

HeatWatch

Extreme heat in the Kimberley

Increases in extreme heat events in the Kimberley region will have severe impacts on the wellbeing of people in the region, particularly indigenous communities. It will also impact key industries, including tourism and agriculture, and damage natural ecosystems. CSIRO and Bureau of Meteorology projections estimate up to a tenfold increase in days over 40 degrees within the lifetime of children living in Broome today (up to 62 days per year over 40 degrees by 2090) without policies to reduce greenhouse gas emissions.

Audrey Quicke

November 2019

Commissioned by Environs Kimberley

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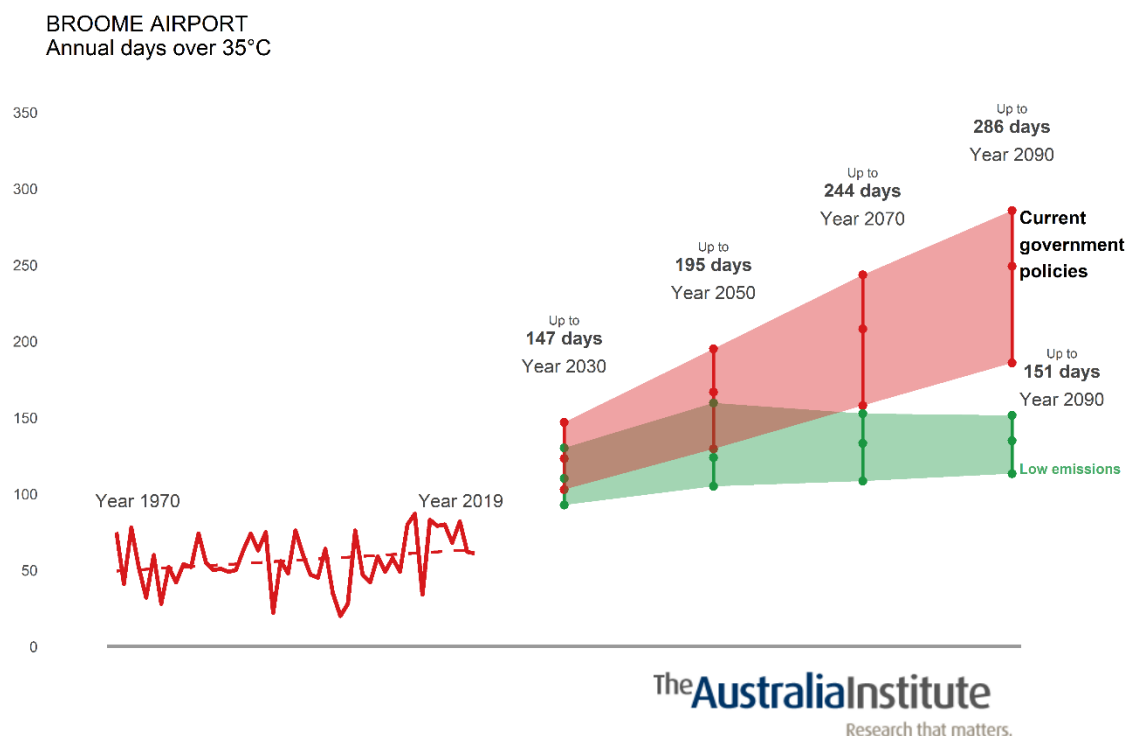
Summary

The projected rise in extremely hot days as a result of global warming presents a serious risk to the health and wellbeing of the Kimberley community.

There has already been a clear increase in numbers of these extreme heat days across Australia over recent decades. The CSIRO and Bureau of Meteorology (BoM) projects this could rise steeply in the Kimberley region. Extreme heat days (days over 35 degrees) in Broome are projected to increase from an average of 81 days above 35 degrees, to up to 195 days by 2050 and potentially up to 286 days by 2090.

Historically there have been 6 days per year on average above 40 degrees. This is projected to increase by up to double by 2030 and up to tenfold by 2090, within the lifetime of children born in Broome today.

Figure 1: Forecast number of days over 35 degrees in Broome



Exposure to extreme heat can lead to serious illness and death. At temperatures above 35 degrees, the human body's ability to cool itself reduces which can lead to a cascading series of Heat Related Illnesses (HRI) and ultimately heatstroke that can cause organ failure and

death. Heatwaves have caused more deaths in Australia since 1890 than cyclones, bushfires, floods, earthquakes and severe storms combined.¹

The extreme heat risk to the Kimberley region is exacerbated by high humidity during the wet season. The region experiences extreme seasonal variation due to its tropical monsoonal climate. It has distinct dry and wet seasons with large variation in relative humidity throughout the year. During the wet season (November-April), Broome has historically experienced a mean 3pm relative humidity of 60%.

Combined with 50% humidity, conditions over 35 degrees are considered “dangerous” by government agencies such as the US Government National Oceanic and Atmospheric Administration (NOAA). Temperatures of 35 degrees combined with 70% humidity are considered “extremely dangerous”. Cool night time temperatures are essential for good health and allow people to recover from hot days. Broome already has a high proportion of hot nights, with around 114 nights above 25 degrees per year. This could increase substantially to up to 224 nights by 2090 and leave essentially all of summer with extreme heat nights.

Extreme heat events present a risk to critical infrastructure including road, rail and electricity generation and have a major impact on productivity and economic activity. The Kimberley is particularly vulnerable to transportation infrastructure impacts due to its remote geographic nature. Major arterial routes are subject to closure during extreme weather events, restricting the supply of food and energy.

The Kimberley workforce is also particularly vulnerable to increasing extreme heat with many workers employed in industries that frequently require strenuous outdoor activities in many important industries including tourism, construction and agriculture.

Aboriginal and Torres Strait Islanders make up 46% of the Kimberley population. The Indigenous community is disproportionately affected by extreme heat due to exposure to climate, pre-existing health conditions, income inequality, cultural connection to Country and disproportionately poor access to services and amenities.

None of this is inevitable. CSIRO modelling shows that if emissions are reduced decisively in line with the globally agreed target of 1.5 degrees, the number of days in Broome per year over 35 degrees could peak at a maximum of 160 days around 2050 before reducing to around 151 days by 2090, ensuring relatively safe temperatures for our children and grandchildren.

The Kimberley has a central role to play in ensuring Australia’s carbon emissions are reduced in line with the Paris Agreement. The Canning Basin in the Kimberley region is one

¹ McMichael et al (2003) *Climate change and human health, risks and responses*, p 53.
<https://www.who.int/globalchange/publications/climchange.pdf>

of the largest shale gas deposits in the world² and as such one of the largest potential sources of greenhouse gas. Ensuring this gas remain largely securely in the ground is essential to avoiding the projected increase in extreme heat and many other devastating impacts of global warming.

² U.S. Energy Information Administration (2013) *Technically Recoverable Shale Oil and Shale Gas Resources: An Assessment of 137 Shale Formations in 41 Countries Outside the United States*.
<https://www.eia.gov/analysis/studies/worldshalegas/pdf/overview.pdf>

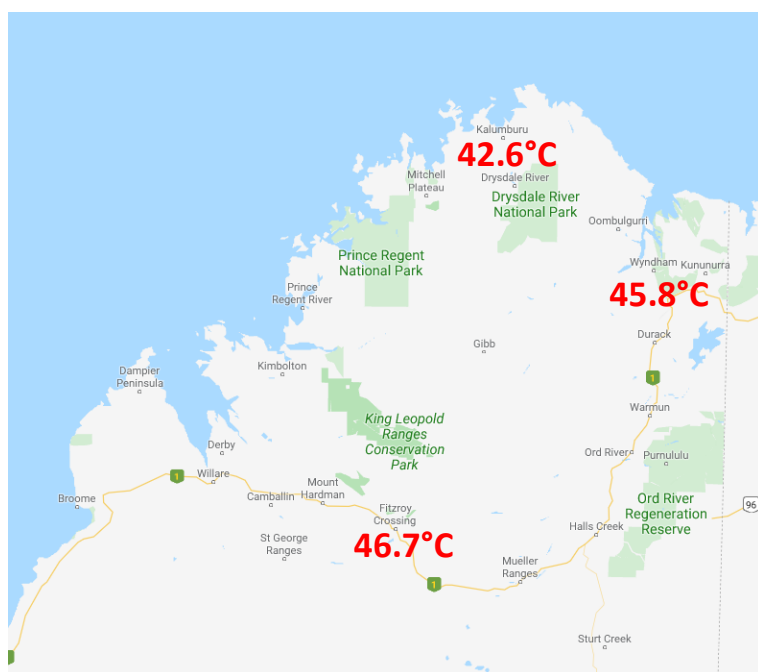
Introduction

The Kimberley region has a tropical monsoon climate, defined by distinct wet and dry seasons. The wet season is typically hot and humid. As the climate warms, the Kimberley region is particularly vulnerable to increases in extreme heat events.

The 2018-19 summer heatwave saw persistent high temperatures and a number of temperature records broken at individual locations across the country including Western Australia. The event was classified as an 'extreme heatwave', the highest intensity and rarest heatwave defined by the Bureau of Meteorology (BoM).³

In the Kimberley region, December temperature records were broken in Fitzroy Crossing (46.7°C), Kalumburu (42.6°), and Wyndham (45.8°) (see Figure 2 below), and Halls Creek experienced a record 88 days with maximum temperature over 35 degrees.⁴

Figure 2: December heat records broken during summer 2018/19, Kimberley region.



Source: BoM (2019) *Special Climate Statement 68*

Extreme heat events such as these are expected to increase in frequency across the Kimberley region without a reduction in greenhouse gas emissions.

³ BOM (2019) *Special Climate Statement 68 - widespread heatwaves during December 2018 and January 2019*, p 33. <http://www.bom.gov.au/climate/current/statements/scs68.pdf>

⁴ Ibid.

Establishing new gas developments in Western Australia would undermine efforts to curb Australia's greenhouse gas emissions.⁵ The Canning Basin, a geological basin in the Kimberley region covering an onshore area of 530,000 km², has some of the largest shale gas potential in the world.⁶

Analysis by Climate Analytics shows the global carbon footprint of the Canning basin's unconventional gas resources alone accounts for 2.3%-3.6% of the global carbon budget. In other words, around twice as much CO₂ than Australia is allowed to emit under the Paris Agreement. Figure 3 (below) shows the emissions potential of WA's unconventional gas resources compared to the National and Western Australian carbon budgets.⁷

Allowing the exploitation of Canning Basin shale gas would significantly undermine global efforts to avoid the worst impacts of global warming including increasing extreme temperatures in the Kimberley region itself.

In 2018, 50 of Australia's most prominent scientists and energy experts wrote an open letter to the Western Australian Government calling for fracking to be permanently banned in Western Australia. The letter noted that "Western Australia is already experiencing severe impacts of global warming, which will become far worse if emissions are not decisively reduced" and that allowing fracking to proceed would be "grossly irresponsible given urgency of the climate situation."⁸

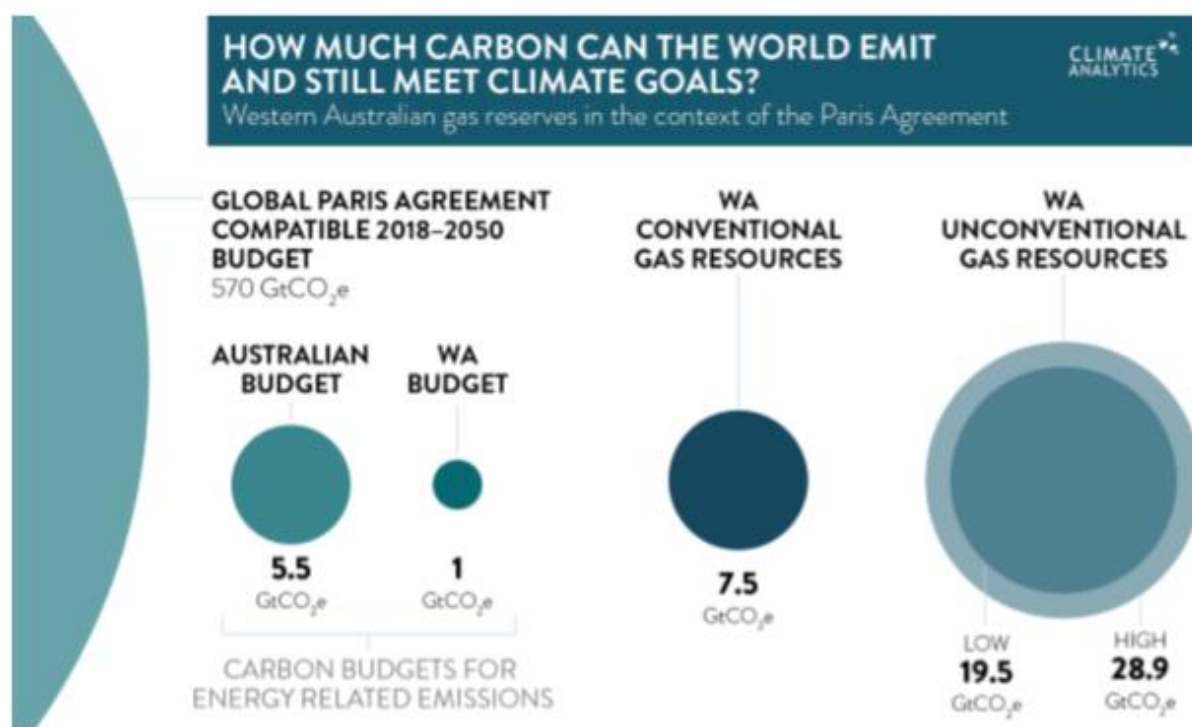
⁵ Climate Analytics (2018) *Western Australia's Gas Gamble: Implications of exploiting Canning Basin and other unconventional gas resources for achieving climate targets*.

⁶ US EIA (2013) *Technically Recoverable Shale Oil and Shale Gas Resources*.

⁷ Government of Western Australia Department of Mines, Industry, Regulation and Safety (2019) *Canning Basin*. <https://www.dmp.wa.gov.au/Petroleum/Canning-Basin-10989.aspx>,

⁸ The Australia Institute (2018) *50 experts call for WA fracking ban: open letter*. <https://www.tai.org.au/content/50-experts-call-wa-fracking-ban-open-letter>

Figure 3: Western Australian gas reserves compared to Paris Agreement carbon budget;
Climate Analytics



Source: Climate Analytics (2018) *Western Australia's Gas Gamble*

EXTREME HEAT

Extreme heat is dangerous for human health, for ecosystems and agriculture. At temperatures above 35 degrees, the human body's main cooling mechanism – sweating – is far less effective. Sweating exchanges heat from the body to the atmosphere, but this heat exchange process diminishes significantly beyond 35 degrees, so body temperature rises. This creates discomfort and a range of health impacts, from mild to severe, and can ultimately be fatal without intervention.⁹

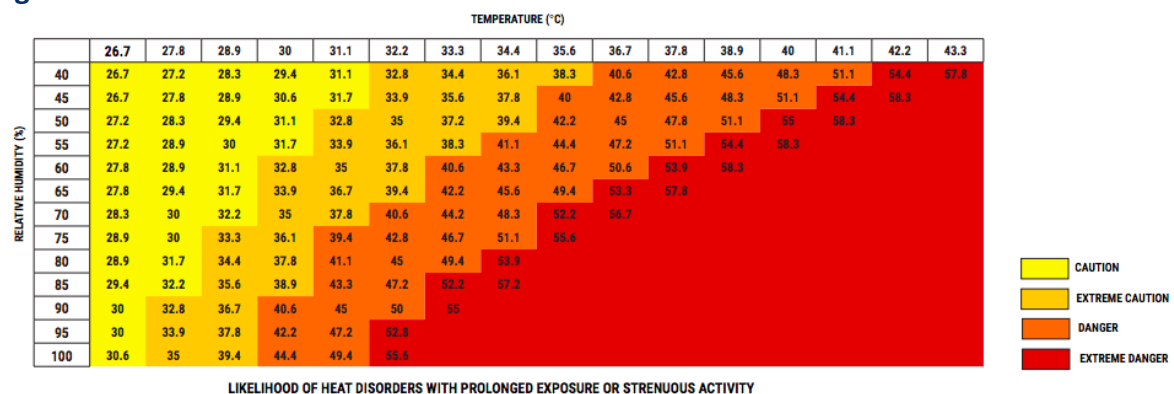
Because of this, many regulators and researchers use 35 degrees as an important threshold for safety, work and climatic conditions. 35 degrees is seen as the "limit of high temperature tolerance" by the Occupational Health and Safety Representatives of the Victorian Trades Hall Council and many academic researchers note it as the point where substantial

⁹ Hanna and Tait (2015) *Limitations to thermoregulation and acclimatisation challenges human adaptation to global warming*, International Journal of Environmental Research and Public Health.
<https://academic.oup.com/heapro/article/30/2/239/561863>

productivity is lost. The CSIRO and Bureau of Meteorology publish 35-degree threshold predictions.¹⁰

Temperature and humidity are often combined into a heat index figure to provide a simple indicator of the body's ability to cool itself. Of a number of indices available, one of the most important is published by the US Government National Oceanic and Atmospheric Administration (NOAA). As shown in the NOAA heat stress chart in Figure 4 below, the combination of temperatures in the low thirties with high humidity are considered "dangerous" to human health.

