Earth Systems and Climate Change Hub

National Environmental Science Programme

WORKSHOP REPORT

Impact of climate change on mango production in the Northern Territory

May 2019

Earth Systems and Climate Change Hub Report No. 9

Australian Government

National Environmental Science Programme

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Key points from the workshop

Climate change, mango production and the Northern Territory

Climate change and the Northern Territory

- There are three climate change strategies of relevance to primary production in the Northern Territory: Northern Territory Climate Change Strategy; Supporting Agriculture to Adapt to Climate Change; and Climate Research Strategy for Primary Industries.
- Primary industries contribute $697 million annually to the NT economy. Most of this is from cattle production, but horticultural production is increasingly important.
- Department of Primary Industry and Resources (DPIR) is the Northern Territory Government department responsible for this sector.

Northern Territory mango industry

- The Northern Territory is the country's largest grower of mangoes, producing around half of the national crop in 2018/19.
- The industry is based around four varieties: Kensington Pride, R2E2, Calypso® and Honey Gold®. Other varieties – including Keitt, Tommy Atkins, Palmer, Nam Dok Mai – are grown in much smaller quantities.
- Less than 2% of mangoes produced in the Northern Territory are exported. This represents around 16% of the national export market, which was valued at $30 million in 2016/17.
- The peak season for mango production in the Northern Territory is from October to December, however some fruit is available from July.

Mango production and climate

Environmental limits to mango production in northern Australia

- Increases in extreme weather and mean temperatures are already affecting mango production in Cambodia, Pakistan, China and the Philippines.
- In Kununurra, Kensington Pride (the most widely grown variety) is already struggling physiologically. Increasing temperatures will exacerbate this.
- Response of other varieties to changing conditions needs to be examined, as do adaptation options.

Relationship between temperature and mango flower induction

- Mango flowering in the Northern Territory is promoted by low night temperatures and can be inhibited by high day time temperatures.
- Mango cultivars differ in their temperature requirements.

- Changes in absolute maximum and minimum temperatures and the frequency of these events will affect flowering and fruit production in northern Australian mango production regions.

Understanding the changing climate

Climate drivers and climate trends for northern Australia

- The El Niño–Southern Oscillation, Indian Ocean Dipole, Madden-Julian Oscillation, Australian monsoon, tropical cyclones and northwest cloudbands are major influences on the climate of northern Australia.
- Average surface air temperature in Australia has risen just over 1ºC since 1910, and the frequency of extreme heat events is increasing.
- Average rainfall has increased across parts of northern Australia since 1900.
- The ocean surface around Australia has warmed over recent decades at a similar rate to the air temperature.
- Fire conditions are worsening across large parts of the country, including the northern part of the Northern Territory.

Climate change projections for northern Australia

- Climate change is a long-term change in the average pattern of weather that occurs over many decades. Natural variability occurs over the top of this long-term trend.
- Climate change projections tell us about the response of the climate system to possible future scenarios. They are not predictions that tell us a sequence of weather events.
- Projections are developed by combining our current understanding of the climate system with possible future scenarios in a global climate model. These models simulate climate processes based on laws of physics.
- Our confidence in climate projections is based on how well we understand climate processes and how well the climate model can simulate these processes.
- We are more confident in some projections (e.g. temperature) than others (e.g. average rainfall).

Future climate for the Northern Territory

- Average temperatures will continue to increase in all seasons (very high confidence)
- More hot days and warm spells are projected (very high confidence)
- Extreme temperatures - substantial increase in the temperature reached on hot days, the frequency of hot days, and the duration of warm spells
- Changes in average rainfall are possible, but uncertain (large decreases are less likely than increases or little change)

- Increased intensity of extreme short-duration (hourly, sub-daily) rainfall events (high confidence)
- In regions with abundant rain (e.g. Top End and the Kimberley), no change projected in fire frequency. In more southerly locations, changes to future rainfall will be determining factor of change to fire frequency. (The primary determinant of bushfire in the Monsoonal North is fuel availability.)
- Evaporation is projected to increase in all seasons as warming progresses (high confidence)
- Humidity is projected to decrease (medium confidence)
- Mean sea level will continue to rise and height of extreme sea-level events will also increase (very high confidence).

Using climate change information to plan ahead

Using climate change information and projections

- The Northern Territory Government has been supplied with projected temperature threshold datasets out to 2090.
- In addition to this data, there are a number of relevant tools and datasets on the *Climate Change in Australia* website.
- A useful tool is the Analogues Explorer, which equates the future climate at a location to the current climate at another location.
- To demonstrate the use of climate change information for sectoral decision-making, the ESCC Hub will work with NT DPIR on a case study examining the impact of climate change on flowering induction in mango in the Northern Territory.

Introduction

Background

Mangoes are the Northern Territory's largest horticultural product, and the Territory is the country's largest grower of mangoes. In 2017/18, the Northern Territory produced almost half of the national mango crop, worth around A$90 million.

Induction of mango flowering is sensitive to minimum and maximum temperatures in May–August (depending on the variety). Flowering is important for fruit set and critical for mango production. Understanding the impact of the changing climate will provide commercially important information to the industry. However, finding and applying appropriate climate change information for decision making is not always easy.

The Earth Systems and Climate Change Hub is working with a number of sectoral stakeholders to find and apply relevant climate change information for sectoral planning through a series of case studies. The Northern Territory mango industry is one of these stakeholders.

About the workshop

On 28 February 2019, an expert meeting was convened in Darwin to learn about the Northern Territory mango industry, how the changing climate might impact it, and how climate change projections could be used to support industry resilience and sustainability into the future.

The meeting was attended by representatives from the Northern Territory Government (Department of Primary Industry and Resources), NT Farmers Association, the Australian Mango Industry Association and a number of growers along with a project team from the ESCC Hub. The workshop program and participant list are included in the appendices of this report.

The following day, the Hub project team met with DPIR researchers and industry representatives to scope out a case study that would provide critical planning information for the NT mango industry and demonstrate more broadly the utility of climate change projections for the industry.

This report provides a summary of the information presented at the workshop and maps out the scope and time line for the resulting case study.

Climate change, mango production and the Northern Territory

Climate change and the Northern Territory

Mila Bristow, NT Department of Primary Industry and Resources

- There are three climate change strategies of relevance to primary production in the Northern Territory: Northern Territory Climate Change Strategy; Supporting Agriculture to Adapt to Climate Change; and Climate Research Strategy for Primary Industries.
- Primary industries contribute $697 million annually to the NT economy. Most of this is from cattle production, but horticultural production is increasingly important.
- Department of Primary Industry and Resources (DPIR) is the Northern Territory Government department responsible for this sector.

Climate change policies and strategies

Northern Territory Climate Change Strategy

The Northern Territory Government is developing a climate change strategy and action plan, due to be finalised in 2019. A discussion paper[1] to inform the development of the strategy was released for comment by the Government in October 2018, with submissions closing in November 2018.

Supporting Agriculture to Adapt to Climate Change

The Supporting Agriculture to Adapt to Climate Change project was initiated by agriculture ministers (AgMin) from the states and territories, and is being led by Victoria and consultants ACIL Allen. The project has three stages:

1. An overview of climate change scenarios and the implications for agricultural industries over time; a stocktake of current work and approaches across jurisdictions to adaptation and emissions management in agriculture.
2. An analysis of risks and opportunities that climate change presents for the sector, involving high priority industry stakeholders.
3. Actions and a work program for a nationally coordinated approach to climate change adaptation and emissions management in the agriculture sector, with considerations for how this could inform national strategy.

Stage 2 is currently under way. The final report will be delivered at AgMin August 2019.

[1] *Climate change: Mitigation and adaptation opportunities in the Northern Territory* – available at https://haveyoursay.nt.gov.au/climatechange

Climate Research Strategy for Primary Industries

The Climate Research Strategy for Primary Industries (CRSPI) is a national collaboration between organisations that invest in climate change research for primary industries. It involves the rural research and development corporations, state and territory governments, the Australian Government Department of Agriculture and Water Resources, and CSIRO.

