reserves. The gross value production (GVP) in 2014-15 of agricultural commodities in the Southern Gulf region was $538 M region was 5% of the state total GVP for agricultural commodities ($11.9 B, ABS 2016a).

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Climate Trends and Projections

Historical changes in the key climate variables relevant to agricultural production including temperature, evaporation, rainfall, 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	+0.05 to +0.15	-0.05 (west) to +0.15 (east)	0 to +0.20
Minimum Temperature (°C)	1950	+0.05 to +0.15	+0.05 to +0.3	+0.1 to +0.30
Mean Temperature (°C)	1950	+0.10 to +0.30	NSC (west) to +0.20 (east)	+0.05 to +0.20
Pan Evaporation (mm)	1970	-15 (north) to NSC (south)	-5 (north) to 0 (south)	0 to 2.5
Rainfall (mm)	1950	-15 (east) to +10 (west)	-5 (east) to +15 (west)	+5 to -5
Number of Hot Days	1970	0 days (west) to +2.5 days (east)		
Cold Spell Duration	1970	+1.5 days		

NSC - No significant change | Unknown Growing Season Length | Pan Evaporation = the amount of water evaporated from an open pan per day **| Hot Days** = annual count of days with maximum temperature >35°C **| Cold Spell Duration** = Annual count of nights with at least 4 consecutive nights when daily minimum temperature < 10th percentile

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).
- 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	**25.4**	**30.3**	**25.5**	**18.8**	**27.1**
	Projections for 2030	**+1** **+0.4 to +1.7**	**+1** **+0.2 to +1.9**	**+1** **0 to +1.6**	**+1** **+0.3 to +1.8**	**+1** **+0.5 to +1.6**
Rainfall (mm)	Historical means	**453**	**291**	**76**	**22**	**65**
	Projections for 2030	**-3%** **-19% to +13%**	**1%** **-19% to +19%**	**-5%** **-28% to +31%**	**-15%** **-54% to +36%**	**-10%** **-28% to +25%**
Potential Evaporation (mm)	Historical mean	**1876**	**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%** **+0.5% to +6%**				
Relative Humidity	Projections for 2030	**-2%** **-7% to +7%**				
Wind Speed	Projections for 2030	**+1%** **-3% to +14%**				

Sale Yards, Hughenden, Queensland

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Impacts of a variable and changing climate in the North West Queensland Region

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

Human Well-Being

The variable and changing climate of the region will have both direct and indirect impacts on health, location and living arrangements. There are a range of adaptations and NRM planning processes that will increase both community and individual resilience (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. • 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. • 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 de-bilitating effects of extreme stress, emotional injury and de-spair. • 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. • 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 Northwest Highlands (NH), Gulf Plains (GP) and Mitchell Grass Downs (MGD) bioregions are represented within the North West Queensland region. The NH has low levels of endemism and plants that do not live close to their climatic limits. As such, there is limited tree death during drought, however combined fire and heatwaves pose a serious threat to vegetation and animal survival in this bioregion. Some endemic species, such as the grass wren (*Amytornis ballarae*), the mallee (*Eucalyptus nudicaulis*) and the pea bush (*Cajanus lanuginosus*) are well adapted to the arid environment of this bioregion.

The GP bioregion is dominated by vast plains vulnerable to increased flooding over large areas and is an important bioregion for waterbirds such as Brolgas. This bioregion has very few threatened species. The MGD has large, treeless areas in which plant and animal diversity is low. Most of the species in this bioregion are well adapted to high summer temperatures, low rainfall and frequent droughts, however, a hotter drier climate may shift many species beyond their limits causing biodiversity decline. There has been a recent decline in Mitchell grass (*Astrebla*) due to extended drought. The degree of ecological change caused by climate change is more likely to be greater in the plant biological group than that of mammals, amphibians or reptiles (Williams et al. 2014).