Figure 4: NOAA Heat Stress Index



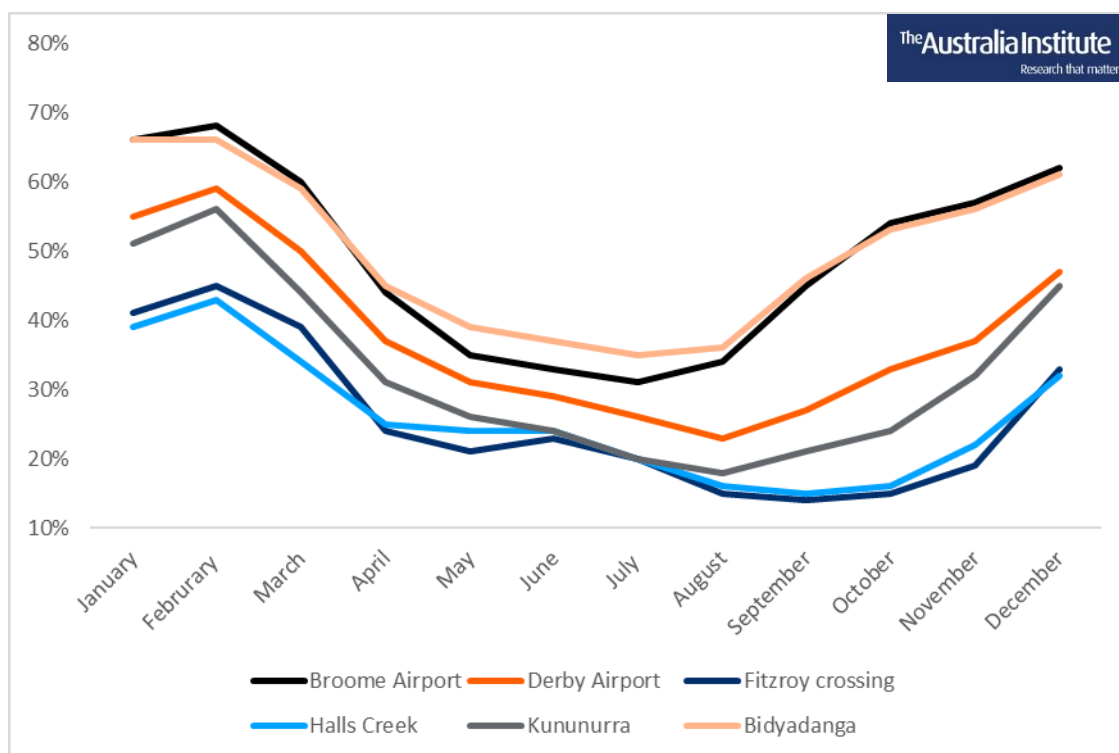
Source: <https://www.weather.gov/safety/heat-index>

NOAA's heat stress index rises to "Extreme Danger" at temperatures over 35 degrees combined with 80% humidity, and at temperatures over 40 degrees combined with 50% humidity.

The Kimberley region already experiences extreme seasonal variation due to its tropical monsoonal climate. The region has distinct dry and wet seasons with large variation in relative humidity throughout the year. During the wet season (November-April), Broome has historically experienced a mean 3pm relative humidity of 60% (see Figure 5).

¹⁰ Victorian Trades Hall Council (2018) *Heat*. <http://www.ohsrep.org.au/hazards/workplace-conditions/heat>; Singh et al. (2015) *Working in Australia's heat: health promotion concerns for health and productivity*, Health Promotion International. <https://academic.oup.com/heapro/article/30/2/239/561863>; CSIRO and BoM (2015) *Climate change in Australia: Projections for Australia's NRM Regions*. <https://www.climatechangeinaustralia.gov.au/en/publications-library/technical-report/>

Figure 5: Mean monthly 3pm relative humidity; Broome, Derby, Fitzroy Crossing, Halls Creek, Bidyadanga and Kununurra (1981-2010)



Source: Bureau of Meteorology (2019) *Monthly climate statistics*,
<http://www.bom.gov.au/climate/data/index.shtml>

Note: Data for Fitzroy Crossing is only available from 1997. The mean monthly 3pm relative humidity for Fitzroy Crossing is calculated for the period 1997-2010.

A future of such extreme heat days matched with high humidity represents a serious threat to the wellbeing of people in the Kimberley region and to Australia's wider population. The rise in extreme heat increases irritability and psychological stress, and can lead to heat-related illness and death.¹¹ Hot weather affects patterns in domestic violence,¹² interrupts sleep patterns and reduces capacity and willingness to exercise. All carry broad ramifications, such as increased accident risk, sedentary life style-induced diabetes and cardio vascular disease.¹³

¹¹ Queensland Health (2015) *Heatwave Response Plan*.

https://www.health.qld.gov.au/__data/assets/pdf_file/0032/628268/heatwave-response-plan.pdf

¹² Auliciems and Di Bartolo (1995) *Domestic violence in a subtropical environment: police calls and weather in Brisbane*. International Journal of Biometeorology 39 (1).

¹³ Kjellstrom T et al (2009) *The Direct Impact of Climate Change on Regional Labor Productivity*, Archives of Environmental & Occupational Health 64 (4).; World Health Organisation (2017) *Preventing noncommunicable diseases (NCDs) by reducing environmental risk factors*.
<http://apps.who.int/iris/bitstream/10665/258796/1/WHO-FWC-EPE-17.01-eng.pdf?ua=1>

Tracking and minimising the way climate change is affecting the number of hot days is of direct interest to the wellbeing of local communities, particularly in areas of high vulnerability to heatwaves like the Kimberley.

ABOUT HEATWATCH

The Australia Institute's HeatWatch initiative puts current Australian research about temperature increases due to global warming into context, using data from the Bureau of Meteorology and the CSIRO.

Global temperature increases of 1.5 or 2 degrees above pre-industrial levels will have dramatic impacts on human health, the ecosystem and the economy. The IPCC has found that human-induced warming reached 1 degree above pre-industrial levels in 2017.¹⁴

Current policy settings would see more extreme warming than 2 degrees above pre-industrial levels. However, temperatures fluctuate by much more than a few degrees every day, meaning that the compounding and extreme effects of temperature increases can be difficult to imagine.

HeatWatch uses extreme heat days (days over 35 degrees) along with other thresholds like 37 degrees and 40 degrees to highlight that the effects of global warming will include a dramatic increase in days where it is uncomfortable or dangerous to operate outside – affecting industries like construction, sport and other outdoor activities.

HeatWatch began with *Cooked with gas: Extreme heat in Darwin*, which highlighted that the Northern Territory's plans to exploit emission-intensive oil and gas reserves will contribute to global warming which could increase the number of days over 35 degrees in Darwin from the current rate of 22 per year to 275 per year in 2070.¹⁵

Other HeatWatch reports have covered extreme heat in Rockhampton, Gladstone, Roma, the Sunshine Coast, the Gold Coast, Western Sydney and Adelaide amongst other areas. Three Queensland reports were presented alongside Queensland Fire and Emergency Services workshops on extreme heat. A special Heatwatch Queensland Report was prepared for the inaugural Queensland Climate Week.

The Australia Institute will continue to focus on additional locations and welcomes interest in collaborating on local versions of the reports.

All HeatWatch reports are available on our website: <http://www.tai.org.au/heatwatch>

¹⁴ IPCC (2018) *Global Warming of 1.5 °C*, p 1:4. <https://www.ipcc.ch/report/sr15/>

¹⁵ Hanna and Ogge (2018) *Cooked with gas: Extreme heat in Darwin*.
<http://www.tai.org.au/content/cooked-gas-extreme-heat-darwin>

THE KIMBERLEY

CSIRO and the Bureau of Meteorology (BoM) have produced temperature projections under several climate change scenarios for most of terrestrial Australia. The CSIRO–BoM data is a time series from the Australian Water Availability Project (AWAP) where the average temperature was compiled in roughly five kilometre by five kilometre spatial grids between 1981 and 2010.¹⁶ This time series uses between five and eight models to predict days over 35 degrees, over 37 degrees and over 40 degrees in 2030, 2050, 2070 and 2090.¹⁷ It also has a historical average for the years 1981–2010.

This report employs the IPCC scenarios for global climate action: RCP 2.6 (“low emissions”), RCP 4.5 (“intermediate emissions”) and RCP 8.5 (“high emissions/current government policies”). RCP 2.6 equates roughly to what is required to keep the world below 1.5 degrees warming, RCP 4.5 to what is required to keep the world below 2 degrees warming, and RCP 8.5 is the “business as usual” scenario where the world fails to act decisively on climate change and suffers global warming of 3 degrees and above. RCP 8.5 is the current trajectory due to the failure of most major polluting governments to implement necessary climate policies.

For historic temperatures this report uses both BoM observational data from measurement stations located in major Kimberley towns and CSIRO and BoM gridded historical data. The historic temperatures shown in the HeatWatch figures are based on available observational data. Years with less than 329 (90%) observations have not been included. The historic temperatures provided in the HeatWatch tables are based on the AWAP five kilometre gridded data set and provide an average for the period 1981-2010.

The BoM has two measurement stations in Broome: one located at the airport and the other at the port, and two measurement stations in Halls Creek: The Halls Creek Meteorological Office and Halls Creek Airport. The Broome Airport measurement station and Halls Creek Meteorological Office station have been used for this report, along with measurement stations at Derby, Fitzroy Crossing, Halls Creek, Kununurra and Bidyadanga.

For the purposes of temperature projections, the closest AWAP grid square to each measurement station was used for the 2030, 2050, 2070 and 2090 projections.

¹⁶ 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.

¹⁷ All eight models – ACCESS1.0, CESM1-CAM5, CNRM-CM5, GFDL-ESM2M, HadGEM2-CC, CanESM2, MIROC5 and NorESM1-M – are available for the RCP 4.5 and RCP 8.5 scenarios. Five models – CESM1-CAM5, CNRM-CM5, CanESM2, MIROC5 and NorESM1-M – are available for the RCP 2.6 scenario.

Increasing hot days

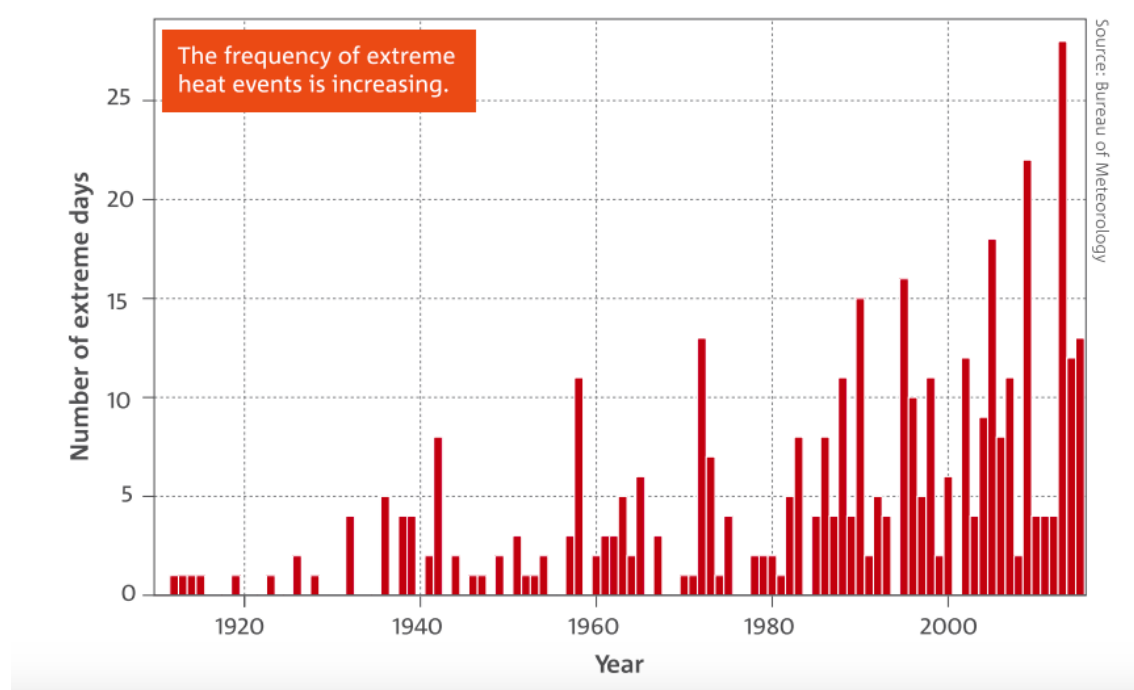
In Australia and globally there has been a clear trend of increasing temperatures and extreme heat events that are attributable to global warming.

The increase in extreme heat events across Australia as a whole is shown in Figure 6 below. This Bureau of Meteorology graph shows the annual number of days exceeding the 99th percentile of each month from 1910–2015.

The Bureau of Meteorology attributes this trend to climate change:

As the global climate system has warmed, changes have occurred to both the frequency and severity of extreme weather. In Australia, the most obvious change has been an increase in the occurrence of record-breaking heat.¹⁸

Figure 6: Frequency of extreme heat days, Australia



Source: BoM (2016) *State of the Climate*

¹⁸ BoM (2016) *State of the Climate*. <http://www.bom.gov.au/state-of-the-climate/State-of-the-Climite-2016.pdf>

Projected increases in days over 35 °

BROOME

Broome is the largest town in the Kimberley region. It has historically enjoyed a tropical coastal climate, with consistently warm weather. However, this is at risk as the number of extreme heat events increases with the warming climate.

Under current government policies, in Broome days over 35 degrees would go from an historical average of 81 days per year to a maximum of 147 days by 2030, 195 days by 2050, 244 days by 2070 and 286 days by 2090. This would be concentrated in summer, where up to 95% of summer days would be over 35 degrees by 2090.

Broome would benefit significantly from climate policies that would keep warming below 1.5 degrees, as represented by the RCP 2.6 scenario. Climate policies to keep warming below 1.5 degrees would keep predicted days over 35 degrees to below 130 days by 2030, increasing to 160 days by 2050 and stabilising at 151 days by 2090.

Figure 7: Forecast number of days over 35 degrees in Broome

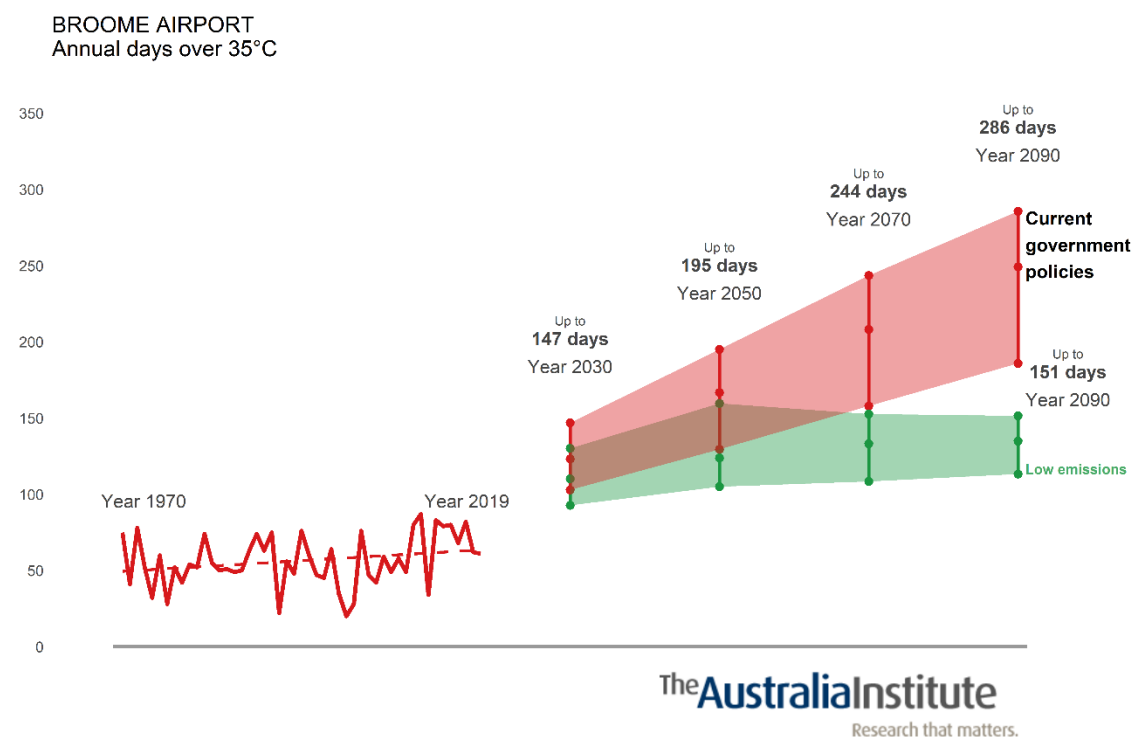


Table 1: Broome projected days over 35 degrees

	2030	2050	2070	2090
Historical average	80.9			
Low emissions	92.7-130.2	105.0-159.6	108.4-152.7	113.3-151.4
Intermediate emissions	97.3-145.0	114.6-169.3	126.2-177.8	137.0-195.6
Current policies	102.8-146.8	129.5-195.1	157.9-243.6	185.8-285.6

Source: CSIRO and Bureau of Meteorology (2018) *Climate projections*, provided on request

DERBY

Derby is known for its tropical climate, with warm winters and hot, humid summers. Extreme heat days are already common in Derby and expected to increase unless emissions are reduced.