The Climate Research Strategy for Primary Industries 2017–2020[2] focuses on:

- adaptation to climate change
- emissions intensity and markets
- climate change in business and policy.

The strategy aims to build the resilience of primary industries by making well informed choices about responding to climate signals and investing in research that's going to make improvements in industry productivity and sustainability.

Primary industry in the Northern Territory

Agriculture, forestry and fisheries contributes $697 million annually to the NT economy. Most of this is from cattle production, but horticultural production is increasingly important. The Department of Primary Industry and Resources (DPIR) is the Northern Territory Government department responsible for this sector.

Irrigated agriculture

There is approximately 50,000 ha of land under irrigated agriculture in the Northern Territory. Mangoes, melons and Asian vegetables account for a little over a third of this area (see Figure 1). The remaining land produces, tropical tree crops, hay, table grapes, rice and other vegetables. By value (at the farm gate, 2015 figures), mangoes are the biggest commodity ($88.5 million) followed by melons ($52.6 million) and Asian vegetables ($28.53 million). In 2015, the total estimated value of irrigated agriculture (at the farm gate) was $244.4 million.

[2] Available at http://www.ccrspi.net.au/crspi-strategic-plan-2017-2020

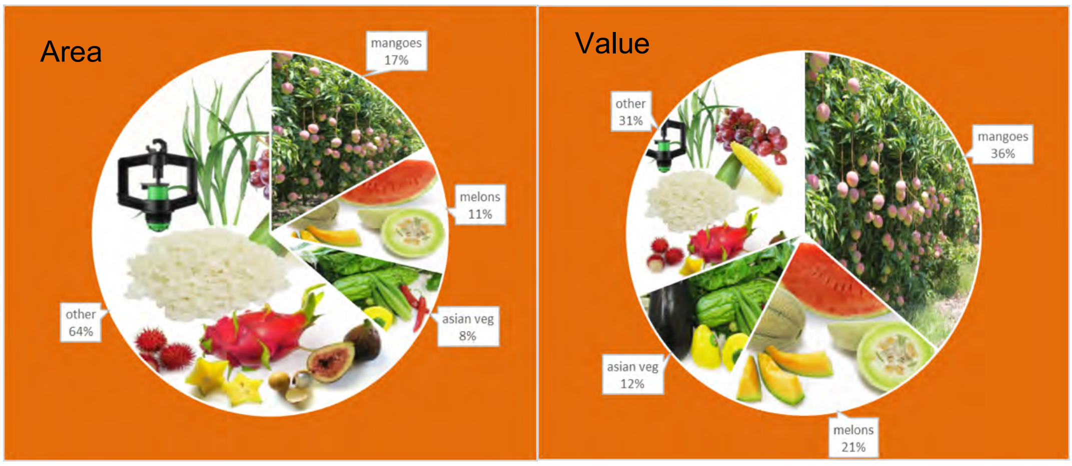

Figure 1. Area[3] and value[4] of irrigated agriculture in the Northern Territory (2015–16) (Source: M Bristow workshop presentation)

The climate is an important determinant of crop and land selection, with regional differences in temperature, rainfall and humidity (Figure 2).

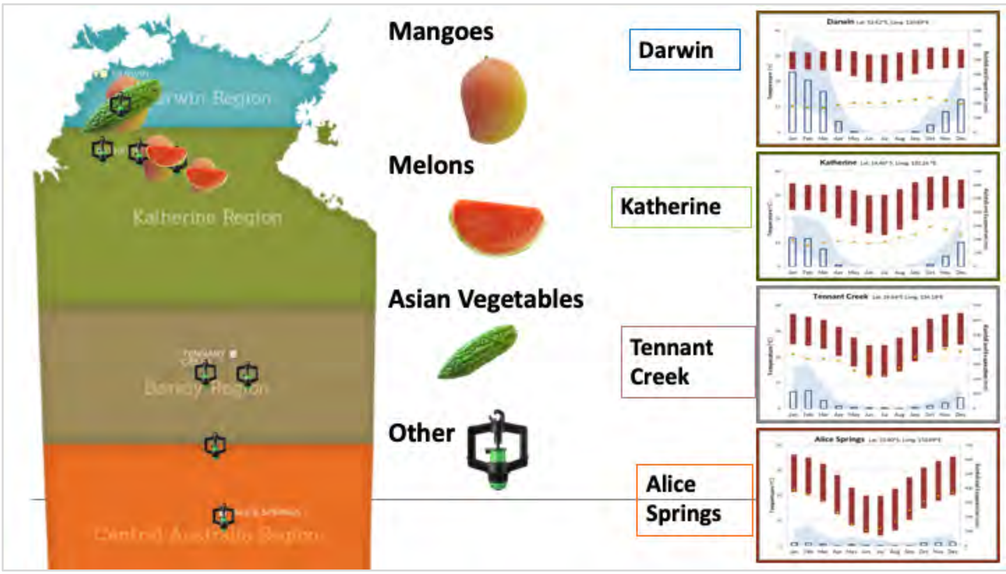

Figure 2. Irrigated agriculture regions of the Northern Territory. Plots on right show annual climate profiles for temperature (red) and rainfall (blue). (Source: M Bristow workshop presentation)

Biosecurity and product integrity

The DPIR plays a key role in biosecurity and product integrity to ensure market access. This is based on legislation, surveillance, producer accreditation and joint efforts between producers and the DPIR.

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[3] Staben G and Edmeades B (2017). *Northern Territory Land Use Mapping Project for Biosecurity 2016.* Technical Report 18/2017D, NTG.

[4] Northern Territory Farmers Association. (2016). Economic profile of plant-based industries in the Northern Territory 2015. NTFA.

DPIR and the mango industry

In the context of climate change, DPIR is working with mango growers to:

- measure soil greenhouse gas emissions from beneath mango orchards
- quantify and understand how to reduce nitrogen losses in orchards
- study suitability of new cultivars for future climates
- monitor pests and diseases.

DPIR is also undertaking work to select new plant cultivars and align production with potential markets for low-carbon-intensity produce.

Overview of the Northern Territory mango industry

Leo Skliros, NT Mango Industry Association

Production and value

The Northern Territory is the country's largest grower of mangoes, producing around half of the national crop in 2018/19 (Table 1).

Table 1. Northern Territory mango production statistics 2014–19. (Source: L Skliros workshop presentation)

	Trays (million)		**Tonnes**		**Production value ($ million)**		**NT market proportion**
	National	*NT*	*National*	*NT*	*National*	*NT*	
2014/15	9.44	3.80	66,087	26,600	190.7	-	40%
2015/16	9.11	3.78	63791	26500	210.3	88.5	42%
2016/17	8.78	3.98	61474	27819	195.7	88.3	45%
2017/18	12.00	5.60	84,000	39,700	241.7	112.8	47%
2018/19	10.23	5.3	71,631	37,100	-	-	52%

Producers range from large companies to small family enterprises.

Varieties

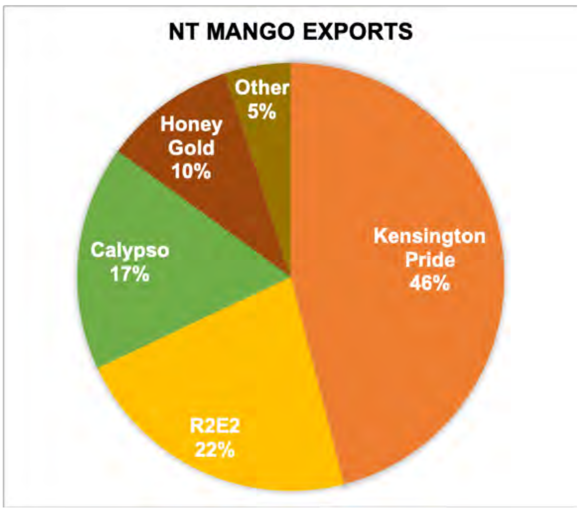
The Northern Territory industry is based around four varieties: Kensington Pride, R2E2, Calypso® and Honey Gold®. Other varieties – including Keitt, Tommy Atkins, Palmer, Nam Dok Mai – are grown in much smaller quantities.