Likely Impacts	***Potential Strategies for Adaptation***
Extremes of weather and climate (drought, flood, cyclones, heatwaves etc.) on Biodiversity (Low 2011)	
Impacts in the Northwest Highlands • An increase in temperature and reduced rainfall may cause the inland edges of some flora species ranges to contract towards the north-east. • Severe drought events in central Australia could drive the feral camel population into the NH bioregion which may have serious consequences for woody vegetation. • Increased rainfall may promote fire risk, resulting in many eucalypt deaths and possible vegetation shifts. • The purple-necked rock-wallaby, largely endemic to the NH bioregion, may be threatened if temperatures increase several degrees, forcing populations to contract back to rugged areas near permanent water and where substantial caves and overhangs provide shelter. **Impacts in the Gulf Plains** • Long dry spells, followed by heavier precipitation events could lead to increased flooding events on the GP. This may result in cattle and wildlife loss, widespread pasture death and weed invasion (*Parkinsonia aculeta*). • Ground dwelling reptile species, including common skinks, geckoes and dragons, may disappear in the GP due to more severe flood events. Only those species who can survive in trees, such as the gecko (*Heteronotia binoei*) and the skink (*Carlia munda*), are likely to survive the increase in flood severity. • More severe flooding events in the GP may also affect kangaroo and wallaby populations, which can get stranded and die from starvation and exposure, and reduce populations of birds and centipedes. • The vulnerable purple-crowned fairy wren (*Malurus coronatus*) is an example of a species susceptible to population decline during drought due to increased trampling by cattle of the riparian vegetation they are dependent on and increased fire intensity in its restricted habitat. **Impacts in the Mitchell Grass Downs** • Mitchell grasses are very well adapted to a hot climate and severe drought, however widespread die-offs can occur during severe droughts with serious implications for wildlife.	• Fire management. • Manage flammable invasive pasture grasses, such as buffel grass in the NH, to prevent their spread and keep them out of conservation areas. • Control invasive camels in central Australia. • Conduct research in the GP bioregion as sound management is currently restricted by high grazing pressure and lack of data about biodiversity. • Destock cattle after major floods to facilitate recovery of pastures. • Protect riparian habitat damaged from large cattle numbers to protect the purple-crowned fairy wren and other fauna. • Increase control of parkinsonia weeds to reduce the threat to seasonal wetlands used by water birds. • Control flammable invasive pasture grasses, such as gamba grass and buffel grass, to prevent their spread. • Develop management guidelines to maximise Mitchell grass survival during drought. • Conserve all permanent waterholes and deep waterholes to prevent desiccation during droughts. • Actively control prickly acacia, mesquite and parkinsonia in the MGD.

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 Southern Gulf region were 1.2 million in 2014-15 which was 11% of the total cattle numbers for Queensland (ABS 2016b). In 2014-15 the GVP for cattle, sheep and wool for Southern Gulf was $537 M (ABS 2016a) or 5% of state and 99% of the value of Southern Gulf 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 NWQ are Mitchell grass (35% of region), Spinifex (34%) Bluegrass browntop pastures (10%) and Aristida-Bothriochloa (10%) (Tothill and Gillies 1992). The soil fertility is very good (Mitchell grass) to poor (Spinifex) and growth of pastures is usually limited by inadequate rainfall, or lack of nitrogen in Spinifex pastures. A review of the beef industry in the Monsoonal North is provided by Crowley 2015.

Case Study - Impacts in the North West Queensland Region

The impacts of a changing climate are complex because of interacting and opposing forces operating within the biophysical system (McKeon et al. 2009). The process of assessing the impacts of a changing climate often involves deriving the 'best estimate' projections of future climate, simulating the grass growth and grazing strategies under changing climate conditions using well-calibrated grass/grazing system models, and combing 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 North West Queensland region were undertaken for the Barkly Downs, Julia Creek and Hughenden 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 (3.88 m^2/ha tree basal area) resembled that of open parkland.

Table 3: Matrix showing potential opportunities and risks associated with the average impacts of future climate scenarios from Barkly Downs, Julia Creek and Hughenden 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	-H	LC
2xCO_2	**+H**	-M	**+H**	**+H**	LC
+3°C, 2xCO_2	+M	LC	+M	+M	LC
+3°C, 2xCO_2, +10% rainfall	**+H**	-M	**+H**	**+H**	LC
+3°C, 2xCO_2, -10% rainfall	-M	LC	-M	-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:

- the benefits of doubled carbon dioxide associated with pasture growth, liveweight gain and frequency of burning outweighed the disadvantages caused by a 3°C rise in temperature;
- doubled carbon dioxide will reduce the quality of native pasture grasses;
- the combined effects of a 3°C rise in temperature, doubled carbon dioxide and 10% more rainfall is likely to increase pasture growth, liveweight gain and burning frequency (providing more opportunity for prescribed burning to control weeds, regrowth and dry vegetation);
- the combined effects of higher temperature, doubled carbon dioxide and 10% less rainfall is likely to reduce pasture growth, liveweight gain and burning frequency; and
- with the future climate studied here there is likely to be little to no impact on green pasture growing days.