Under current government policies, in Derby days over 35 degrees would go from an historical average of 178 days per year to a maximum of 237 days by 2030, 268 days by 2050, 305 days by 2070 and 330 days by 2090. In other words, as things stand a child in Derby could expect up to 90% of their days will be 35 degrees and over by the time they can access a pension.

This would be concentrated in summer, where a maximum of 96% of summer days would be over 35 degrees by 2090.

Derby would benefit significantly from climate policies that would keep warming below 1.5 degrees, as represented by the RCP 2.6 scenario. Climate policies to keep warming below 1.5 degrees would keep predicted days over 35 degrees to 221 days by 2030, increasing to 241 days by 2050 and stabilising at 235 days by 2090.

Figure 8: Forecast number of days over 35 degrees in Derby

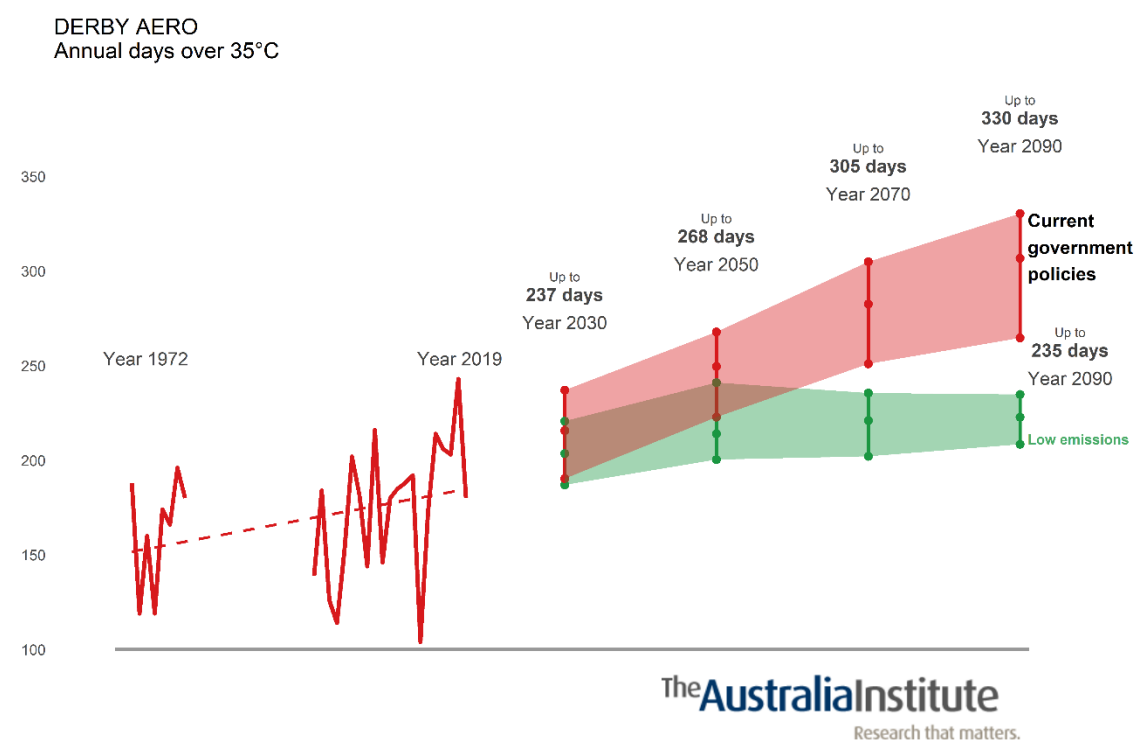


Table 2: Derby projected days over 35 degrees

		2030	2050	2070	2090
Historical average	178.1				
Low emissions		187.0-220.7	200.4-241.1	202.1-235.5	208.5-234.8
Intermediate emissions		192.3-234.8	208.1-252.1	217.0-258.3	228.1-275.1
Current policies		190.3-237.0	222.8-267.8	250.9-304.9	264.7-330.3

Source: CSIRO and Bureau of Meteorology (2018) *Climate projections*, provided on request

FITZROY CROSSING

Fitzroy Crossing sits inland in the Kimberley region. It is a semi-arid, monsoonal area with typically hot and humid summers. Extreme heat days (over 35 degrees) are common in Fitzroy Crossing, and expected to increase in frequency without strong action on climate change.

Under current government policies, in Fitzroy Crossing days over 35 degrees would go from an historical average of 215 days per year to a maximum of 260 days by 2030, 279 days by 2050, 310 days by 2070 and 328 days by 2090. This would be concentrated in summer, where a maximum of 99% of summer days would be over 35 degrees by 2090.

Fitzroy Crossing would benefit significantly from climate policies that would keep warming below 1.5 degrees, as represented by the RCP 2.6 scenario. Climate policies to keep warming below 1.5 degrees would keep predicted days over 35 degrees to 243 days by 2030, increasing to 260 days by 2050 and stabilising at 254 days by 2090.

Figure 9: Forecast number of days over 35 degrees in Fitzroy Crossing

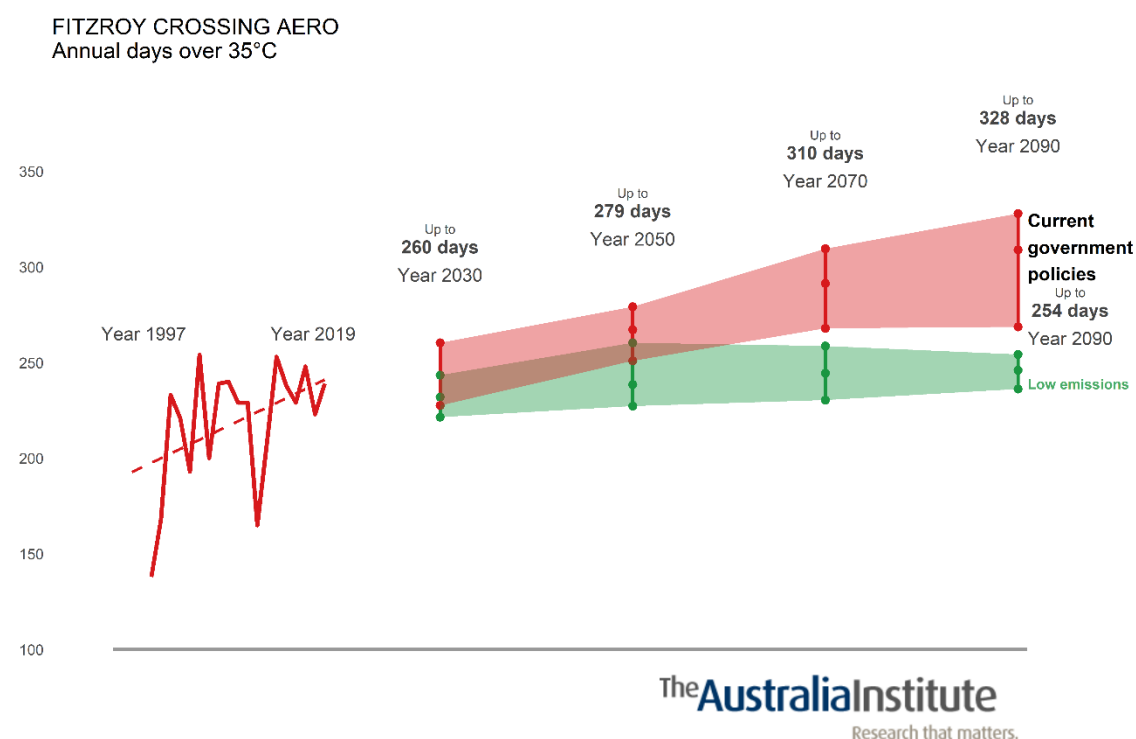


Table 3: Fitzroy Crossing projected days over 35 degrees

		2030	2050	2070	2090
Historical average	214.9				
Low emissions		221.5-243.4	227.3-260.4	230.4-258.7	236.2-254.3
Intermediate emissions		219.2-262.2	233.6-269.1	239.3-273.8	251.3-287.7
Current policies		227.6-260.4	250.9-279.1	267.9-309.5	268.7-327.9

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Source: CSIRO and Bureau of Meteorology (2018) *Climate projections*, provided on request

HALLS CREEK

Halls Creek historically experiences hot summers and warm winters. The frequency of extreme temperature days in Halls Creek is expected to rise dramatically unless emissions are reduced.

Under current government policies, in Halls Creek days over 35 degrees would go from an historical average of 156 days per year to a maximum of 200 days by 2030, 228 days by 2050, 259 days by 2070 and 284 days by 2090. This would be concentrated in summer, where a maximum of 96% of summer days would be over 35 degrees by 2090.

Halls Creek would benefit significantly from climate policies that would keep warming below 1.5 degrees, as represented by the RCP 2.6 scenario. Climate policies to keep warming below 1.5 degrees would keep predicted days over 35 degrees to 184 days by 2030, increasing to 203 days by 2050 and stabilising at 195 days by 2090.

Figure 10: Forecast number of days over 35 degrees in Halls Creek

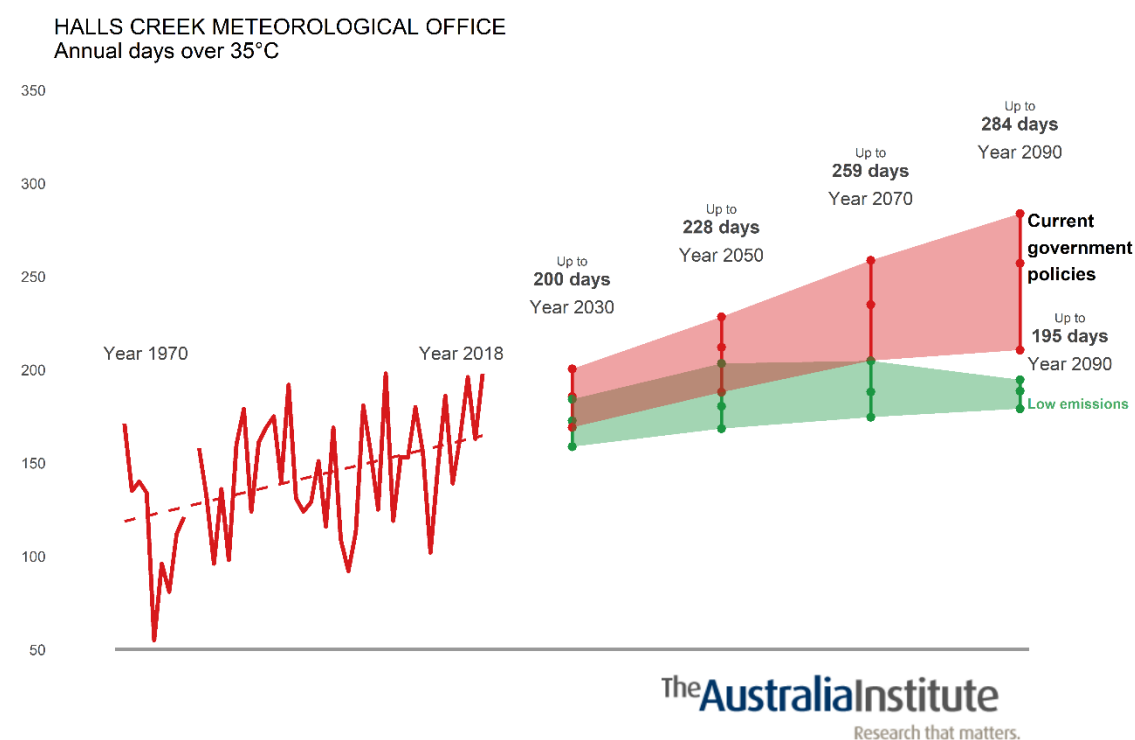


Table 4: Halls Creek projected days over 35 degrees

		2030	2050	2070	2090
Historical average	155.7				
Low emissions		158.8-184.2	168.4-203.4	174.6-204.8	179.2-194.7
Intermediate emissions		164.7-203.5	171.5-211.0	185.6-219.6	186.4-229.2
Current policies		169.1-200.5	188.0-228.4	204.9-258.7	210.6-283.7

Source: CSIRO and Bureau of Meteorology (2018) *Climate projections*, provided on request

KUNUNURRA

Kununurra sits in the north-east corner of the Kimberley region close to the Northern Territory border. Its climate is characterised by high heat and humidity during the wet season. Without action to reduce emissions, extreme heat events in Kununurra will continue to increase in frequency.

Under current government policies, in Kununurra days over 35 degrees would go from an historical average of 207 days per year to a maximum of 253 days by 2030, 279 days by 2050, 312 days by 2070 and 328 days by 2090. This would be concentrated in summer, where a maximum of 96% of summer days would be over 35 degrees by 2090.

Kununurra would benefit significantly from climate policies that would keep warming below 1.5 degrees, as represented by the RCP 2.6 scenario. Climate policies to keep warming below 1.5 degrees would keep predicted days over 35 degrees to 240 days by 2030, increasing to 258 days by 2050 and stabilising at 254 days by 2090.

Figure 11: Forecast number of days over 35 degrees in Kununurra

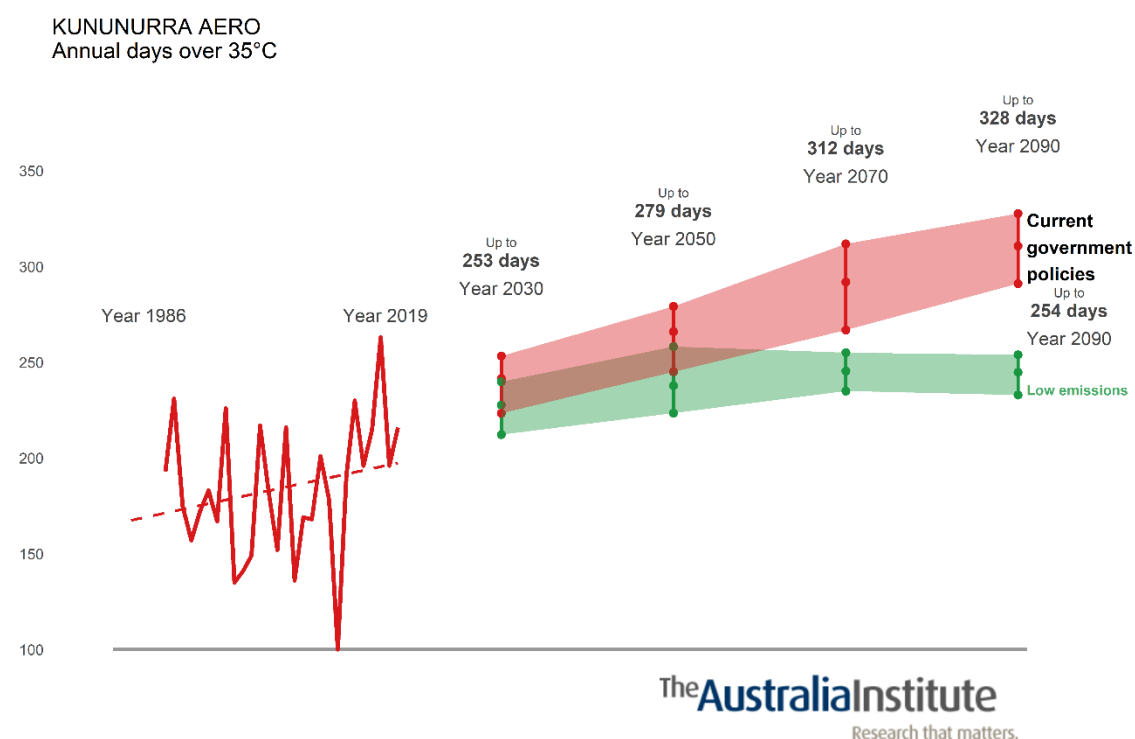


Table 5: Kununurra projected days over 35 degrees

		2030	2050	2070	2090
Historical average	206.5				
Low emissions		212.3-239.9	223.4-258.2	235.0-255.1	232.9-253.9
Intermediate emissions		217.2-248.8	230.2-262.2	243.5-272.2	251.0-279.3
Current policies		223.4-253.3	245.0-279.2	266.8-311.8	291.0-327.6



Source: CSIRO and Bureau of Meteorology (2018) *Climate projections*, provided on request

BIDYADANGA

Bidyadanga is the largest remote Aboriginal community in Western Australia. It is located on the East coast of the Kimberley region, approximately 190 kilometres south of Broome.