Exports

Less than 2% of mangoes produced in the Northern Territory are exported. This represents around 16% of the national export market, which was valued at $30 million in 2016/17.

Nearly half of the mangoes exported are Kensington Pride.

(Figure from L Skliros workshop presentation)



Seasonal availability

The peak season for mango production in the Northern Territory is from October to December, however some fruit is available from July (Figure 3).

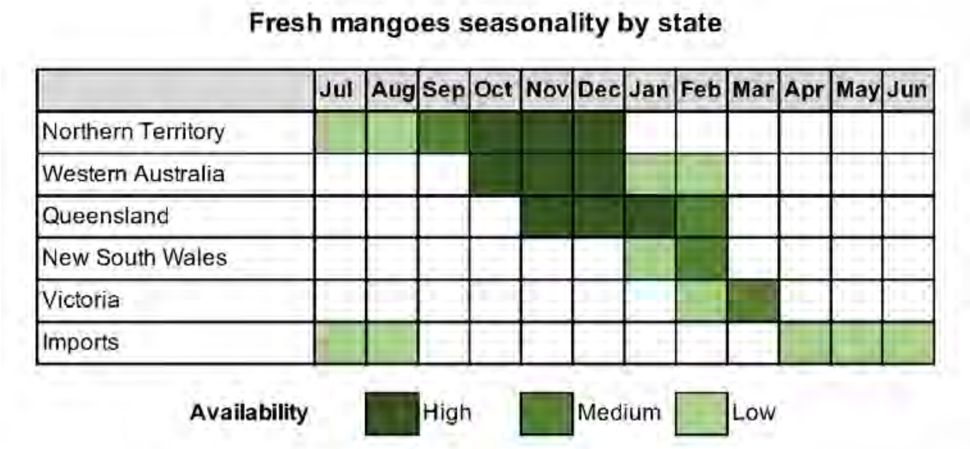


Figure 3. Availability of mangoes in Australia (Source: L Skliros workshop presentation)

Managing impacts of climate change

The industry is introducing a number of mitigation and adaptation strategies, including:

- Water usage
- Power usage
- Land clearing
- Trees/ha – trays/tree (based on six trays per tree)
- Canopy management
- Flowering
- Other

Mango Best Practice Resource

- Orchard management
  - Canopy management
  - Nutrition
  - Irrigation
- Harvest practices
  - Forecasting
  - Harvest
- Post-harvest temperature control
  - During packing and transport
  - Harvest practices

NMBP mango varieties

Mango production and climate

Environmental limits to mango production in northern Australia

Peter Johnson, Consultant (formerly Western Australian Department of Primary Industries and Regional Development)

- Increases in extreme weather and mean temperatures are already affecting mango production in Cambodia, Pakistan, China and the Philippines.
- In Kununurra, Kensington Pride (the most widely grown variety) is already struggling physiologically. Increasing temperatures will exacerbate this.
- Response of other varieties to changing conditions needs to be examined, as do adaptation options.

Regional experiences

In neighbouring South-East Asian countries increases in extreme weather events and mean temperatures already appear to be having an impact on mango production: flood and drought in Cambodia has resulted in seasonal declines; severe frosts in Pakistan have affected 50-year-old trees; and in China, production is moving into more northern provinces (e.g. Sichuan) that were previously thought too cold for mango production. Increased typhoons in Guangdong and Hainan are also impacting mango production there.

A case study in the Philippines examining the Carabao mango, a variety with many physiological similarities to Kensington Pride, found that changing rainfall patterns, a lack of cool spells and southward-moving typhoons led to very poor fruit set. Declining yields at the farm level are reflected at the national level (Figure 4).

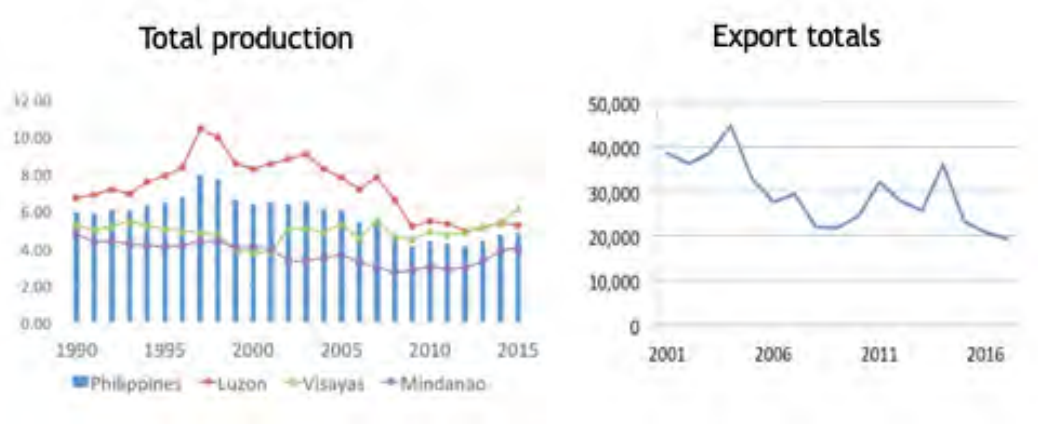


Figure 4. Carabo production (left panel) in the Philippines by region (coloured lines) and nationally (blue bars). National export totals (right panel) for the same variety. (Source: P Johnson workshop presentation)

Kununurra

Kununurra has the highest mean temperature of all mango growing regions in Australia, so any temperature-related production issues will be apparent here first.

Kensington Pride is the most widely grown variety in Kununurra. Research investigating this variety's physiological suitability for production in high temperature conditions shows that photosynthesis, stomatal conductance and transpiration is far more sensitive to higher temperature conditions, particularly when combined with low humidity (Figure 5). Stomatal conductance rapidly declines at temperatures above 30ºC.

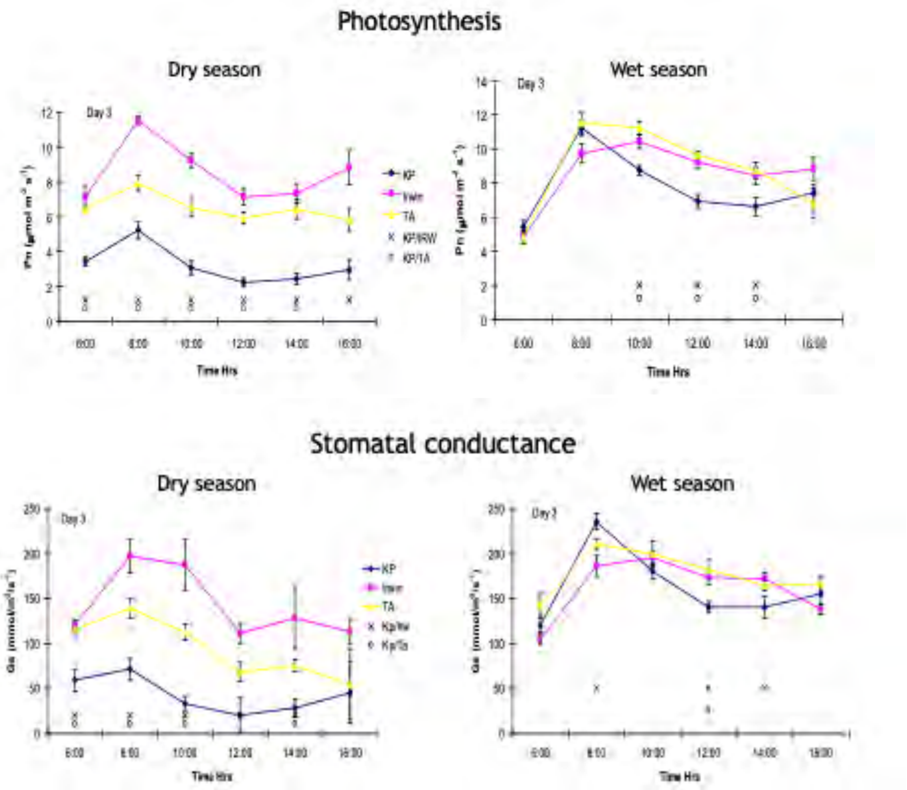


Figure 5. Photosynthesis (top) and stomatal conductance (bottom) for five varieties of mango in Kununurra (Source: P Johnson workshop presentation)

Pollination is also sensitive to temperature and humidity.[5] The typical pollination window in Kununurra in June is 2–3 hours (compared to 3–4 hours in Darwin and 4–6 hours in Mareeba), July 1–3 hours and August 0–0.5 hour. Late flowering in Kununurra rarely amounts to fruit set.