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Opportunities for the Grazing Industry

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

Case Study – Impacts in the Richmond area

Modelling studies at Richmond under doubled carbon dioxide (700 ppm) showed a 3°C rise in temperature and 17% more rainfall is likely to result in an increase in forage production of 20% (Webb et al. 2011). On the other hand a 2^{o}C rise in tem-perature and 7% less rainfall resulted in little change in forage production, with the improved efficiency of water use from el-evated carbon dioxide balancing the negative effects of higher temperature and lower rainfall. A 3^{o}C rise and 46% less rainfall resulted in 68% less forage production

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 Richmond has fluctuated between -13 and +11% compared with the long-term average since 1881 (Figure 1). The extended periods of lower rainfall (mid 1910s to mid-1920s, 1930s to 1950s, 1980s 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.

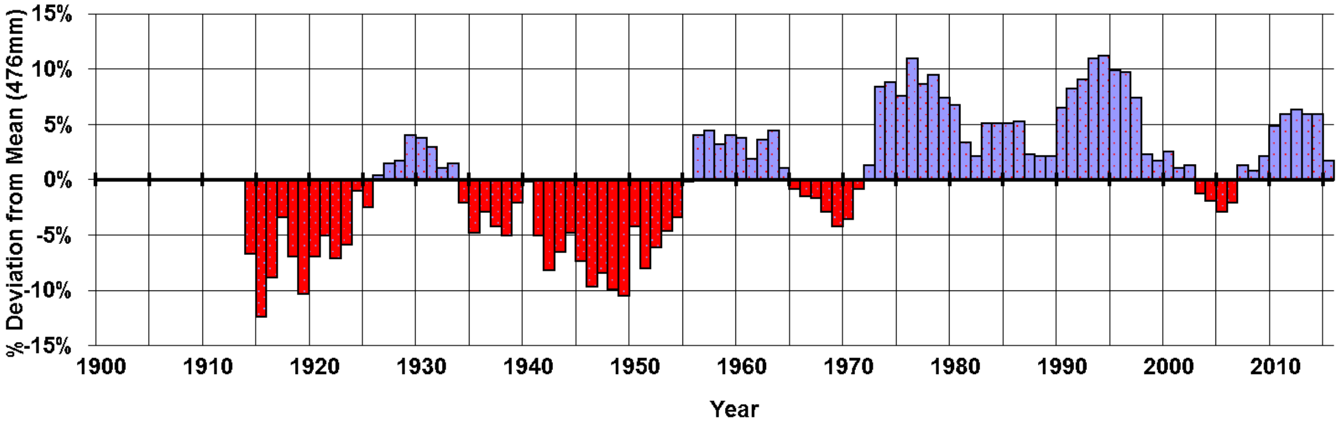

Figure 1: 25-year moving average rainfall (12 months, April in year 1 to March in year 2) at Richmond, Queensland (Source: Clewett et al. 2003).

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

Barkly Highway, Mt Isa, 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, Richmond under warming of 3°C is likely to receive temperatures currently experienced north of Kowanyama (Figure 2). • Livestock will be exposed to a greater risk of heat stress. They are unlikely to travel as far to water which concentrates grazing pressure and increases the risk of adverse pasture composition changes and soil degradation (Howden et al. 2008). • Increased day time temperatures increases water turn-over and evaporative heat loss resulting in reduced rate of passage and forage intake in livestock (Daly 1984). • Increased night time temperatures can reduce recovery time of livestock and increase the effects of heat stress during the day. • Increased heat stress reduces fertility, conception, peri-partum survival and follicle development in sheep. • Warmer conditions favour vectors and the spread of animal disease (White et al. 2003). • Pastures could cure earlier under warmer climates shifting the timing of fires to earlier in the season. • Warmer drier conditions with higher frequency of storms could increase the risk of wildfires.	• Arrange water points to reduce distance to water and even out grazing pressure. • Select the time of mating to optimise nutritional requirements and reduce the risk of mortality in new-borns. • Select cattle lines with effective thermoregulatory controls, efficient feed conversion and lighter coat colour (Finch et al. 1984, King 1983). • Proactively control disease by targeting known sources of disease and vectors (Sutherst 1990). • Maintain high standards of animal welfare to build domestic and export meat and fibre markets (Mott and Edwards 1992). • Incorporate greater use of prescribed burning to reduce the risk of wildfires and control woody thickening. • Rotate paddocks of heavier grazing for use as fire breaks. • Maintain or improve quarantine capabilities, monitoring programs and commitment to identification and management of pests, disease and weed threats. • Develop species resistant to pests and disease. • Use area-wide improved management practices.