Under current government policies, in Bidyadanga days over 35 degrees would go from an historical average of 107 days per year to a maximum of 173 days by 2030, 215 days by 2050, 256 days by 2070 and 291 days by 2090. This would be concentrated in summer, where a maximum of 97% of summer days would be over 35 degrees by 2090.

Bidyadanga would benefit significantly from climate policies that would keep warming below 1.5 degrees, as represented by the RCP 2.6 scenario. Climate policies to keep warming below 1.5 degrees would keep predicted days over 35 degrees to 158 days by 2030, increasing to 182 days by 2050 and stabilising at 176 days by 2090.

Figure 12: Forecast number of days over 35 degrees in Bidyadanga

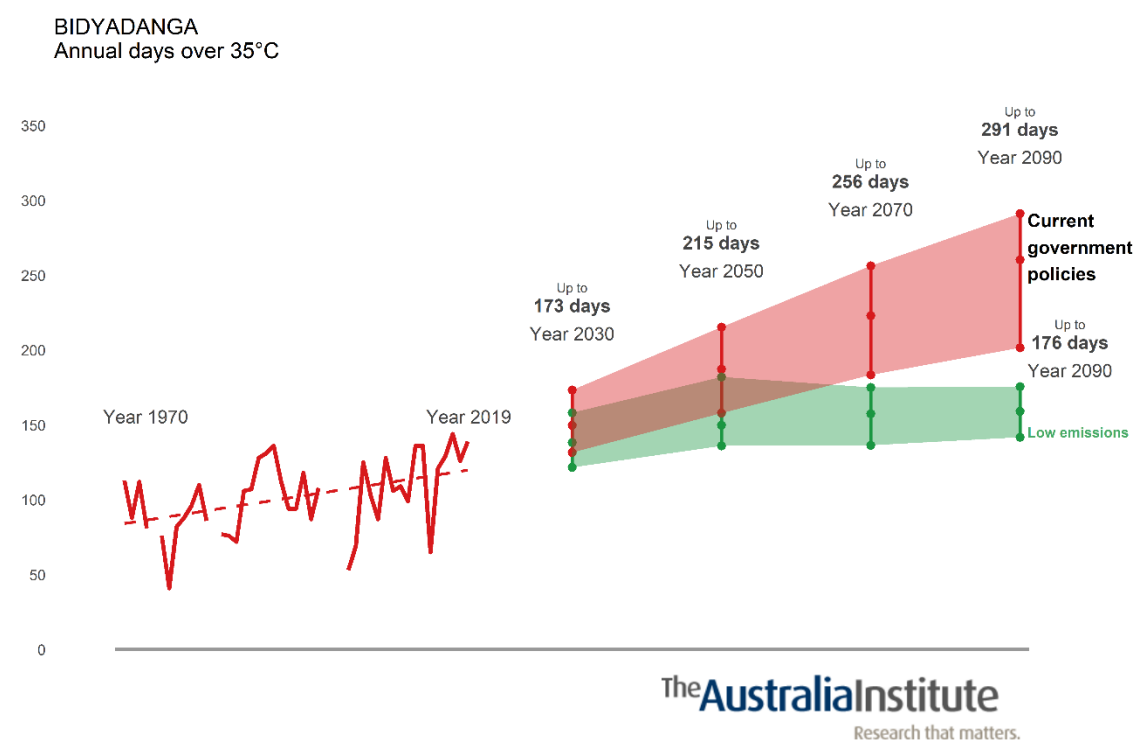


Table 6: Bidyadanga projected days over 35 degrees

		2030	2050	2070	2090
Historical	106.9				
Low emissions		121.6-158.1	136.0-182.1	136.5-175.0	141.8-175.6
Intermediate emissions		121.9-170.8	142.7-190.9	155.1-199.6	164.2-213.3
Current policies		131.6-173.4	157.9-215.3	183.4-256.3	201.5-291.2

Source: CSIRO and Bureau of Meteorology (2018) *Climate projections*, provided on request

Projected increases in days over 40 °

In most parts of the Kimberley region, the increase in days over 40 degrees will have serious consequences. The number of days over 40 degrees in Derby is expected to increase dramatically in the coming decades according to the eight climate models used by the CSIRO and BoM. Under a business as usual (BAU) scenario on greenhouse emissions, the CSIRO projects that Derby could experience as many as 41 days over 40 degrees per year in 2030, and up to 168 days per year by 2090. This would be 12 times the BoM average, currently 14 days per year from 1981–2010.

Some regions of the Kimberley, including Fitzroy Crossing and Kununurra are expected to experience days over 40 degrees for the majority of the year by 2090, under BAU.

When the air temperature exceeds 40 degrees, NOAA's heat stress index rises to "Extreme Danger" when relative humidity levels reach 45%. Broome and Bidyadanga have a mean 3pm relative humidity at or above 45% for six months of the year (September-March). Both Derby and Kununurra have mean 3pm humidity above 45% for January and February (see Figure 5).

Figures 13-18 and Tables 7-12 below present the CSIRO predictions out to 2090 under the BAU and the RCP 2.6 scenario that include a significant reduction in emissions, for each of the major Kimberley towns.

BROOME

Figure 13: Forecast number of days over 40 degrees in Broome

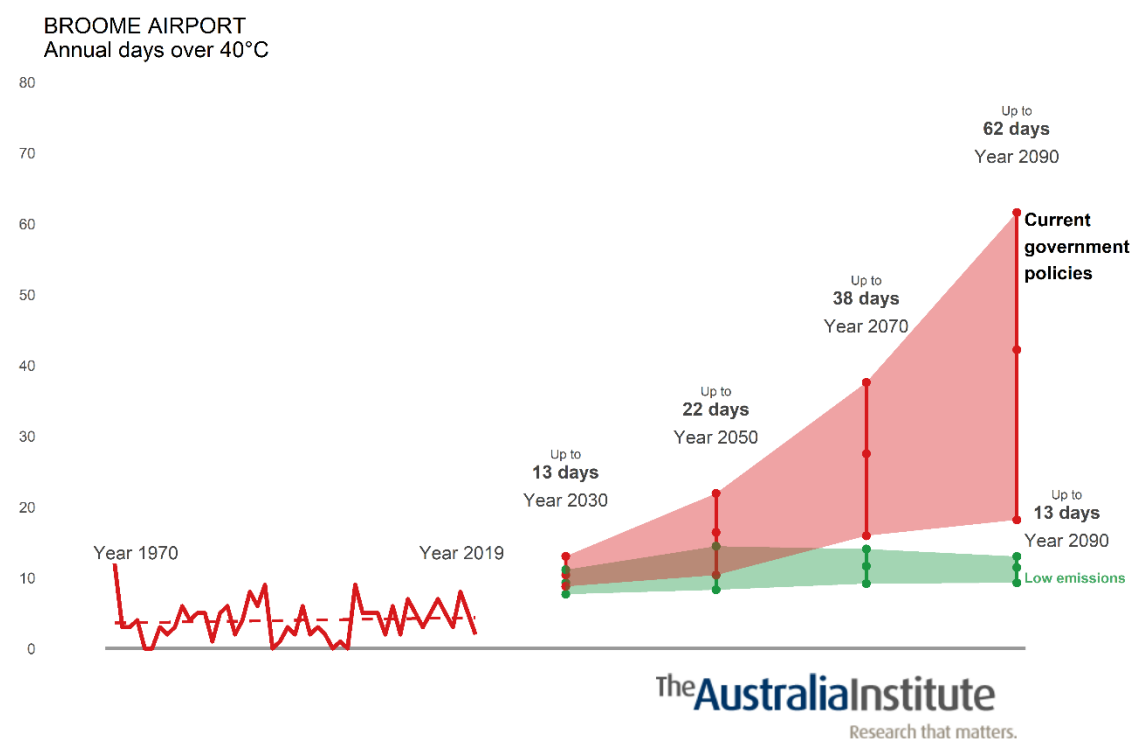


Table 7: Broome projected days over 40 degrees

		2030	2050	2070	2090
Historical average	6.1				
Low emissions		7.7-11.1	8.3-14.5	9.2-14.1	9.3-13.0
Intermediate emissions		7.9-12.9	9.3-15.9	10.4-19.3	11.5-21.9
Current policies		8.8-13.0	10.4-21.9	15.9-37.6	18.2-61.6

The Australia Institute
Research that matters.

Source: CSIRO and Bureau of Meteorology (2018) *Climate projections*, provided on request

DERBY

Figure 14: Forecast number of days over 40 degrees in Derby

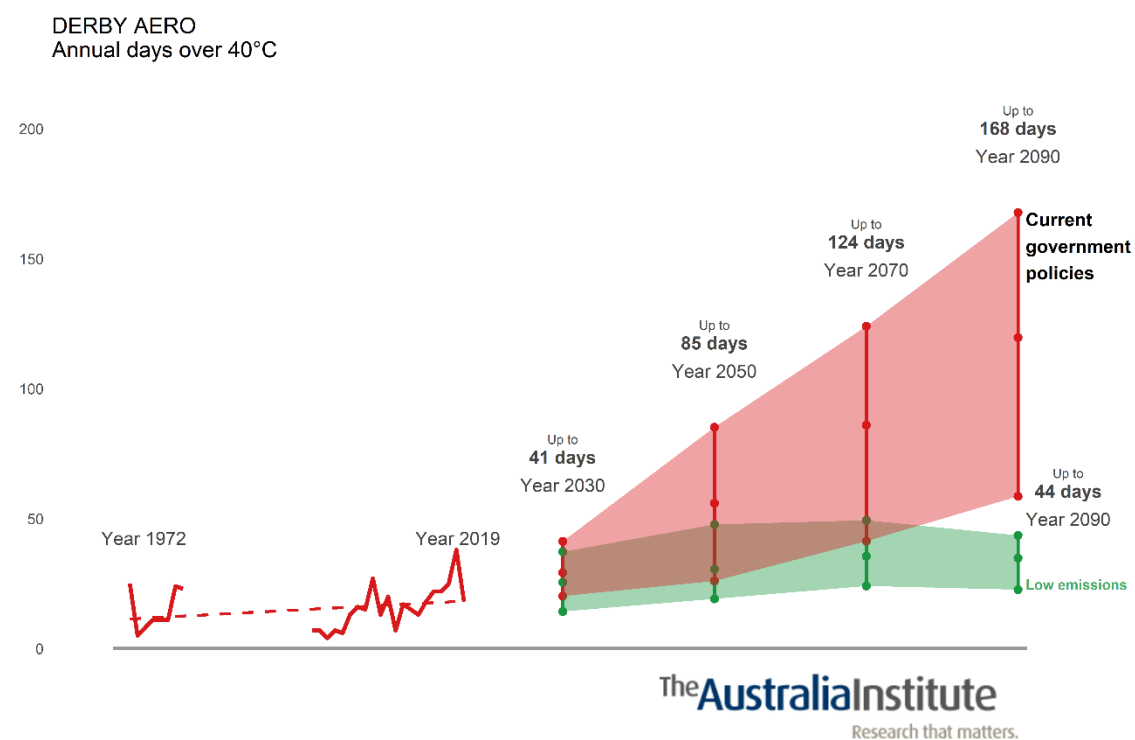


Table 8: Derby projected days over 40 degrees

		2030	2050	2070	2090
Historical average	13.9				
Low emissions		14.3-37.2	19.1-47.8	24.1-49.3	22.7-43.5
Intermediate emissions		17.1-42.0	25.0-56.4	26.7-64.2	26.2-74.8
Current policies		20.2-41.2	26.0-85.1	41.3-124.0	58.6-167.7

The Australia Institute
Research that matters.

Source: CSIRO and Bureau of Meteorology (2018) *Climate projections*, provided on request

FITZROY CROSSING

Figure 15: Forecast number of days over 40 degrees in Fitzroy Crossing

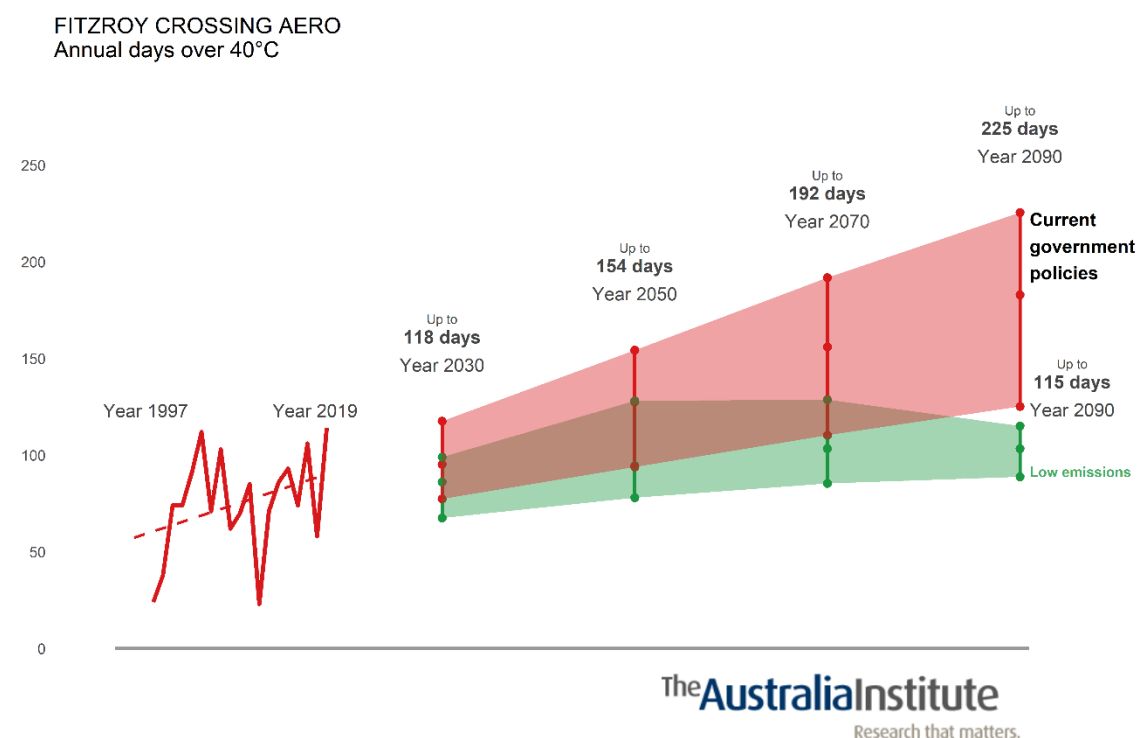


Table 9: Fitzroy Crossing projected days over 40 degrees

		2030	2050	2070	2090
Historical	67.8				
Low emissions		67.4-99.0	77.9-128.1	85.4-128.7	88.8-115.1
Intermediate emissions		74.2-109.8	84.9-129.0	91.7-134.9	90.8-151.7
Current policies		77.3-117.5	93.9-154.3	110.3-191.8	125.1-225.4

Source: CSIRO and Bureau of Meteorology (2018) *Climate projections*, provided on request

HALLS CREEK

Figure 16: Forecast number of days over 40 degrees in Halls Creek

HALLS CREEK METEOROLOGICAL OFFICE
Annual days over 40°C

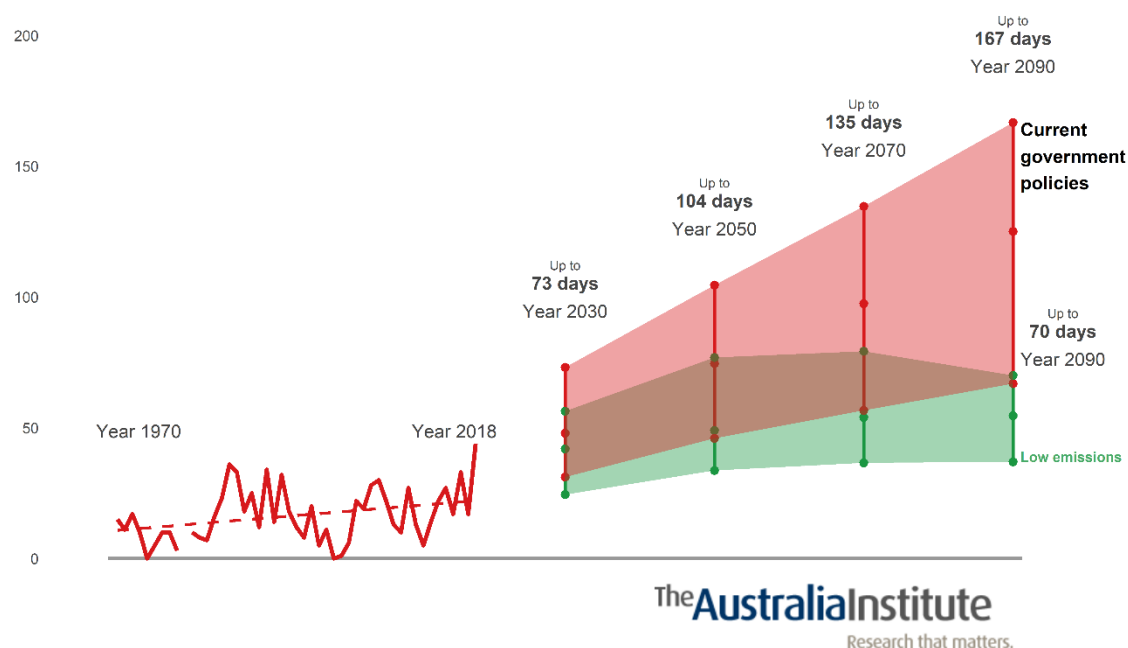


Table 10: Halls Creek projected days over 40 degrees

		2030	2050	2070	2090
Historical average	26.4				
Low emissions		24.4-56.4	33.7-76.8	36.6-79.3	37.0-70.0
Intermediate emissions		28.9-64.8	36.9-81.8	44.2-86.5	43.1-91.2
Current policies		31.1-73.1	45.9-104.5	56.7-134.6	66.9-166.7

The Australia Institute
Research that matters.