Kensington Pride also makes a net carbon loss for nine months a year. This means that productivity is dependent carbon fixation that occurs is the remaining three months.

[5] The National Mango Breeding Program used hand pollination techniques, so it gave a unique opportunity to understand the conditions required for pollination.

What does this mean?

Kensington Pride is struggling physiologically under Kununurra conditions to accumulate enough carbohydrates to support a crop. The variety is under high stress for most of the growing season. Any increases in average temperature will only exacerbate the problem, and more irregular wet season patterns will severely limit the variety's ability to accumulate carbohydrates.

This study in Kununurra suggests that industry will need to change varieties in order to remain viable. However, there have been limited studies looking at the response of other varieties to the environment. Adaptation options such as growing crops under structures where some of the environmental conditions can be manipulated will also need to be considered.

Relationship between temperature and mango flower induction

Cameron McConchie and Maddison Clonan, NT Department of Primary Industry and Resources

- Mango flowering in the Northern Territory is promoted by low night temperatures and can be inhibited by high day time temperatures.
- Mango cultivars differ in their temperature requirements.
- Project changes in absolute maximum and minimum temperatures and the frequency of these events will affect flowering and fruit production in northern Australian mango production regions.

Mango flowering

How do mangoes flower?

Mango trees grow by recurrent terminal flushes. These flushes can be either vegetative or reproductive depending on the prevailing weather conditions and the maturity of the preceding vegetative growth. The presence of immature vegetative flush inhibits flower initiation while mature leaves are able to respond to cool inductive temperatures. The floral stimulus is produced by the mature leaves and transmitted to the growing terminal shoots that then give rise to flowering structures. The process of flower induction occurs during first few centimetres of growth of the shoot. Excessively high temperatures at this stage can inhibit flower.

Manipulating flowering

Mango flowering can be manipulated by using growth regulators that are not taken up by the fruit. They are applied to reduce tree vigour, enhancing the tree's stored reserves while assisting in the production of mature leaves able to respond to inductive conditions. Different growth regulators can be used to selectively remove immature vegetative flush that might otherwise inhibit flowering. A similar effect can be achieved by mechanically pruning the tree to remove the immature flush and stimulate tree growth during floral inductive temperatures.

Where there is a predictable wet and dry period (as in the Northern Territory), tree growth can be restricted by reducing irrigation during the end of the wet season, which also assists in the production of mature temperature-responsive leaves.

To synchronise growth that will produce flowers with inductive temperature, specific foliar fertilisers are applied that promote bud break and assist in flower development. In the Northern Territory and Kununurra, cool night conditions associated with mango flower induction are associated with anticyclonic weather systems in the Great Australian Bight bringing cool south-westerly winds. Since these weather conditions can be anticipated to some extent, growers can increase irrigation and apply appropriate foliar treatments so the trees are in a condition to flower. These conditions may only last for a few weeks but this is sufficient to stimulate flowering and fruit set before returning to the usual hot and dry conditions.

The weather during the dry season is a further advantage for these regions as it accelerates fruit growth, making the crop first to market and receiving premium prices while the lack of rain dramatically reduces the need for fungicides and pesticides.

Commercial considerations

Mango orchards are long-term commitments, remaining commercially viable for 30–50 years and potentially longer. There are high establishment costs compared to annual crops. Commercial production commences three to five years after establishment: at this time the grower is at the stage of greatest debt. The time from commencement to breakeven using historic orchard designs is about 12–13 years. New cultivars have been developed that further extend early production and expand the regional production season while improving mango appeal for consumers. New high-density planting designs, while increasing the capital cost of orchard, shorten the time to breakeven. Mangoes provide high returns per unit of water input and have a small production footprint in comparison to broadacre agriculture.

International understanding

In the most recent reviews[6] describing the conditions that lead to flowering in mango commercial cultivars are divided into two types based on a USA climate classification system[7]. There are tropical mangoes that rarely experience temperatures below 18°C and flower when mature flush experience extend periods without growth of 4 months or more. The other form occurs in the subtropical mangoes or at altitude in the tropics that regularly experience temperatures below 10°C resulting in cold induced flowering (Figure 6).

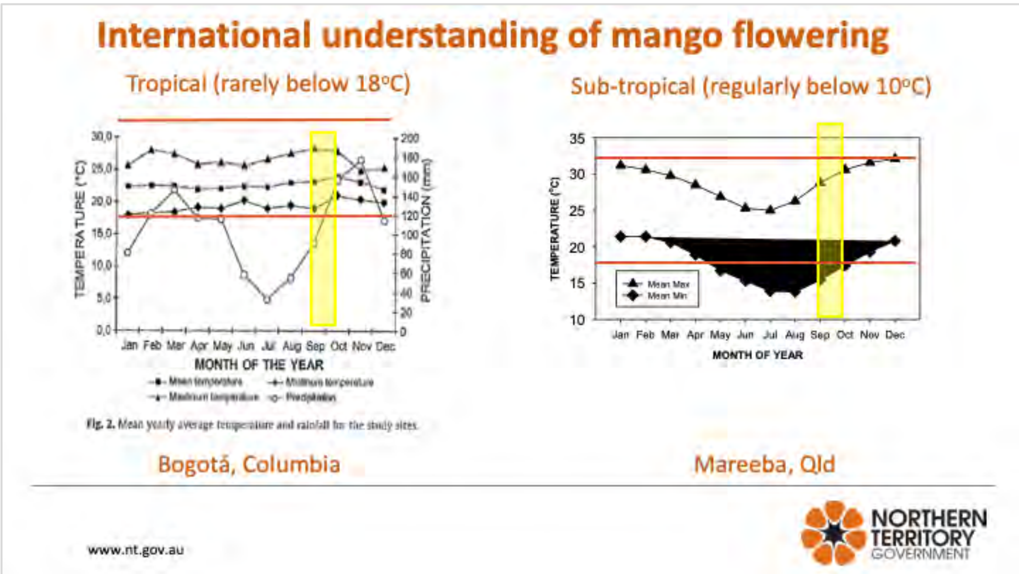


Figure 6. The yellow bar indicates the flowering period. (Source: C McConchie workshop presentation)

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[6] Ramírez F, Davenport TL. 2012. Reproductive biology (physiology)—the case of mango. In: Valavi SG, Rajmohan K, Govil JN, Peter KV, Thottappilly G. (Eds.) *Mango: Vol. 1. Production and Processing Technology*. Stadium Press LLC, Houston, Texas. pp. 56–81.

[7] Jordan R. 2001. USDA Plant Hardiness Zone Map. http://www.usna.usda.gov/Hardzone/. US National Arboretum, Agricultural Research Service, US Department of Agriculture, Washington DC. 2000 2

Tropical Australia provides another scenario for mango flower induction where bursts of cool night temperatures can trigger flowering while high night temperatures inhibit flower development. In areas such as the Atherton tablelands where there are extended periods with the mean minimum below the threshold required for flower induction are less threatened by climate change provided cultural practices and the cultivars grown are adapted to these conditions.