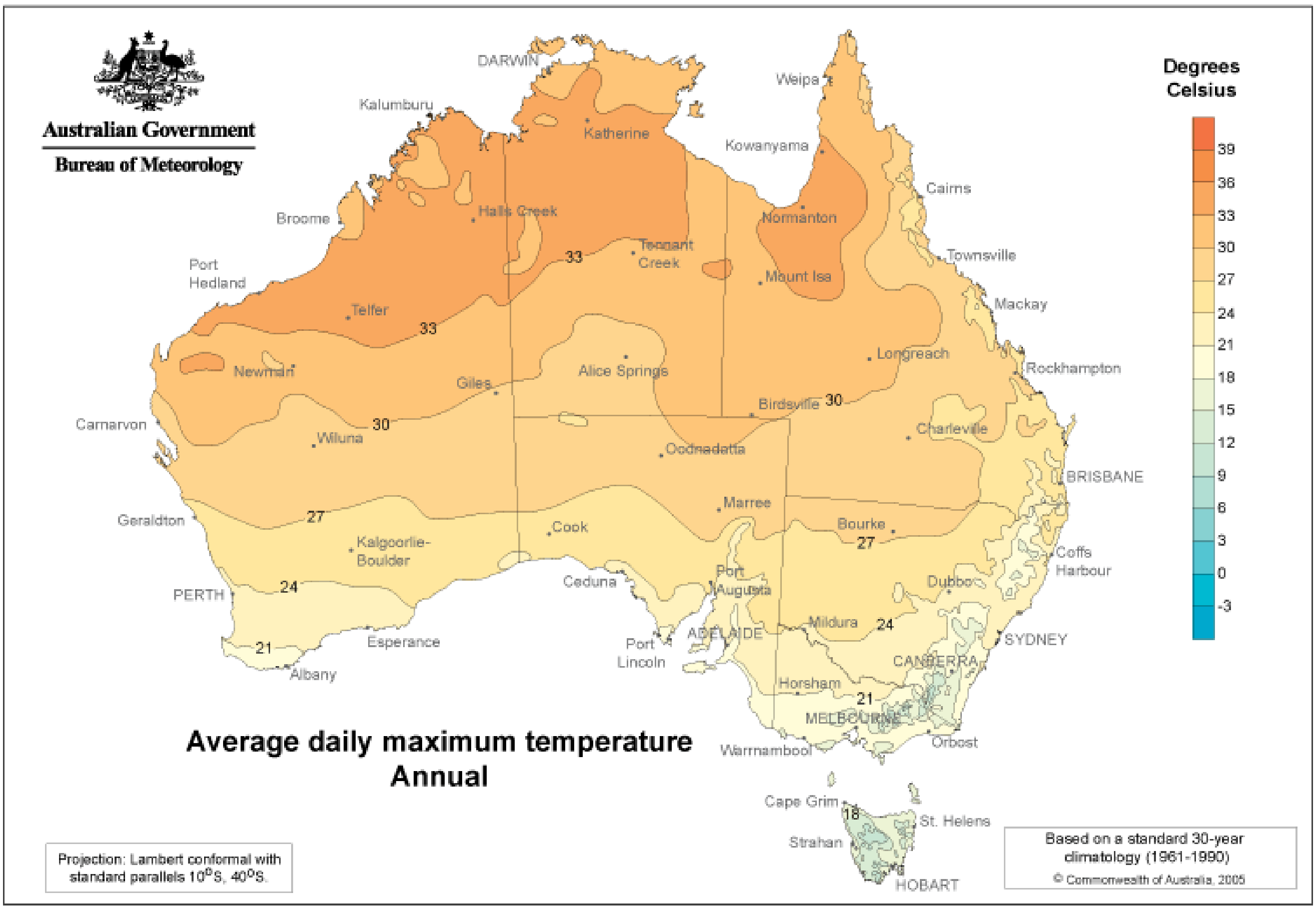

Figure 2: Annual average temperature in Australia (Source: Bureau of Meteorology). One degree of warming is roughly equivalent to moving 145 km toward the equator.