Source: CSIRO and Bureau of Meteorology (2018) *Climate projections*, provided on request

KUNUNURRA

Figure 17: Forecast number of days over 40 degrees in Kununurra

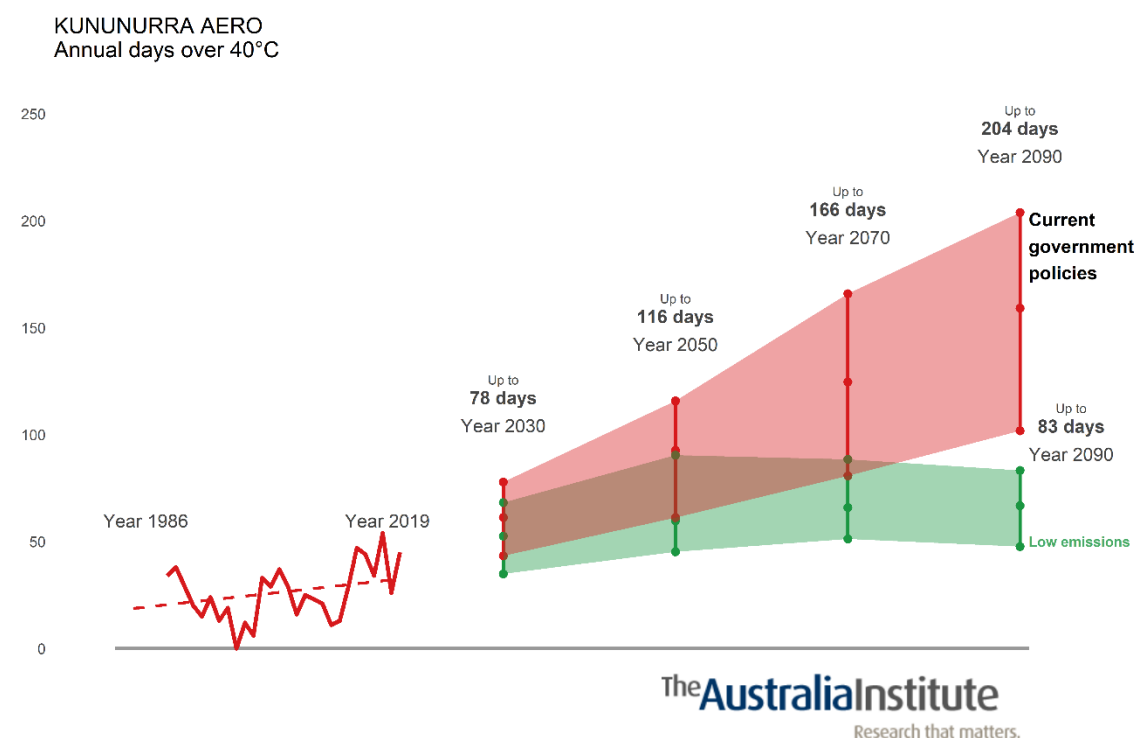


Table 11: Kununurra projected days over 40 degrees

		2030	2050	2070	2090
Historical average	35.3				
Low emissions		34.9-68.2	45.2-90.4	51.3-88.5	47.6-83.3
Intermediate emissions		38.2-73.2	51.4-90.2	59.4-96.6	60.7-108.8
Current policies		43.3-77.9	61.2-115.8	80.8-165.9	101.8-203.8

The Australia Institute
Research that matters.

Source: CSIRO and Bureau of Meteorology (2018) *Climate projections*, provided on request

BIDYADANGA

Figure 18: Forecast number of days over 40 degrees in Bidyadanga

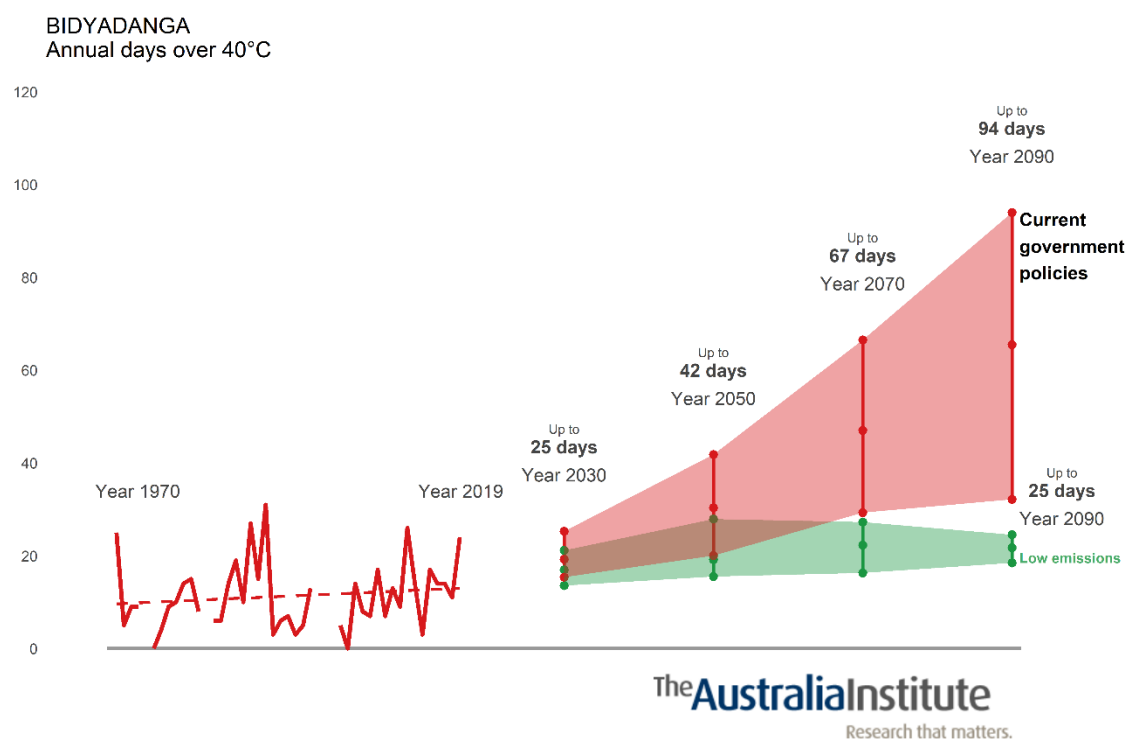


Table 12: Bidyadanga projected days over 40 degrees

		2030	2050	2070	2090
Historical	10.4				
Low emissions		13.6-21.2	15.5-27.9	16.3-27.3	18.5-24.5
Intermediate emissions		14.8-24.4	16.8-30.0	19.5-39.3	22.6-39.7
Current policies		15.4-25.3	20.0-41.8	29.3-66.5	32.2-94.0

Projected increases in nights over 25°

When hot days are combined with hot nights, heat load and stress carry over and the body has no opportunity to cool down and recover.

The number of hot days in the Kimberley will be accompanied by an even greater increase in the frequency of extreme summer nights. Part of this more rapid warming at night is characteristic of the climate system however, as night-time temperatures are more sensitive to a build-up of greenhouse gases.¹⁹ The BoM classifies nights with extreme heat as those with a minimum temperature of 25 degrees.

In February 2019, Fitzroy Crossing recorded its highest ever minimum temperature for that month.²⁰ As shown in Figures 19-24 and Tables 13-18 below, minimum temperatures are expected to rise dramatically in the Kimberley region under a BaU scenario.

¹⁹ Davy et al. (2016) *Diurnal asymmetry to the observed global warming* - *International Journal of Climatology*.

²⁰ BOM (2019) *Special Climate Statement 68- widespread heatwaves during December 2018 and January 2019*. p 48, <http://www.bom.gov.au/climate/current/statements/scs68.pdf>

BROOME

Figure 19: Forecast number of nights above 25 degrees in Broome

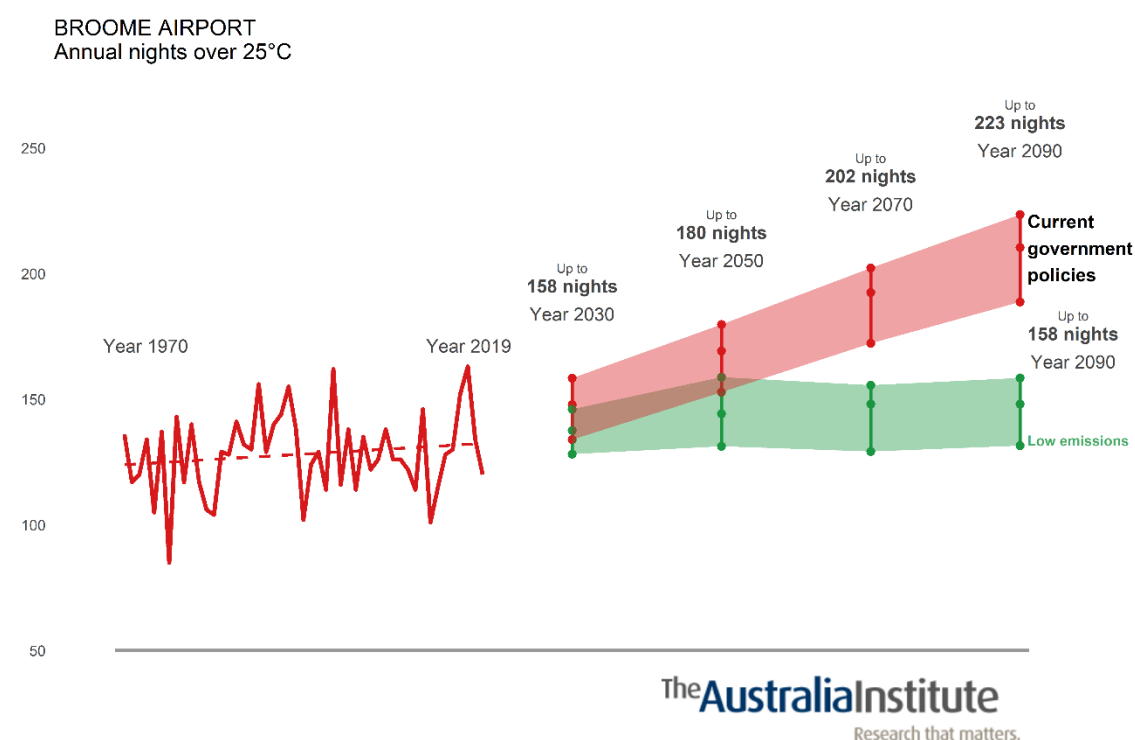


Table 13: Broome projected nights over 25 degrees

		2030	2050	2070	2090
Historical average	113.6				
Low emissions		128.2-146.0	131.3-158.8	129.2-155.6	131.5-158.5
Intermediate emissions		125.1-150.3	138.9-165.6	145.7-176.0	156.1-182.2
Current policies		133.9-158.4	152.8-179.8	172.2-202.2	188.7-223.5

Source: CSIRO and Bureau of Meteorology (2018) *Climate projections*, provided on request

DERBY

Figure 20: Forecast number of nights above 25 degrees in Derby

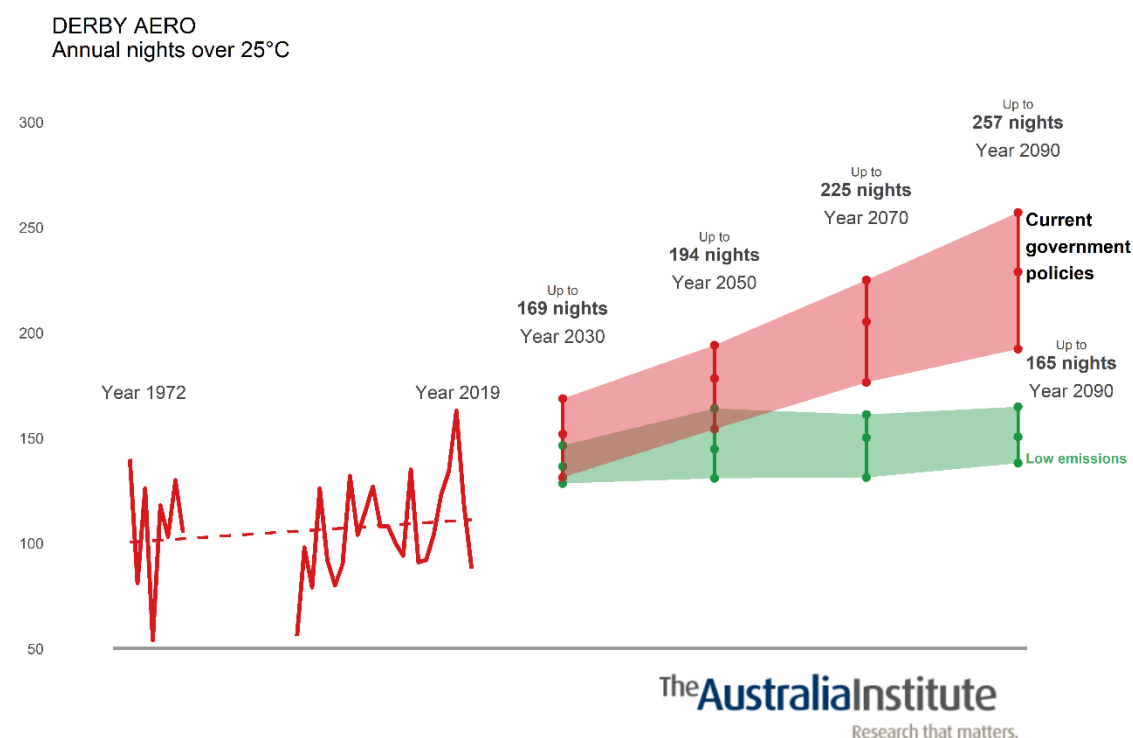


Table 14: Derby projected nights over 25 degrees

		2030	2050	2070	2090
Historical average	111.4				
Low emissions		128.4-146.4	130.9-164.0	131.2-161.1	138.1-164.8
Intermediate emissions		123.8-163.1	137.6-179.8	145.1-189.1	153.8-198.1
Current policies		131.3-168.7	154.1-194.1	176.4-225.0	192.3-257.0

Source: CSIRO and Bureau of Meteorology (2018) *Climate projections*, provided on request

FITZROY CROSSING

Figure 21: Forecast number of nights above 25 degrees in Fitzroy Crossing

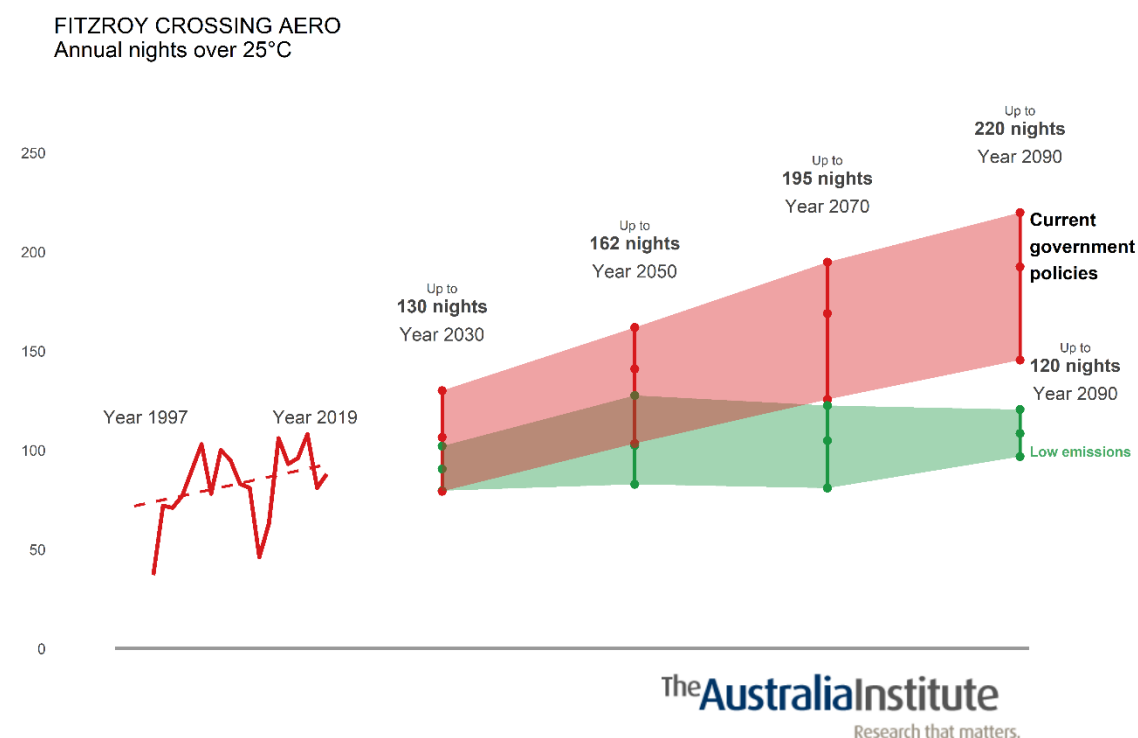


Table 15: Fitzroy Crossing projected nights over 25 degrees

		2030	2050	2070	2090
Historical average	64.3				
Low emissions		79.6-102.0	82.8-127.6	80.9-122.6	96.8-120.5
Intermediate emissions		72.6-112.9	88.8-136.9	97.3-152.4	98.1-163.4
Current policies		79.3-130.0	103.4-161.9	125.6-194.7	145.4-219.8