Temperature, flowering initiation and mango production in the Northern Territory

The main mango growing areas in northern Australia experience different periods at maximum and minimum temperature and rainfall thresholds (Figure 7).

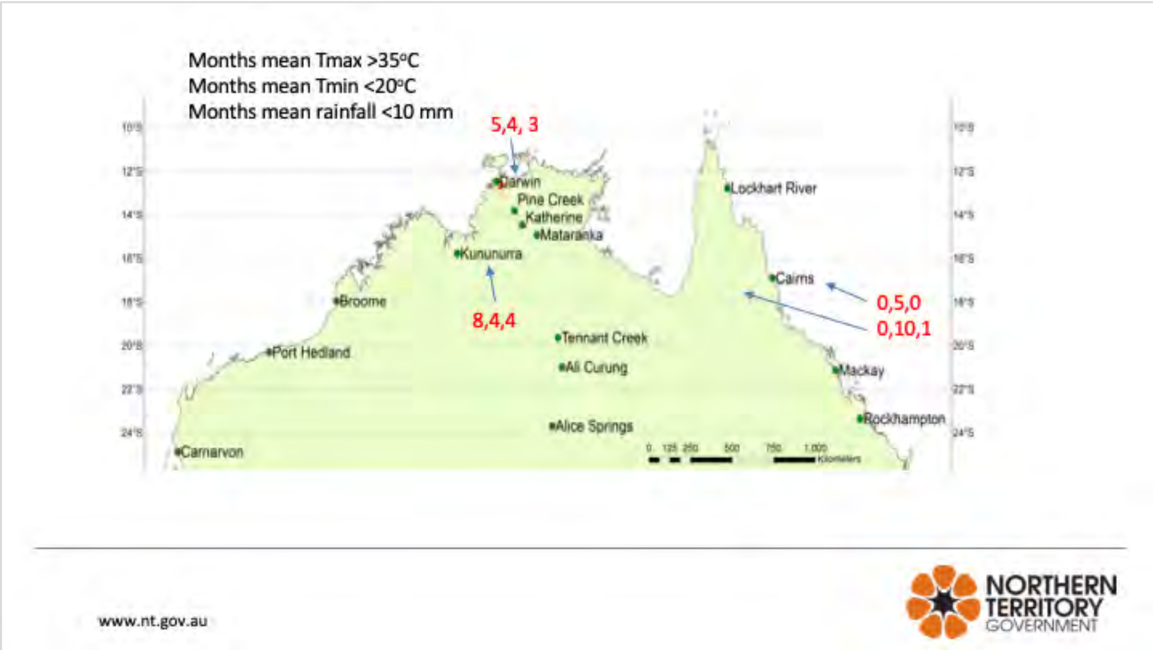


Figure 7. Months at above and below important temperature and rainfall thresholds in four mango growing areas in northern Australia (Source: C McConchie workshop presentation; summarised from BoM data for Kununurra (WA), Middle Point (NT), Mareeba (Qld) and Cairns (Qld))

NT DPIR has investigated the effects of temperature on flower induction in mango.[8] Terminal shoots branches were tip-pruned to remove any immature flush. This procedure was performed on a different set of trees at three weekly intervals over six months. This generated actively growing buds that were subjected to a range of temperature conditions. By carefully measuring bud development and monitoring ambient temperature it was possible to relate the effects of temperature different stages of development of flower development. Findings included:

[8] Sarkhosh A, Khal M, Clonan M, Olesen T and McConchie C. 2019. The impact of different tip-pruning times on flowering, yield, and maturity in two Australian mango cvs. Honey Gold and B74 in Katherine (Northern Territory). In McConchie, C. 2019. Manipulating mango flowering to extend harvest window. Final Report. Horticulture Innovation Australia MC12012.

- Ambient temperatures during active growth when buds are 1 mm to 15 mm in length are critical in determining whether they will develop floral or vegetative growth.
- Both minimum night temperatures and maximum day temperatures were critical in determining whether buds produced flowers.
- Small changes in the timing of inductive temperatures can influence to commercial value of the crop.
- Small changes in the duration and absolute day and night temperature can influence the success of flowering and may prevent flowering all together

Past results for B74 and Honey Gold varieties found:

- 50 days between vegetative flush and floral flush.

Implications

Options for adaptation

- Select existing adapted cultivars
- Develop new cultivars
- New chemicals that disconnect flowering from climate.

Understanding the changing climate

Climate drivers and climate trends for northern Australia

Greg Browning, Bureau of Meteorology

- The El Niño–Southern Oscillation, Indian Ocean Dipole, Madden-Julian Oscillation, Australian monsoon, tropical cyclones and northwest cloudbands are major influences on the climate of northern Australia.
- Average surface air temperature in Australia has risen just over 1ºC since 1910, and the frequency of extreme heat events is increasing.
- Average rainfall has increased across parts of northern Australia since 1900.
- The ocean surface around Australia has warmed over recent decades at a similar rate to the air temperature.
- Fire conditions are worsening across large parts of the country, including the northern part of the Northern Territory.

Major large-scale climate drivers that affect northern Australia

There are many large-scale climate drivers that affect Australia (Figure 8).[9] For northern Australia, the most important are El Niño–Southern Oscillation (ENSO), Indian Ocean Dipole, Madden-Julian Oscillation, Australian monsoon, tropical cyclones and north-west cloudbands (Table 2).

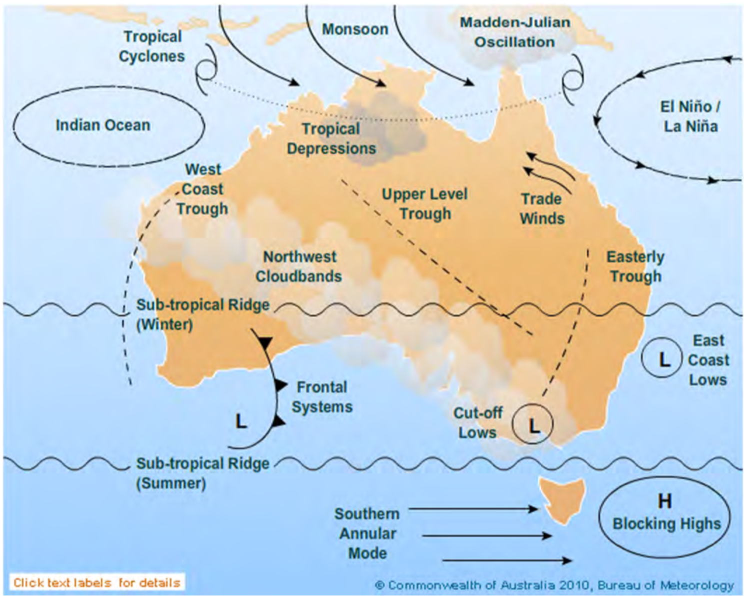


Figure 8. Climate influences on Australia (Source: Bureau of Meteorology)

[9] For more detail about each of these drivers see http://www.bom.gov.au/watl/about-weather-and-climate/australian-climate-influences.shtml

Table 2. Influence of major climate drivers on northern Australia (Source: G Browning workshop presentation)