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 (e.g. increase *Bos indicus* content), efficient feed conversion and lighter coat colour (Finch et al. 1984, King 1983).

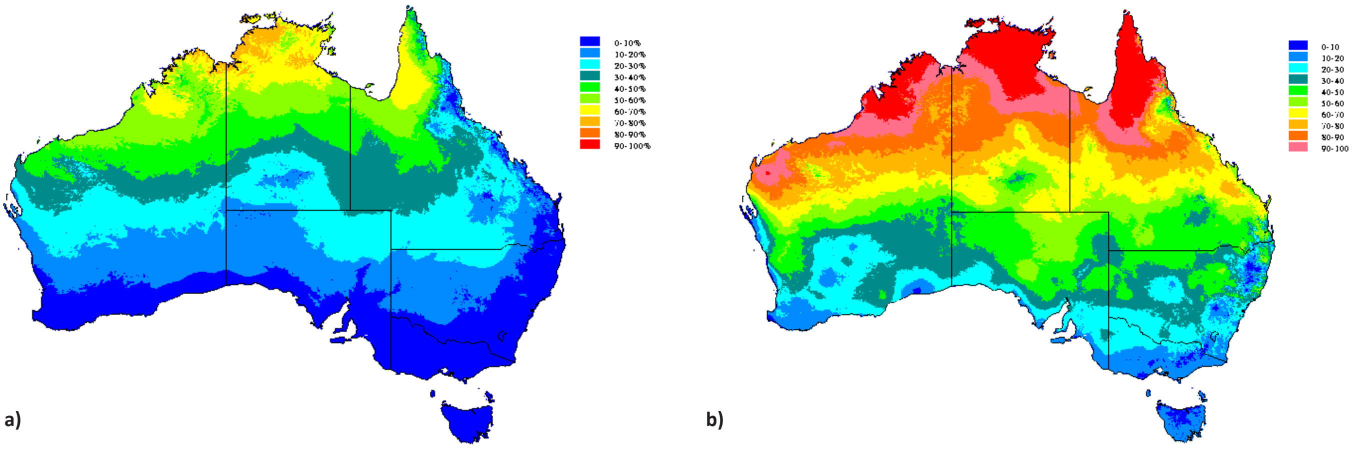

Figure 3: Frequency of days per year that the THI>80 for a) 1957-97 and b) a future climate scenario of +2.7°C. Thermal stress is significant in beef cattle when the THI exceeds 80 (Source: Howden et al. 1999).

More Information

For more information, including projections for 2050 and 2070, please refer to *http://www.climatechangeinaustralia.gov.au/en/* *or Moise 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*

Citation
Cobon DH, Terwijn MJ, and Williams AAJ (2017). Impacts and adaptation strategies for a variable and changing climate in the NORTH WEST QUEENSLAND REGION. International Centre for Applied Climate Sciences, University of Southern Queensland, Toowoomba, Queensland, Australia.

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

The authors would like to acknowledge the expertise in reviewing this document by staff in the Queensland Department of Science, Information Technology and Innovation, the Queensland Department of Agriculture and Fisheries, CSIRO.

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.

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

Cai, W., 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.

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.

Close, P, Bartolo, R, Pettit, N & Ward, D & Kennard, M. 2015. Vulnerability and risk assessment of northern Australian catchments and biodiversity. Climate Change Adaptation across Australia's Monsoonal North – Northern Monsoon NRM Cluster, Griffith University, Nathan.

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 and McKeon, GM 2003, Impact of climate change on pasture and animal production, Sustainable grazing - balancing resources and profit in western Queensland (Authors Cobon and Park), pp.29-33.

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

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

Crowley, G.M. 2015. Trends in natural resource management in Australia's Monsoonal North: The beef industry. Cairns: The Cairns Institute, James Cook University.

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

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

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.

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.

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

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.

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

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

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

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

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

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

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

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

Moise, A. et al. 2015, Monsoonal North 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.

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

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

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.

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

Smith, K.R.; Woodward, A.; Campbell-Lendrum, D.; Chadee, D.; Honda, Y.; Liu, Q.; Olwoch, J.; Revich, B.; Sauerborn, R. Human health: Impacts, adaptation, and co-benefits. In Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandewa, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., et al. Eds.; Cambridge University Press: Cambridge, UK, 2014; Chapter 11.

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.

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.

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.

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.