Source: CSIRO and Bureau of Meteorology (2018) *Climate projections*, provided on request

HALLS CREEK

Figure 22: Forecast number of nights above 25 degrees in Halls Creek

HALLS CREEK METEOROLOGICAL OFFICE
Annual nights over 25°C

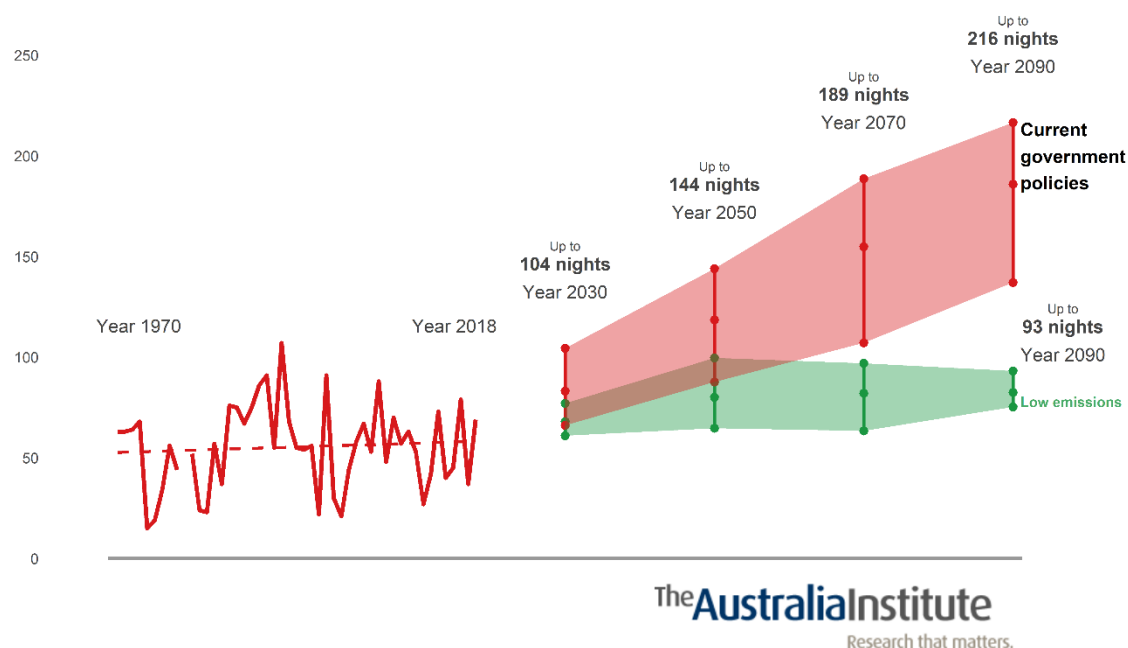


Table 16: Halls Creek projected nights over 25 degrees

		2030	2050	2070	2090
Historical average	45.8				
Low emissions		61.0-77.1	64.7-99.7	63.4-97.0	75.3-93.2
Intermediate emissions		61.5-85.7	76.0-109.0	83.9-132.3	83.5-145.9
Current policies		66.1-104.5	87.7-144.0	107.2-188.6	137.0-216.5

The Australian Institute
Research that matters.

Source: CSIRO and Bureau of Meteorology (2018) *Climate projections*, provided on request

KUNUNURRA

Figure 23: Forecast number of nights above 25 degrees in Kununurra

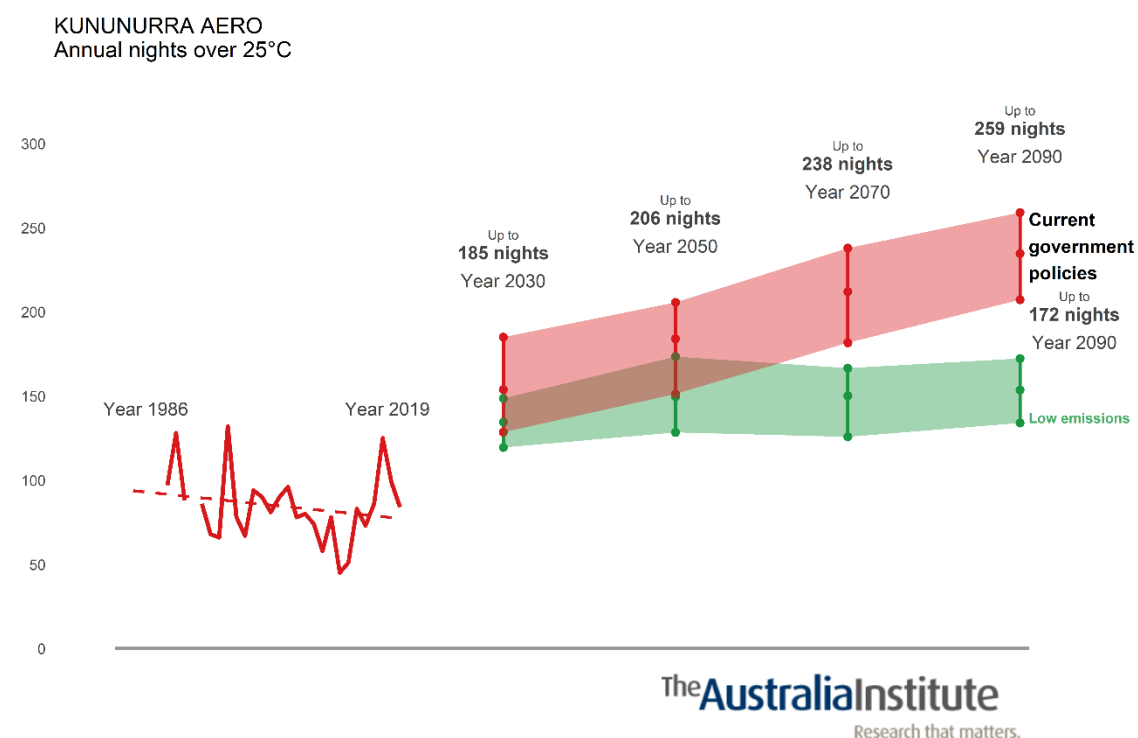


Table 17: Kununurra projected nights over 25 degrees

		2030	2050	2070	2090
Historical average	104.7				
Low emissions		119.5-148.5	128.4-173.5	125.8-166.6	134.0-172.3
Intermediate emissions		126.4-157.4	138.3-182.6	149.3-194.0	156.0-204.4
Current policies		128.5-185.0	151.2-205.6	181.7-237.9	207.3-259.0

Source: CSIRO and Bureau of Meteorology (2018) *Climate projections*, provided on request

BIDYADANGA

Figure 24: Forecast number of nights above 25 degrees in Bidyadanga

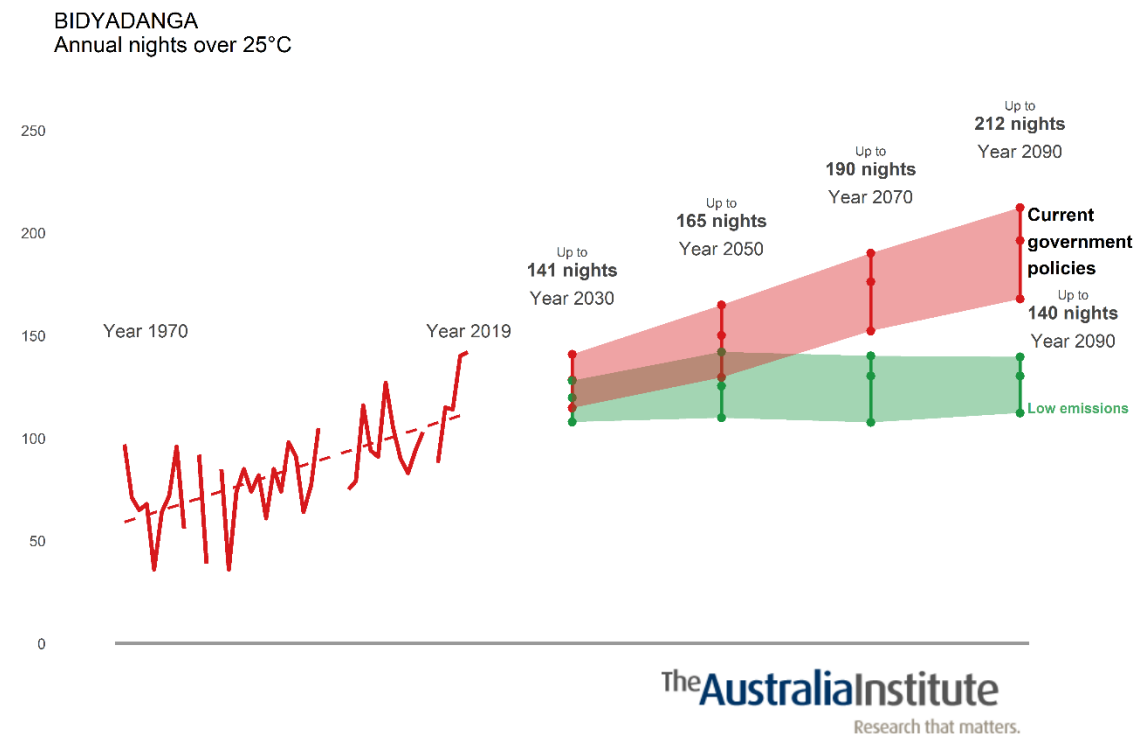


Table 18: Bidyadanga projected nights over 25 degrees

		2030	2050	2070	2090
	88.2				
Low emissions		107.9-128.1	110.0-142.1	107.7-140.1	112.3-139.6
Intermediate emissions		105.7-131.7	118.9-147.1	124.2-155.7	134.2-161.6
Current policies		114.7-140.9	129.6-164.9	152.3-190.2	167.8-212.3

Source: CSIRO and Bureau of Meteorology (2018) *Climate projections*, provided on request

Health and lifestyle impacts of extreme heat in the Kimberley

The impact of extreme heat on human health, particularly over extended periods, is severe. Although people living in hot areas do acclimatise to help cope with extreme temperatures, there are limits.²¹ A large increase in days over 35 degrees will push past those limits.

The health impacts of increasing extreme heat can include both direct heat illnesses such as heat exhaustion and indirect illnesses such as heart failure and even death.

WorkSafe Western Australia lists a range of illnesses arising directly from the body's inability to balance heat inputs during extreme temperatures. These include cramps, rashes, and nausea to severe injuries such as heat stroke, exhaustion and even death if treatment is delayed.²² As climate change worsens this can be expected to put people that are more vulnerable at increasingly greater risk.

The groups most vulnerable to heat impacts include the elderly, the very young, and those with pre-existing health conditions. Illnesses such as angina, kidney disease, and diabetes are at higher risk of being triggered or exacerbated when people are unable to maintain a safe body temperature.²³

People suffering from mental disorders are also vulnerable. This vulnerability to extreme heat can result from altered behavioral responses to high temperatures or the impact of medications.

The Kimberley region has a low Socio-Economic Indexes for Areas score (SEIFA) and high prevalence of physical and mental health conditions. The hospitalization rate and mortality for Kimberley residents is significantly above the State rate (2.0 and 1.7 times respectively), and notifiable diseases in adults aged 15-64 is far above the State average (3.8 times).²⁴ Suicide was the leading cause of death for 15-24 year olds in the Kimberley, significantly

²¹ Hanna and Tait (2015) *Limitations to thermoregulation and acclimatisation challenges human adaptation to global warming*, Int J Environ Res Public Health 12.

²² WorkSafe Western Australia (2019) *Working safely in hot conditions*.
<http://www.commerce.wa.gov.au/worksafe/working-safely-hot-conditions>

²³ Hanna et al. (2016) *The silent killer: Climate Change and the Health Impacts of Extreme Heat*, The Climate Council. <https://research-management.mq.edu.au/ws/portalfiles/portal/72578140/72578105.pdf>

²⁴ Western Australian Government (2018) *Kimberley Health Profile*, p 5-6.
http://www.wacountry.health.wa.gov.au/fileadmin/sections/publications/Publications_by_topic_type/Reports_and_Profiles/Kimberley_Health_Profile_2018.pdf

higher (3.8 times) than the State. Kimberley residents aged 15-64 are also more likely to access community mental health services than the state average (1.5 times).²⁵

As stated earlier, irritability and psychological stress also increase in heat. Nights above 25 degrees restrict the body's ability to cool down and recover from hot days. Studies show that there is an association between the mortality of not just stroke patients but also the general population and high night temperatures.²⁶ The 'synergistic effect' of night humidity, increased temperatures, and urban heat island effects in heatwaves has been estimated in some studies to double general mortality risk by the end of the century under RCP 8.5.²⁷

Often underrated, major heatwaves have been dubbed the 'silent killer', causing more deaths in the last century in Australia than all natural disasters put together.²⁸

Extreme heat nights also cause increased insomnia and lack of rest. This is exacerbated by the higher relative humidity overnight. As sleep is vital for healthy human functioning, a deficit means more susceptibility to disease, obesity, chronic illness and harm to our psychological and cognitive functioning.²⁹

Productivity decreases significantly under these stresses as people are affected with the consequences of extreme heat. Workplace safety and the ability to work declines. This can also be displayed in economic terms as costs rise to account for the lack of labor productivity and changes needed in workplaces.³⁰

Like most parts of Australia, a significant proportion of the local Kimberley workforce is exposed to the heat. Construction, outdoor tourism and agriculture are significant employers in Kimberley region and are particularly exposed to extreme heat events. Increases in extreme heat events impact both the health and productivity of these workers.

The cost of lost productivity because of extreme heat in Australia has been estimated at almost \$7 billion in 2013-14 alone.³¹

²⁵ Ibid.

²⁶ Murage et al (2017) *Effect of night-time temperatures on cause and age-specific mortality in London*, Environmental Epidemiology 1.; Roye (2017) *The effects of hot nights on mortality in Barcelona, Spain*, International Journal of Biometeorology 61.

²⁷ Zhao et al (2018) *Interactions between urban heat islands and heat waves*, Environmental Research Letters 13.

²⁸ Hanna et al (2016) *The silent killer: Climate Change and the Health Impacts of Extreme Heat*, The Climate Council.

²⁹ Obradovich et al (2017) *Night-time temperature and human sleep loss in a changing climate*, Science Advances 3.

³⁰ Climate Council (2014) *Heatwaves: Hotter, Longer, More Often*.

<https://www.climatecouncil.org.au/uploads/9901f6614a2cac7b2b888f55b4dff9cc.pdf>

³¹ Zander, Opperman and Garnet (2015) *Extreme heat poses a billion-dollar threat to Australia's economy*. <https://theconversation.com/extreme-heat-poses-a-billion-dollar-threat-to-australias-economy-41153>

INDIGENOUS AUSTRALIANS

Some communities are disproportionately impacted by increasing extreme heat as a result of their location, as well as their social and economic circumstances.³² Aboriginal communities in Australia are particularly impacted by climate change and extreme heat.

Indigenous and Torres Strait Islanders make up approximately 46% of the Kimberley population,³³ are largely located in rural or remote areas and are less transient than the non-Indigenous Kimberley population.

Climate change and extreme heat disproportionately affect Indigenous communities due to interrelating factors. These include exposure to climate, pre-existing health conditions, income inequality, cultural connection to Country and disproportionately poor access to services and amenities.

Extreme heat events exacerbate the already large health and income disparities between the Kimberley's Indigenous and non-Indigenous populations. The prevalence and burden of chronic disease is greater amongst Aboriginal people; the Kimberley Aboriginal population are more likely to suffer from diabetes, cardiovascular diseases, asthma, kidney disease and mental health problems.³⁴

The relative gap between median disposable income of Indigenous populations and non-Indigenous populations is greatest in remote areas like the Kimberley. The Indigenous poverty rate of the West Kimberley region is 55%.³⁵

Anna Dwyer, a Karajarri woman from Bidyadanaga Aboriginal Community and linguist, interpreter and researcher at the Nulungu Research Institute, has explored Indigenous concerns around climate change on Karajarri Country. Her work documents Karajarri community concerns about extreme heat, particularly its effect on hunting practices and harvesting times.³⁶

³² Coates et al. (2014) *Exploring 167 years of vulnerability: An examination of extreme heat events in Australia 1844-2010*, Environmental Science and Policy 42, p 34.