<table>
<tr><th>Driver</th><th colspan="2">Impact on northern Australia</th><th>The future</th></tr>
<tr><td>El Niño–Southern Oscillation (ENSO) is a natural cycle that moves between El Niño and La Niña conditions. It is driven by sea surface temperature (SST) and winds in the central and eastern tropical Pacific. An El Niño develops when trade winds weaken and SST in this region is warmer than usual. A La Niña is when the opposite occurs: winds are stronger and SST is cooler than usual.</td><td>El Niño
Cooler minimum temps due to reduced cloud cover
Reduced build-up rainfall
Fewer tropical cyclones
Significantly higher min and max temps in the following dry season</td><td>La Niña
Increased rainfall during the dry season months
Increased rainfall in the build-up months
Higher min temps mainly near coastal areas due to warmer SST
Moderately cooler min and max temps in the following dry season</td><td>ENSO events may become more intense and cause intensification of El Niño-driven drying in Australia; impacts of both El Niño and La Niña will be felt over a larger area
Extreme El Niño events may become more frequent in line with temperature rises</td></tr>
<tr><td>Indian Ocean Dipole (IOD) is the difference in SST between the eastern and western tropical Indian Ocean. Has a positive phase, when SST in the west in warmer than normal and SST in the east (near Australia) is cooler than normal, and negative phase, when SST near Australia is higher than average.</td><td>Positive phase
Dry spring/build-up months in north
Dry winter/spring for central parts
Lack of northwest cloudbands
Higher max temp over central parts</td><td>Negative phase
Higher rainfall for north during early wet season
Higher rainfall over central parts</td><td>Increase in extreme positive phase events as temperature increases</td></tr>
<tr><td>Madden-Julian Oscillation (MJO) is a ~60-day pulse of cloudiness/rain that moves eastwards around the tropics. It influences the timing and intensity of the monsoon.</td><td colspan="2">When the MJO is in the eastern Indian Ocean to western Pacific, northern Australia can experience above-average rainfall. When it moves out of this range, northern Australia can experience below-average rainfall.</td><td></td></tr>
<tr><td>Australian monsoon is a trough of moist air, the position of which is driven by prevailing tropical winds. Onset is associated with ENSO (El Niño often later onset, La Niña earlier). Linked to the MJO.</td><td>Active period
Widespread cloudiness and rain
Strong westerly winds</td><td>Inactive period
Isolated showers and thunderstorms
Trade winds</td><td>Low confidence in direction of rainfall changes but high confidence of increased intensity of extreme rainfall events</td></tr>
<tr><td>Tropical cyclones are low pressure systems that form over tropical waters and produce gale force winds. Links to ENSO and MJO.</td><td colspan="2">Destructive winds, heavy rainfall, flooding and storm surges.</td><td>Fewer but more intense</td></tr>
<tr><td>North-west cloudbands are extensive bands of cloud that extend from the north-west to south-east of Australia. May have links to the IOD.</td><td colspan="2">Bring widespread and often heavy rainfall to north-western and central part of northern Australia</td><td></td></tr>
</table>

Observed trends in northern Australia

Temperature

Average surface air temperature in Australia has risen just over 1ºC since 1910, as has annual mean temperature in northern Australia. The warming trend in northern Australia this century is shown in Figure 9. Regions where temperature is decreasing are affected by other climate-change-related trends, such as increasing sub-tropical ridge strength and winds over north-western Australia.

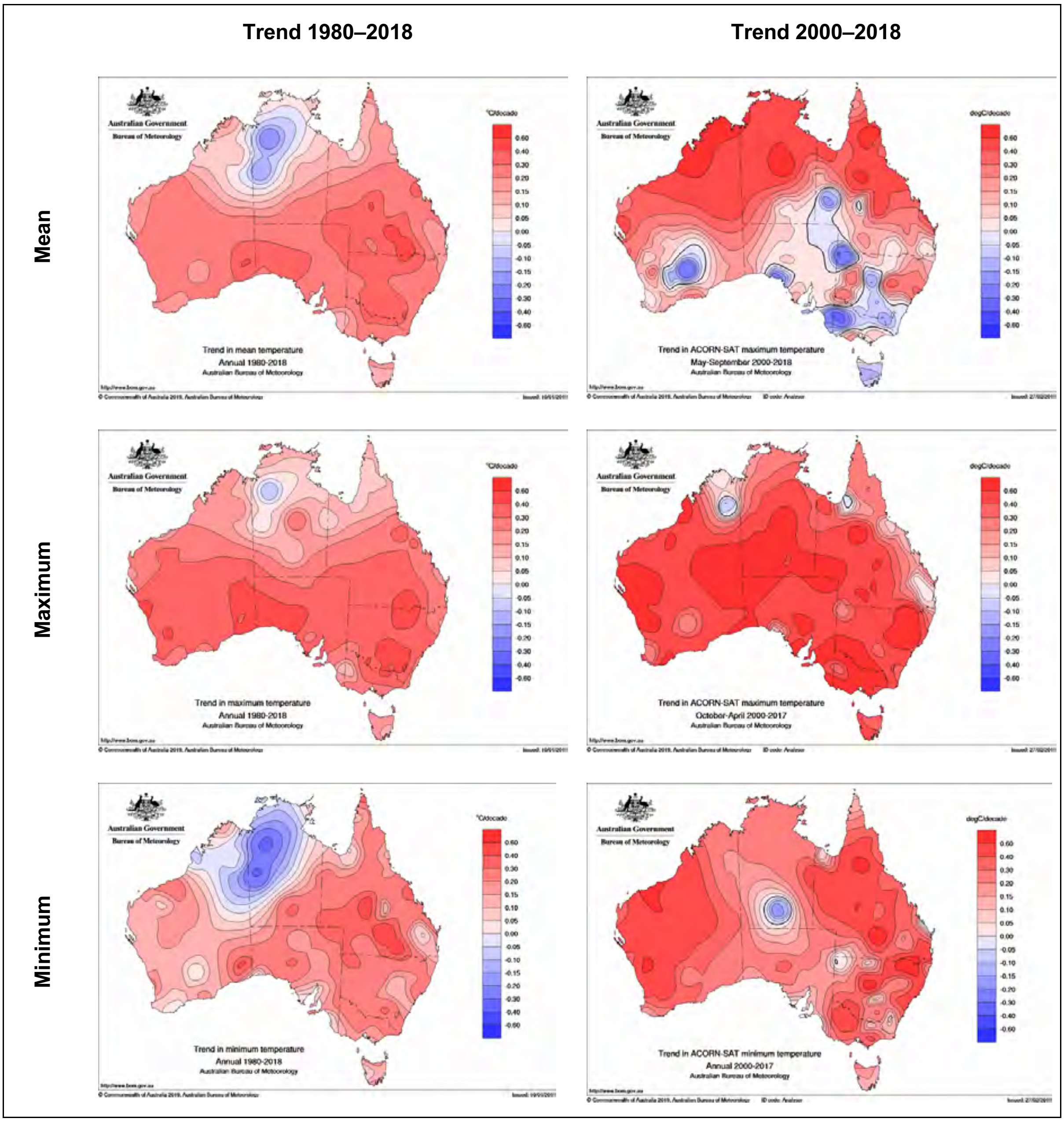


Figure 9. Temperature trend maps for the periods 1980–2018 (left) and 2000–2018 (right) for annual mean (top), maximum (middle) and minimum (bottom) temperatures. (Source: Bureau of Meteorology)

As overall temperature increases so too do the odds of extremely hot days, while the chance of extremely cool days becomes less likely (Figure 10).