³³ The Indigenous population is calculated as the proportion of total population less 'not stated'. Australian Bureau of Statistics (2016) *Census Table Builder*. <https://auth.censusdata.abs.gov.au/webapi/jsf/dataCatalogueExplorer.xhtml>.

³⁴ Government of Western Australia WA Country Health Service (2016) *Rural Health West – Kimberley – Population and health snapshot*. https://ruralhealthwest01.blob.core.windows.net/www-production/docs/default-source/outreach/outreach-regional-profiles/kimberley-population-and-health-snapshot_0417.pdf

³⁵ Australian National University (2018) *Income, poverty and inequality - 2016 Census Paper 2*, p 18-23. https://openresearch-repository.anu.edu.au/bitstream/1885/145053/1/CAEPR_Census_Paper_2.pdf

³⁶ Dwyer (2017) *Climate Change and Adaptation on Karajarri Country and 'Pukarikarra' Places*, Nulungu Research Papers, I.

Extreme heat can affect productivity and education in Indigenous communities. A case study in the Indigenous Kanarra community, about 100 kilometres south of Fitzroy Crossing, notes that during extreme events the productivity of professional staff declines, and teachers often take children to the billabong to cool. Over time, this is likely to interrupt the children's academic progress.³⁷

Indigenous communities also disproportionately face barriers to responding and adapting to extreme heat. Challenges to Indigenous climate change adaptation include limited access to weather warnings, cultural and linguistic diversity in remote Indigenous communities, limited access to resources education, and fragmented engagement between Indigenous communities, emergency and health services, and local governments.³⁸

Natural disaster response in Northern Australia has historically treated Indigenous communities as passive victims, excluding them from the emergency management planning process. The government-funded Nation Climate Change Adaptation Research Facility (NCCARF) notes that:

This has been a disempowering experience for the residents of these communities and an obstacle to their active involvement in recovery processes. This tendency to exclude Aboriginal people from emergency management planning and responses reduces their capacity to develop and use their own specific coping strategies and increases their vulnerability.³⁹

Effective management of extreme heat in the Kimberley region should involve participation and contribution from Indigenous communities in developing extreme heat management frameworks. Additionally, Indigenous communities continue to play a large role in mitigating climate change through Indigenous land management practices and carbon offsetting projects.

³⁷ Australian Government Department of Climate Change and Energy Efficiency (2009) *Risks from Climate Change to Indigenous Communities in the Tropical North of Australia*, p 84.

³⁸ National Climate Change Adaptation Research Facility (2019) *Indigenous climate change adaptation in the Kimberley region of North-western Australia*.
https://www.nccarf.edu.au/sites/default/files/attached_files_publications/Leonard_2013_Indigenous_climate_change_adaptation.pdf

³⁹ Ibid, p 85.

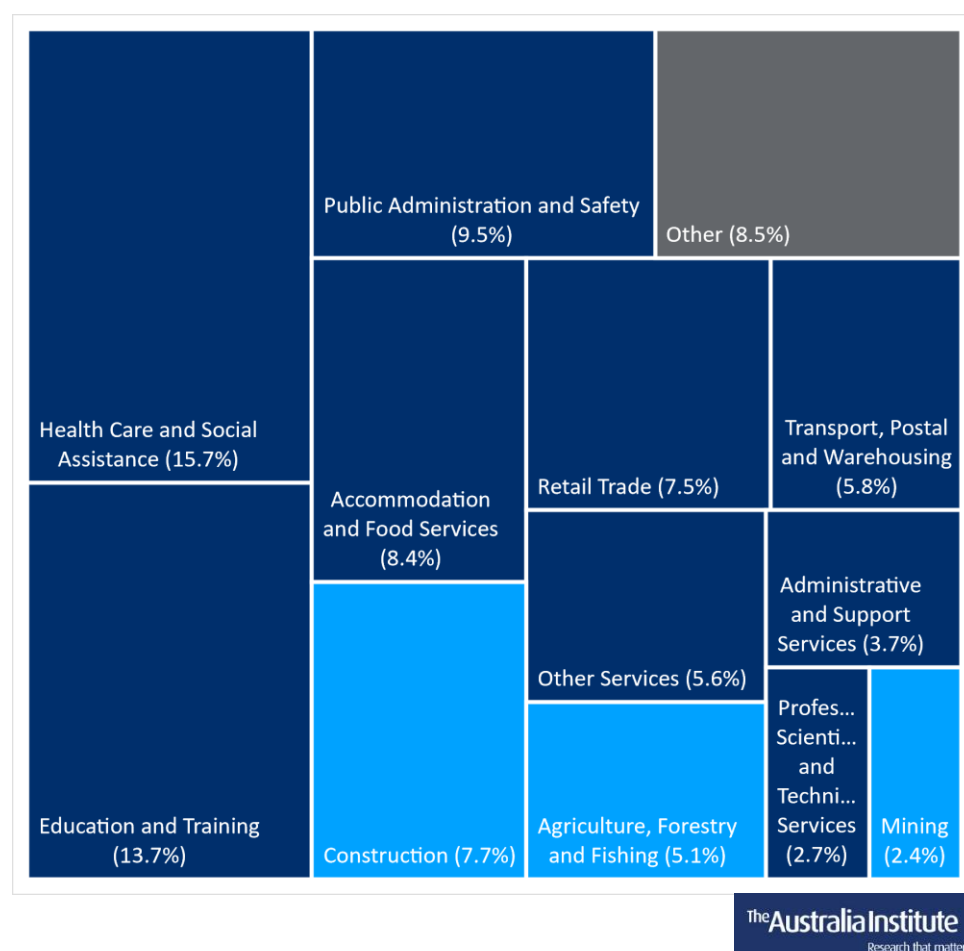
Heat stress and the Kimberley workforce

Increasing extreme heat will have serious consequences for the health and safety of much of the Kimberley workforce.

A significant proportion of the Kimberley workforce is vulnerable to the dangers of increasing extreme heat. Over 15 per cent of the workforce is employed in the mining, construction and agricultural industries, all of which require workers to undertake heavy work in the heat.⁴⁰

Figure 25 (below) shows the main industries of employment for the Kimberley population, with those industries requiring large amounts of outdoor work highlighted.

Figure 25: Main industries of employment in the Kimberley Region; industries involving outdoor work in light blue



⁴⁰ ABS (2016) *Table Builder 2016 Australian Census*.

<https://auth.censusdata.abs.gov.au/webapi/jsf/tableView/tableView.xhtml>

Source: 2016 Census

As discussed above, at temperatures above 35 degrees, sweating is far less effective at cooling the body, which can have mild to severe consequences. Heat stroke can cause permanent damage to the brain and other vital organs and can even result in death.⁴¹

Workplace factors that influence heat stress include work clothing, sun exposure, exposure to hot surfaces, confinement to enclosed spaces, distance from cool rest areas and hydration, the complexity of the tasks being undertaken and metabolic work rate.⁴²

CONSTRUCTION

The construction industry is a large employer in the Kimberley region, employing 7.7% of the Kimberley workforce.

Construction workers are at heightened risk of heat stress due to the physical nature of their work and prolonged exposure to hot outdoor temperatures.

A review of heat stress and health among construction workers in a changing climate found that construction workers in the US are over 13 times more likely to die from heat related illness than workers in other industries.⁴³

In Northern Australia, hot temperatures are restricting the time period in which construction workers are able to do their work.⁴⁴

TOURISM

The tourism industry is important to the Kimberley Region, both in terms of employment and economic impact. Tourism in the Kimberley is largely based on outdoor activity and will be adversely affected by extreme heat events..

⁴¹ Hanna and Tait (2015) *Limitations to thermoregulation and acclimatisation challenges human adaptation to global warming*, Int J Environ Res Public Health.

<https://academic.oup.com/heapro/article/30/2/239/561863>; Australian Mining Review (2017) *WA miners urged to guard against heat stress*, <https://www.miningreview.com.au/wa-miners-urged-guard-heat-stress/>

⁴² Queensland Government (2019) *Heat Stress (Basic) Calculator*.

<https://fswqap.worksafe.qld.gov.au/etools/etool/heat-stress-basic-calculator-test/>

⁴³ Aharya et al. (2017) *Assessing Heat Stress and Health among Construction Workers in a Changing Climate: A Review*, International Journal of Environmental Research and Public Health.

⁴⁴ Bardon (2019) *Outdoor construction workers in NT's tropical north fear changing climate*, ABC News Online. <https://www.abc.net.au/news/2019-11-09/outdoor-construction-workers-fear-changing-climate/11686010>

Tourism directly accounts for 2.4% of Western Australia's economy by Gross Value Added (GVA).⁴⁵

The Kimberley Visitor Factsheet, produced by Tourism WA, estimates that the Kimberley region receives an annual average of 412,700 visitors from intrastate, interstate and overseas, staying an average of 8 nights.⁴⁶

Kimberley tourism is heavily dependent on nature-based attractions and outdoor activities. Popular tourist activities include fishing, visiting beaches, boating, bird watching and camel rides.⁴⁷ The projected increase in extreme heat days will impact the natural environment in the Kimberley region through changes to biodiversity, water security, and the look and accessibility of the landscape. Tourist behaviour will also be affected, including the decisions about where and when to travel, transport options, and activities undertaken.⁴⁸

Half of international visitors to the Kimberley region camp or stay in campervans for accommodation.⁴⁹ Under projected increased heat conditions, these forms of accommodation may become less attractive accommodation options.

AGRICULTURE AND LIVESTOCK

Agriculture is a significant industry in the Kimberley region, with a focus on pastoral and irrigated agriculture. Beef production is the main agricultural industry.⁵⁰ A range of grains and seeds are grown in the Ord Valley and there is an emerging cotton industry.⁵¹ Other

⁴⁵ Tourism Western Australia (2016) *Tourism Satellite Account Western Australia 2015-2016 Fact Sheet*.
<https://www.tourism.wa.gov.au/About%20Us/Documents/TSA%202015-16%20Fact%20Sheet.pdf>

⁴⁶ Government of Western Australia (2018) *Kimberley Visitor Factsheet*.
https://www.tourism.wa.gov.au/Publications%20Library/Research%20and%20reports/2018/RDC%20Profiles%202018/Kimberley_2018%20Factsheet.pdf

⁴⁷ Shire of Broome (2015) *State of the Environment Report*, p 2.
http://www.broome.wa.gov.au/files/assets/public/pub/corporate-plans/final-endorsed-state-of-the-environment-report_march-2016.pdf

⁴⁸ Climate Council (2018) *Icons at risk: Climate change threatening Australian tourism*.
<https://www.climatecouncil.org.au/uploads/964cb874391d33dfd85ec959aa4141ff.pdf>

⁴⁹ Government of Western Australia (2018) *Kimberley Visitor Factsheet*, p 5.
https://www.tourism.wa.gov.au/Publications%20Library/Research%20and%20reports/2018/RDC%20Profiles%202018/Kimberley_2018%20Factsheet.pdf

⁵⁰ Department of Infrastructure, Regional Development and Cities and CSIRO (2018) *Agricultural viability: Fitzroy catchment*.
<https://publications.csiro.au/rpr/download?pid=csiro:EP186200&dsid=DS1>

⁵¹ Kimberley Development Commission (2019) *Primary industries*.
<https://kdc.wa.gov.au/economic-profile/primaryindustries/>

primary products from the Kimberley region include food crops such as mangoes, melons and chickpeas, and Sandalwood.⁵²

Agriculture is on the frontline of global warming impacts in many ways. Increasing temperatures and falling precipitation can reduce cropping and livestock yields. Increasing temperatures can also reduce soil moisture and increase erosion. Extreme heat can damage crops and stress livestock. Floods can destroy crops, livestock and farm infrastructure including buildings, roads, machinery and fencing.

Impacts on cropping

A recent Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) report found that changes in the climate since 2000 have significantly reduced farm productivity and crop yield:

The recent changes in climate have had a significant negative effect on the productivity of Australian cropping farms, particularly in south-western Australia and south-eastern Australia (Figure 2). In Western Australia, climate conditions between 2000–01 and 2014–15 lowered TFP by an average of 7.7 per cent—relative to what would have been seen under long-run average conditions (1914–15 to 2014–15). In New South Wales climate conditions post 2000–01 lowered productivity by an average of 6.5 per cent.

A similar pattern is observed for wheat yields, although the climate effects are larger. Climate conditions between 2000–01 and 2014–15 lowered national wheat yields by around 11.9 per cent relative to long-run conditions (16.3 per cent in Western Australia and 14.8 per cent in Victoria).⁵³

Recent CSIRO research has found potential wheat yields in Australia have already declined by 27% from 1990 to 2015 below what they would otherwise have been due to climate impacts, mostly the fall in rainfall and increasing temperatures over this period.⁵⁴

As would be expected, climate change will continue to reduce agricultural productivity and yields.

⁵² Nikolakis et al. (2011) *Adapting to climate change for water resource management: Issues for northern Australia*. https://crawford.anu.edu.au/research_units/eeh/pdf/EERH_RR108.pdf

⁵³ ABARE (2017) *Farm performance and climate: Climate-adjusted productivity for broadacre cropping farms*. http://data.daff.gov.au/data/warehouse/9aas/2017/FarmPerformanceClimate/FarmPerformanceClimate_v1.0.0.pdf

⁵⁴ Hochman et al (2017) *Climate trends account for stalled wheat yields in Australia since 1990*. <https://onlinelibrary.wiley.com/doi/full/10.1111/gcb.13604>

The Broome *State of the Environment* report notes that alternative agricultural production can have less detrimental impact on the environment and more resilience in a changing climate:

Less intensive agricultural pursuits, such as the wild and enrichment harvesting of bush fruits such as gubinge are already emerging as an economically viable and environmentally and culturally compatible enterprise.⁵⁵

Impacts on grazing

Cattle are vulnerable to rainfall variability and extreme temperatures. Similar to humans, a cow's response to heat stress depends on the combination of temperature and relative humidity. Under hot and humid conditions a cow's ability to cool itself through sweating is severely reduced, leading to illness, modified behaviour, loss of appetite, reduced reproductive efficiency and potentially, death.⁵⁶

Extreme heat events also present indirect effects to the grazing industry. Extreme heat due to climate change can restrict water availability, reduce soil fertility and grain yield for feeding and increase the spread of diseases and pathogens amongst herds.⁵⁷

A recent review on the impact of heat stress on production and reproduction in bovines, highlights the economic impacts of heat stress on cattle, the likelihood of climate change to exacerbate these impacts, and the vast but largely unknown economic impacts of heat stress;

Sackett et al. estimated the economic costs of heat stress to Australian feedlots at approximately 16.5 million (AUD). Given that these analyses were conducted over a decade ago, these estimates may not reflect the current economic impact of heat stress. Furthermore, in conjunction with climate change, it is probable that these estimates are underestimating the economic impact of heat stress on cattle production systems.⁵⁸

⁵⁵ Shire of Broome (2015) *State of the Environment Report*, p 9.

http://www.broome.wa.gov.au/files/assets/public/pub/corporate-plans/final-endorsed-state-of-the-environment-report_march-2016.pdf

⁵⁶ The Conversation (2017) *Severe heatwaves show the need to adapt livestock management for climate*.

<https://theconversation.com/severe-heatwaves-show-the-need-to-adapt-livestock-management-for-climate-73447>

⁵⁷ Lees et al. (2019) *The Impacts of Heat Load on Cattle*, Animals Journal.

<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6616461/>

⁵⁸ Ibid.

MINING

Mining is one of the smaller employers in the Kimberley region, employing fewer than 350 workers, around 2.4% of the workforce.⁵⁹ However, it remains a steadfast and lucrative industry, especially mining for diamonds.⁶⁰

Extreme heat presents a significant health risk to mining workers. The Australasian Mining Safety Journal describes the risks as follows:

When environmental temperatures exceed that of dry skin, sweating becomes the primary source of thermoregulation. However, as temperatures continue to rise, particularly in humid environments with poor airflow, this may not be enough. The body's core temperature rises, resulting in a continuum of ailments, collectively known as heat illness. This ranges from the relatively mild heat rash and muscle cramps, to heat exhaustion and the potentially fatal heat stroke.

Heat illness can present as headache, nausea or vomiting, irritability, clammy skin, dizziness, fatigue, elevated heart rate, and rapid breathing rate. This translates to lower productivity, poor morale and higher rates of accidents in the workplace. When left untreated, heat illness can progress to heat stroke, where confusion, further reduced muscle coordination, convulsions and ultimately a loss of consciousness can occur.⁶¹

A survey of mine workers in Northern Australia found heat stress symptoms were experienced by 87% of open cut mine workers and 79% of underground mine workers. Around 80% of workers experienced these symptoms more than once. The survey also found that only 27% were well hydrated with 10% significantly dehydrated.⁶²

There are also factors that compound the heat risks of mining in particular including having to wear heavy protective clothing that can reduce air circulation to the skin, long shifts and that water is not always readily available.

⁵⁹ ABS (2016) *2016 Census Community Profile, Working Population Profile*.

http://quickstats.censusdata.abs.gov.au/census_services/getproduct/census/2016/communityprofile/318?opendocument

⁶⁰ Government of Western Australia Department of Mines, Industry Regulation and Safety (2019) *A Snapshot of the Kimberley Resources Industry*. <https://www.dmp.wa.gov.au/A-Snapshot-of-the-Kimberley-22098.aspx>

⁶¹ Australasian Mining Safety Journal (October 2015) *Handling the heat*. <https://www.amsj.com.au/handling-the-heat/>

⁶² Hunt et al (2012) *Symptoms of heat illness in surface mine workers*. <https://eprints.qut.edu.au/54048/>

Extreme heat and Infrastructure

Power and transportation infrastructure is impacted by extreme heat conditions. Extreme heat can disrupt transport infrastructure by causing roads can melt,⁶³ rails to buckle,⁶⁴ and disruptions to airlines.⁶⁵

The Kimberley region is particularly vulnerable to transportation infrastructure impacts due to its remote geography. The Great Northern highway is the main transport route for the Kimberley region. This and other major arterial routes within the region are subject to closure during extreme weather events, restricting the supply of food and energy.⁶⁶

Many remote communities are not connected to the electricity grid, instead using diesel generators. The power supply in Broome is generated from diesel and natural gas.

Gas power stations in particular are highly vulnerable to extreme heat, experiencing both reduced output and an increased level of breakdowns. This is exacerbated by high electricity demand as a result increased use of air-conditioning during extreme heat conditions.

During the February 2017 heatwave in South Australia, 17% of gas generation (438 MW) failed to deliver during the peak demand period on the heatwave day (8th of February),⁶⁷ leading to widespread blackouts.⁶⁸

In urbanised environments, air-conditioning can be critical to people's wellbeing during extreme heat. Electricity blackouts during heatwaves lead to the loss of air-conditioning when it is most essential. During the 2009 Heatwave in Melbourne on the evening of the 30th of January, 500,000 people were left without power on a day that reached 44 degrees.

⁶³ Cheer (January 2018) *Traffic delays after 10 kilometers of Victoria's Hume Freeway melts*.

<https://www.sbs.com.au/news/traffic-delays-after-10-kilometres-of-victoria-s-hume-freeway-melts>

⁶⁴ Lauder (2009) *Melbourne railway buckles under heat*.

<http://www.abc.net.au/worldtoday/content/2008/s2477350.htm>

⁶⁵ Coffell and Horton (August 2017) *How hot weather – and climate change – affect airline flights*.

<https://theconversation.com/how-hot-weather-and-climate-change-affect-airline-flights-80795>

⁶⁶ LandCorpo (2016) *Broome Infrastructure Assessment Infrastructure and Services Audit Paper*.

http://broome.infocouncil.biz/Open/2018/06/ECO_25062018_MIN_1561_AT_files/ECO_25062018_MIN_1561_AT_Attachment_4142_6.PDF

⁶⁷ Ogge and Aulby (2017) *Can't stand the heat: The energy security risk of Australia's reliance on coal and gas generators in an era of increasing heatwaves*.

<http://www.tai.org.au/sites/default/files/P454%20Can%27t%20stand%20the%20heat%20FINAL%202.31.pdf>

⁶⁸ Harvey and Shepherd (February 2017) *Rolling blackouts ordered as Adelaide swelters in heatwave*.

<https://www.news.com.au/national/south-australia/rolling-blackouts-ordered-as-adelaide-swelters-in-heatwave/news-story/13394f19db1ee94a59f4036fccdc1ba7>

There were 374 deaths recorded as a result of this heatwave overall. The estimated economic cost of the heatwave was \$800 million.⁶⁹

⁶⁹ NCCARF (2010) *Impacts and adaptation responses of infrastructure communities to heatwaves*, https://www.nccarf.edu.au/business/sites/www.nccarf.edu.au.business/files/attached_files_publications/Pub%2013_10%20Southern%20Cities%20Heatwaves%20-%20Complete%20Findings.pdf

Extreme heat and the Kimberley natural environment

Increased extreme heat events due to climate change will have severe effects on the natural environment. In the Kimberley region, biodiversity, quality and quantity of water sources and fire behaviour are all expected to change due to extreme heat events.

Impacts on biodiversity

Extreme heat represents a threat to biodiversity in the Kimberley region. Some species of plant and animal are expected to respond to changes in the frequency of extreme heat days through migration and geographic range shifts.⁷⁰ Species that are not able to move or lack the level of genetic diversity to rapidly adapt are at higher risk of extinction or dramatic population loss.⁷¹

Across Australia, it is estimated that in a high emissions scenario, only 40% of vascular plants will remain in current ecosystems by 2050.⁷² Loss and reduction of certain species will have a flow on impacts to local ecosystems.⁷³

In the Kimberley, changes to the composition of plant and animal species are likely to change as temperatures increase. Changing temperatures in the Kimberley will especially impact vascular plants, mammals and amphibians but have a lesser impact on reptiles.⁷⁴ Figure 26 (below), from the CSIRO Land and Water Flagship shows expected changes to different species with darker shades representing the most change.⁷⁵

⁷⁰ Garnaut (2008) *The Garnaut Climate Change Review*, s 6.3.4.

<https://webarchive.nla.gov.au/awa/20190509072944/http://www.garnautreview.org.au/chp6.htm>

⁷¹ Ibid.

⁷² AdaptNRM (2014) *How much could biodiversity change?*

<https://adaptnrm.csiro.au/biodiversity-impacts/key-measures-of-ecological-change/how-much-could-biodiversity-change/>

⁷³ Steffen et al (2014) *HEATWAVES: HOTTER, LONGER, MORE OFTEN*, p 52.

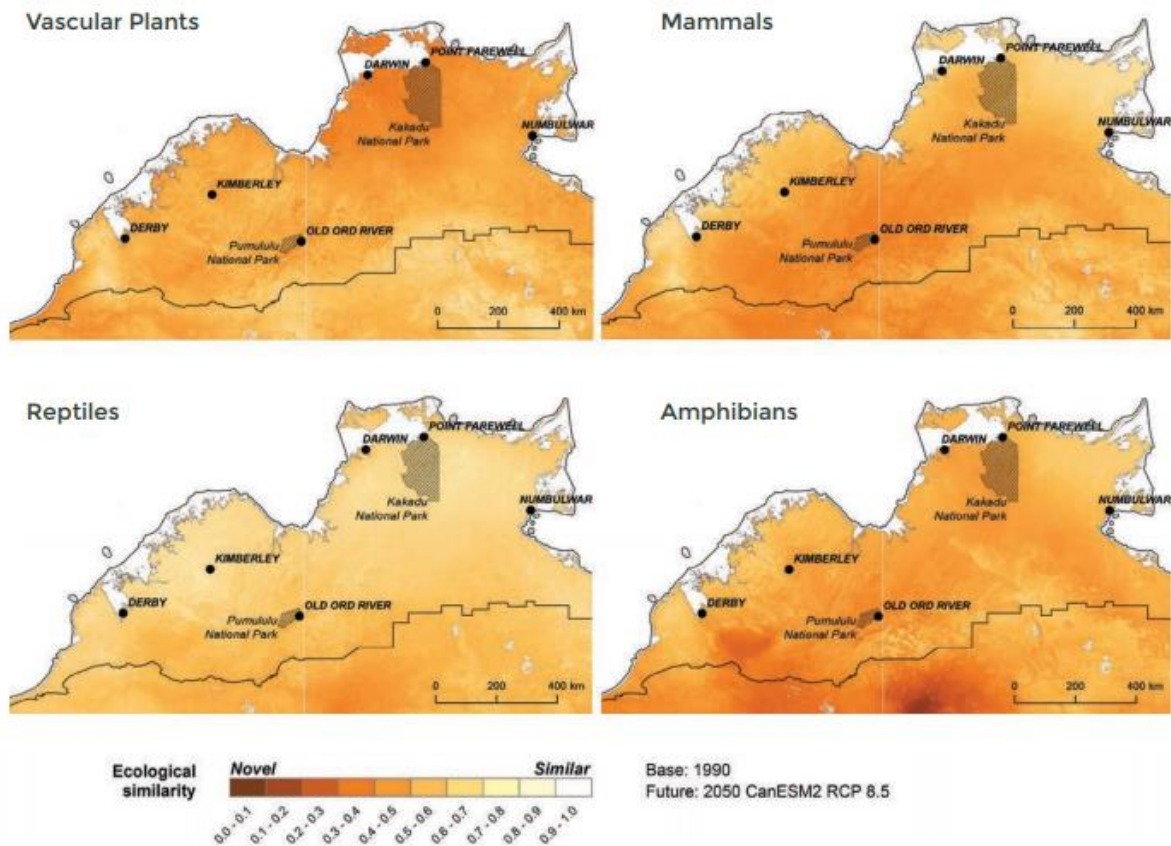
<https://www.climatecouncil.org.au/uploads/9901f6614a2cac7b2b888f55b4dff9cc.pdf>

⁷⁴ CSIRO (2014) *Implications of climate change for biodiversity: a community-level modelling approach*, p 37.

<https://adaptnrm.csiro.au/wp-content/uploads/2014/12/biodiversity-implications-tech-guide.pdf>

⁷⁵ Ibid.

Figure 26: CSIRO degree to which species groups are expected to become novel in Northern Australia



Source: CSIRO (2014) *Implications of climate change for biodiversity*

Increasing temperatures may give a competitive advantage to species more adapted to hotter and drier conditions. For example, snubfin and humpback dolphins are vulnerable to any climatic changes because their breeding patterns mean that they have limited genetic diversity.⁷⁶

As increasing temperatures disrupt the natural ecosystem, invasive species such as cane toads are likely to increase.⁷⁷

Species that are particularly vulnerable to increase heat in the Kimberley region are the Scaly-tailed Possum (Wyulda), Monjon Rock Wallaby and the Gouldian Finch.⁷⁸ Vulnerability

⁷⁶ Towie (2019) *Saltwater Kimberley: is WA's marine wilderness safe?*

<https://www.theguardian.com/environment/2019/jul/03/saltwater-kimberley-is-was-marine-wilderness-safe>

⁷⁷ Kauhanen et al (2011) *Report Card of Climate Change and Western Australian Aquatic Ecosystems*.

https://www.nccarf.edu.au/sites/default/files/attached_files_publications/PDF%20Report%20Card%20Low%20Res.pdf

⁷⁸ Carwardine et al (2011) *Priority threat management to protect Kimberley wildlife*.

<https://publications.csiro.au/rpr/download?pid=csiro:EP102445&dsid=DS4>

to temperature is due to direct temperate vulnerability and increased predation and competition from invasive species.

Extreme heat may also affect the breeding capacity of turtles and crocodiles.⁷⁹ Turtle embryos cannot survive temperatures exceeding 35 degrees, and temperatures above 29 degrees produce female hatchlings, causing the feminisation of the population.⁸⁰

The coral reefs off the coast of the Kimberley are home to “super-corals”, which have evolved to adapt to extreme conditions. Due to the extreme tides in the area, Kimberley coral is often exposed to the air for a number of hours, as well as surviving in mid-day water temperatures of 37 degrees.

Whilst the fluctuating water temperatures off the coast do mean that the Kimberley’s reefs are more resistant to coral bleaching than elsewhere in the world, they are not immune..

During the 2015-2016 El Nino weather conditions, the surface sea temperatures rose 4.5-9.3 degrees, resulting in bleaching of 80% of the coral.⁸¹ A global temperature increase of 2-3 degrees would cause coral bleaching to a similar extent seen elsewhere in Australia.⁸²

Impacts on water sources

Increasing temperatures will impact water sources in the Kimberley. The areas of Fitzroy River, Stokes Bay, Beagle Bay, Pender Bay, Walcott Inlet and Cambridge Gulf will experience increased erosion and salt water as temperatures increase.⁸³

This impact is already being felt in the Fitzroy River system which has seen reductions in mangroves and increasing salt marsh areas, directly caused by climate change as opposed to direct human activity in the area.⁸⁴

Wetlands are at risk from increased heat, from both sea level rises and moisture stress.⁸⁵ Species that rely on the floodplain wetlands will be put under pressure as they are

⁷⁹ Ibid.

⁸⁰ Towie (2019) *Saltwater Kimberley: is WA’s marine wilderness safe?*

<https://www.theguardian.com/environment/2019/jul/03/saltwater-kimberley-is-was-marine-wilderness-safe>

⁸¹ Ibid.

⁸² Schoepf (2015) *Even the super-corals of Australia’s Kimberley are not immune to climate change.*

<https://theconversation.com/even-the-super-corals-of-australias-kimberley-are-not-immune-to-climate-change-51484>

⁸³ Nikolakis et al (2011) *Adapting to climate change for water resource management: Issues for northern Australia*, p 33. https://crawford.anu.edu.au/research_units/eeerh/pdf/EERH_RR108.pdf

⁸⁴ Ibid, p 34.

⁸⁵ Ibid.

transformed into saline marshes.⁸⁶ These water changes will lead to increased pool anoxia and fish kills.⁸⁷

Fire

Whilst fire is a natural part of the Kimberley ecosystem, fires behaviour has increased in severity due to climate change.

In parts of the Kimberley, more than 50% of the savannah region is burned each year. Disruption to traditional Indigenous fire management has also contributed to more intense fires.⁸⁸

As the region is prone to fires, changes in temperature that effect potential fuel are can have severe fire impacts. Increased rain during the wet season will create more fuel to burn. Fires that occur late in the dry season have the most damaging impact.⁸⁹

The window for optimum fire burning to manage the area, between the end of the wet season and the beginning of the dry is likely to decrease as a result of climate change. If these changes inhibit the ability to undertake controlled burning, the severity of fires may increase and the damage they cause could be more extensive.⁹⁰

⁸⁶ Kauhanen et al. (2011) *Report Card of Climate Change and Western Australian Aquatic Ecosystems*.
https://www.nccarf.edu.au/sites/default/files/attached_files_publications/PDF%20Report%20Card%20Low%20Res.pdf

⁸⁷ Ibid.

⁸⁸ Department of Environment (2009) *Assessment of Australia's Terrestrial Biodiversity 2008*, p 199.
<https://www.environment.gov.au/system/files/resources/e9f0d376-78eb-45cc-9359-797c6b0f72ff/files/chapter5.pdf>

⁸⁹ Department of Primary Industries and Regional Development (2019) *Kimberley rangeland pastures and fire*.
<https://www.agric.wa.gov.au/fire-management-kimberley>

⁹⁰ Ibid.

Conclusion

An increase in days of temperature over 35 degrees will have severe impacts on human health, including increased rates of heat-related deaths.

The Kimberley region is expected to experience a dramatic increase in extreme heat events, affecting people's ability to work and enjoy the outdoors, to play and watch sport. The Kimberley's Indigenous population is disproportionately affected by the heat due to limited access to services, exposure to heat, pre-existing medical conditions and socio-economic inequality. Workers in industries with high exposure to heat are also disproportionately affected.

Fortunately, none of this is inevitable. The CSIRO projections clearly show that if emissions are reduced in line with the Paris target of limiting global temperature increases to below 1.5 degrees, the increase in extreme temperature days will be significantly less than the increase projected for our current emissions trajectory.

Australia makes a vastly disproportionate contribution to global warming and is one of the lowest ranked countries in the world on climate action. As well as having one of the highest rates of domestic greenhouse gas emissions per person in the world, Australia is the third biggest fossil fuel exporter globally, in CO2 potential.⁹¹

Australia is the largest exporter of LNG in the world and Western Australia is the biggest producer of LNG in Australia.⁹² Plans to exploit the gas resources of the Canning Basin could add millions of tonnes more of greenhouse gases to the atmosphere and are inconsistent with Australia's commitments under the Paris Agreement.

Failure to limit and sequester gas in WA has led to year-on-year increases in Australia's emissions. This leaves the question open as to how the WA Government will meet its aspirational target of net-zero emissions by 2050. But any credible plan needs to begin with serious climate action now.

At the local level, effective management of extreme heat in the Kimberley region will require participation and contribution from Indigenous communities in the development of extreme heat management frameworks.

At the global level, stopping any further expansion of Australia's coal and gas exports, gradually phasing out existing exports and reducing emissions produced at home are all

⁹¹ Swann (2019) *High Carbon from a Land Down Under*.

⁹² Western Australian Department of Jobs, Tourism, Science and Innovation (2019) *Oil and Gas*.
<https://www.jtsi.wa.gov.au/invest-in-wa/sector/resource-services/oil-gas>

essential to prevent increases in extreme heat that will have such a devastating effect on the Kimberley region and Australia as a whole.