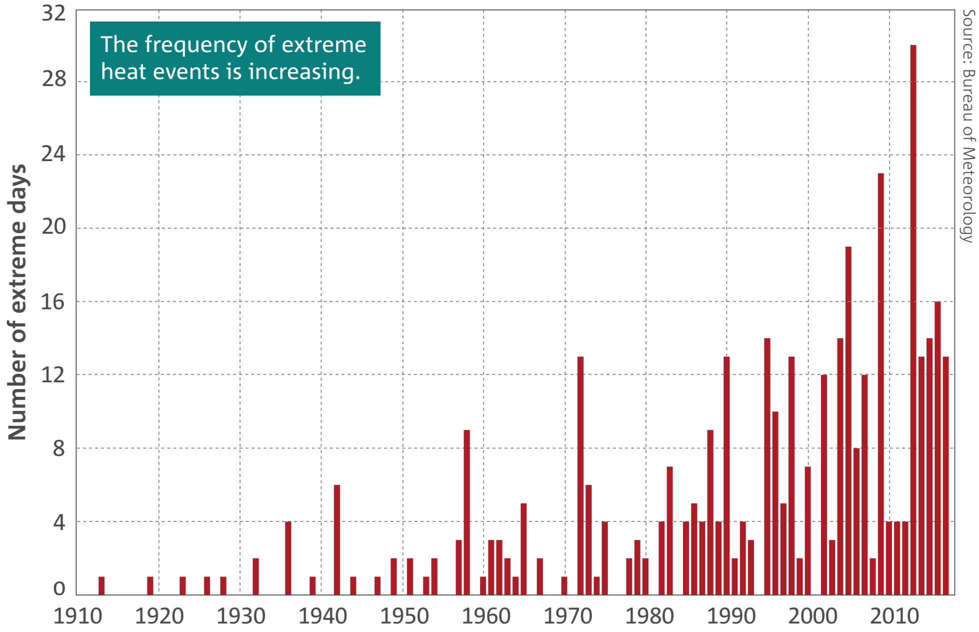


Figure 10. Number of extremely hot days for the period 1910–2018 (Source: *State of the Climate 2018*[10])

Rainfall

Average rainfall has increased across parts of northern Australia since 1900 (Figure 11).

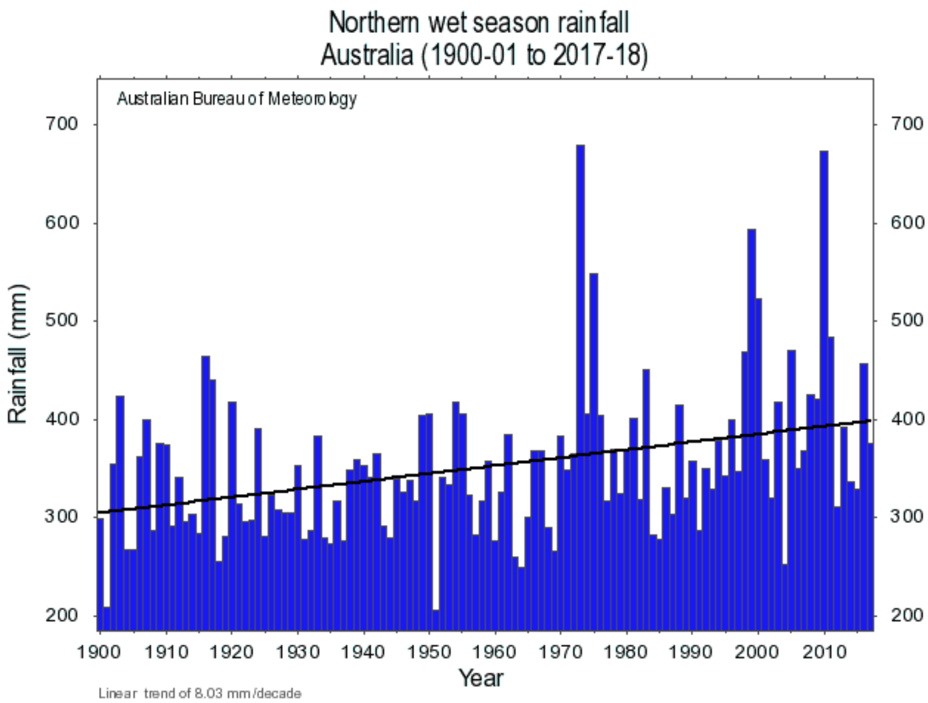


Figure 11. Northern Australia wet season rainfall 1900–2018 (Source: Bureau of Meteorology)

[10] http://www.bom.gov.au/state-of-the-climate/australias-changing-climate.shtml

Over the past 20 years, parts of northern Australia have received the highest rainfall on record (compared to 1900) (Figure 12).

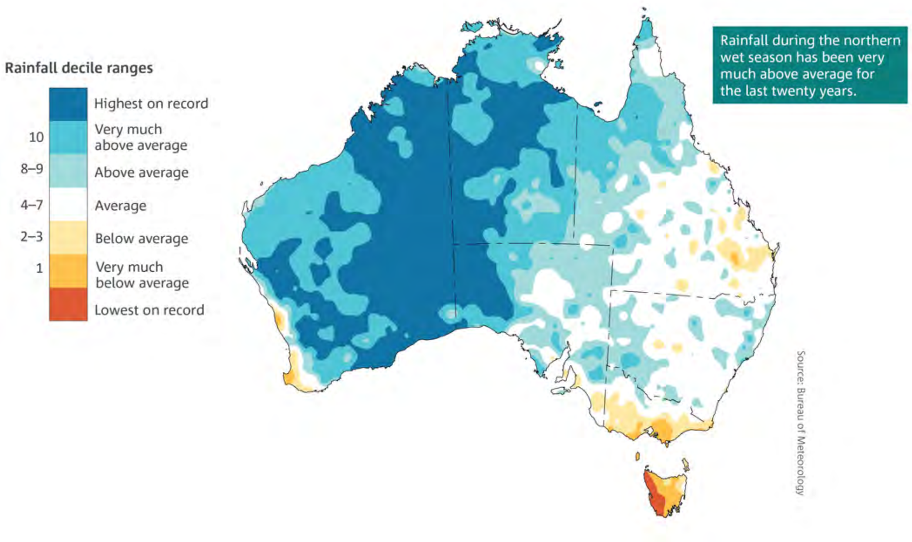
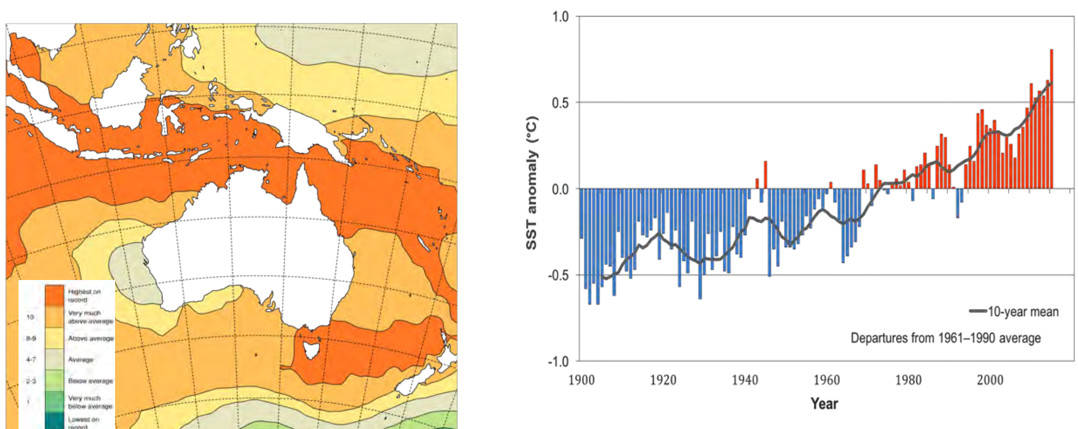


Figure 12. Northern Australia wet season rainfall 1900–2018 (Source: *State of the Climate 2018*[11])

Sea surface temperature

The ocean surface around Australia has warmed over recent decades at a similar rate to the air temperature – around 1 °C since 1910.[12]

Recent increases in SST may be an important factor in increased west season rainfall over north-western Australia (Figure 13).



2015-2016 monsoon season

Northern Australia monsoon season sea surface temperature anomalies

Figure 13. Sea surface temperatures (SST) for the 2015-16 monsoon season (left) and northern Australia SST anomalies 1900–2018 (right) (Source: Bureau of Meteorology (left) and *State of the Climate 2018* (right))

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[11] http://www.bom.gov.au/state-of-the-climate/australias-changing-climate.shtml
[12] http://www.bom.gov.au/state-of-the-climate/oceans.shtml

Fire weather

Fire weather depends on a combination of temperature, rainfall, humidity and wind. Fire weather conditions are worsening across large parts of the country, including the northern part of the Northern Territory (Figure 14).

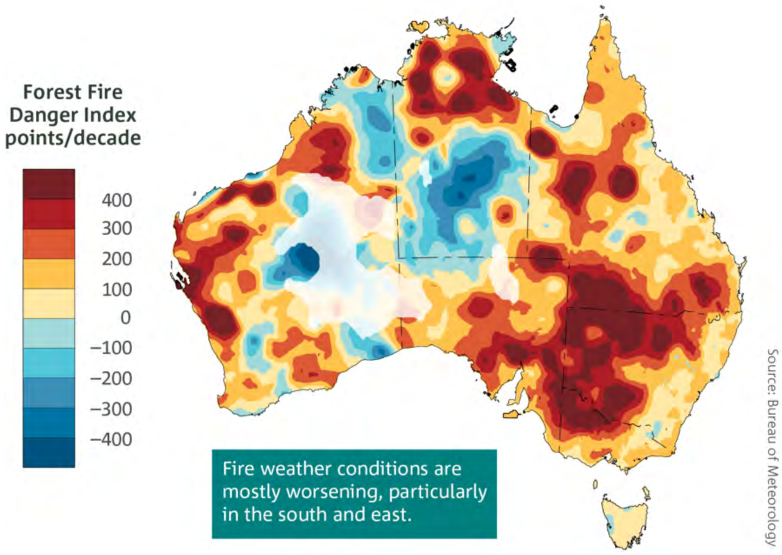


Figure 14. Forest Fire Danger Index trends 1978-2017. Yellow to red colours indicate increasing length and intensity of the fire weather season. (Source: *State of the Climate 2018*[13])

[13] http://www.bom.gov.au/state-of-the-climate/australias-changing-climate.shtml

Climate change projections for northern Australia

Vanessa Hernaman, ESCC Hub/CSIRO

- Climate change is a long-term change in the average pattern of weather that occurs over many decades. Natural variability occurs over the top of this long-term trend.
- Climate change projections tell us about the response of the climate system to possible future scenarios. They are not predictions that tell us a sequence of weather events.
- Projections are developed by combining our current understanding of the climate system with possible future scenarios in a global climate model. These models simulate climate processes based on laws of physics.
- Our confidence in climate projections is based on how well we understand climate processes and how well the climate model can simulate these processes.
- We are more confident in some projections (e.g. temperature) than others (e.g. average rainfall).

Weather, climate, climate variability and climate change

Weather is how we experience climate, but weather and climate are not the same thing. Weather refers to atmospheric conditions and events that occur over short periods of time, typically hours to days. Climate is the average pattern of weather over an extended period of time.

Climate change refers to long-term changes in the average pattern of weather that occur over many decades. Since industrialisation, rapidly increasing concentrations of greenhouse gases in the atmosphere have resulted in global warming. As the climate becomes warmer, other climate processes also change.

At the same time as these long-term changes, we also experience natural variability in the climate system. On a timescale of months, climate varies due to seasonal cycles. On a timescale of years, phenomena such as the El Niño–Southern Oscillation[14] cause variations in climate, while climate variability at a decadal timescale is influenced by processes such as the Interdecadal Pacific Oscillation (sometimes called the Pacific Decadal Oscillation[15]).

[14] http://www.bom.gov.au/watl/about-weather-and-climate/australian-climate-influences.shtml?bookmark=enso
[15] https://www.metoffice.gov.uk/videos/5580792782001

Climate change projections

With the past no longer being a good indicator of what we can expect in the future, climate projections are useful tools for planning ahead. Climate projections are developed using **global climate models**, which simulate the future climate based on **emissions scenarios**.

Projections are typically presented as averages over 20-year periods. For convenience they are referred to by the central year in the period, so projections for 2070 actually cover 2060–2079. Projections are relative to a baseline time period (e.g. 1986–2005), so if a projection was for a 2°C increase in temperature, it is relative to the baseline period and can be presented as the change between the historic and the future (e.g. an increase of 2°C), or change applied to an observational dataset (e.g. mean annual temperature of 30°C).

Climate projections are not predictions. A prediction estimates a sequence of events in the future, including the effect of climate change and variability. Given the timescale and uncertainties (such as emissions concentrations) associated with climate change, predictions are not possible. Instead, we use projections, which tell us about the response of the climate system to a possible future scenario. Climate projections do not tell us the climate of a particular day or month or predict a specific series of events, but rather how the probabilities of climate conditions (including the changing odds of extremes) may change in our changing climate.

Global climate models

Global climate models (GCMs) are mathematical representations of the climate system based on the laws of physics. They take into account interacting processes that shape the global climate, including atmospheric dynamics and physics, oceans and sea ice, land surface processes, and aerosols, and some Earth system models also represent carbon and biogeochemical cycles. The models are very complex and run on powerful supercomputers.

GCMs have been developed in many centres around the world and are continually being improved. A global project – the Coupled Model Intercomparison Project (CMIP) – coordinates experiments and data archiving of climate model simulations. The most recent phase of this project, CMIP5, contains simulations from up to 50 models from 28 modelling centres (including ACCESS, Australia's national climate model).[16]

GCMs are tested for their ability to reproduce past climate, including mean values; seasonal cycle; major processes (e.g. ENSO). The better they are at reproducing the past, the more confidence we have in their simulations of the future. There is no single 'best' model that simulates everything well and in every region of the world. Some are better at simulating different processes and different regions than others.

Each model simulates all the aspects of the climate relative to each other, so when using climate projections, it is important to use results from the same model or models, and not to

[16] https://pcmdi.llnl.gov/mips/cmip5/availability.html

go ‘cherry-picking’ results from different models. This ensures the internal consistency of the projections.

Emissions scenarios

GCMs are comprised of various sub-models that interact to predict rates of global warming for different concentrations of greenhouse gases and aerosols. While the laws of physics govern the climate system, they cannot tell us about social, political and economic aspects of the future, which will have a bearing on emissions. Instead, the science community defined a set of four future scenarios called representative concentration pathways (RCPs) that represent a range of economic, technological, demographic, policy and institutional futures (Table 3).

Table 3. Summary of representative concentration pathways (RCPs)

	At the end of the century (2100)		
RCP	CO_2 concentration*	Radiative forcing**	Warming***
2.6 (low emissions)	420 ppm	2.6 W m^{-2}	0.3°C to 1.7°C
4.5	540 ppm	4.5 W m^{-2}	1.1°C to 2.6°C
6.0	660 ppm	6.0 W m^{-2}	1.4°C to 3.1°C
8.5 (high emissions)	940 ppm	8.5 W m^{-2}	2.6°C to 4.8°C

* 2018 CO_2 concentration is 407 ppm
** Radiative forcing is a measure of the energy absorbed and retained in the lower atmosphere; more forcing = more warming.
*** Global mean surface warming for 2081–2100 relative to 1986–2005.

Because of natural variability in the climate and inertia in the climate system, results from the different emissions scenarios are quite similar to 2030 (2020–2039) – after this time, the higher the emissions, the more climate change signal is evident by 2100.

It is worth noting that these RCPs were developed prior to the Paris Agreement, so they do not align directly with the Paris targets of 1.5°C and 2.0°C (relative to pre-industrial) by 2100. However, RCP2.6 *could* be regarded as a trajectory that would arrive at around 1.5°C by 2100 – but this change is relative to 1986–2005.

Confidence in projections

Our confidence in climate change projections is determined by considering climate model results along with our physical understanding of the climate system and past observations. Confidence is higher for some projections (e.g. temperature) than others (e.g. rainfall).

It is important to recall that variability will continue, and the temperature or rainfall, say, in a particular year will be a result of climate variability, superimposed on the underlying climate trend (see figure below). In effect this means variability will be sometimes reinforcing and sometime opposing climate change. The internal variability of rainfall changes is particularly large over most Australian regions so it may take many years for the climate change 'signal' to emerge clearly from the year-to-year variability.

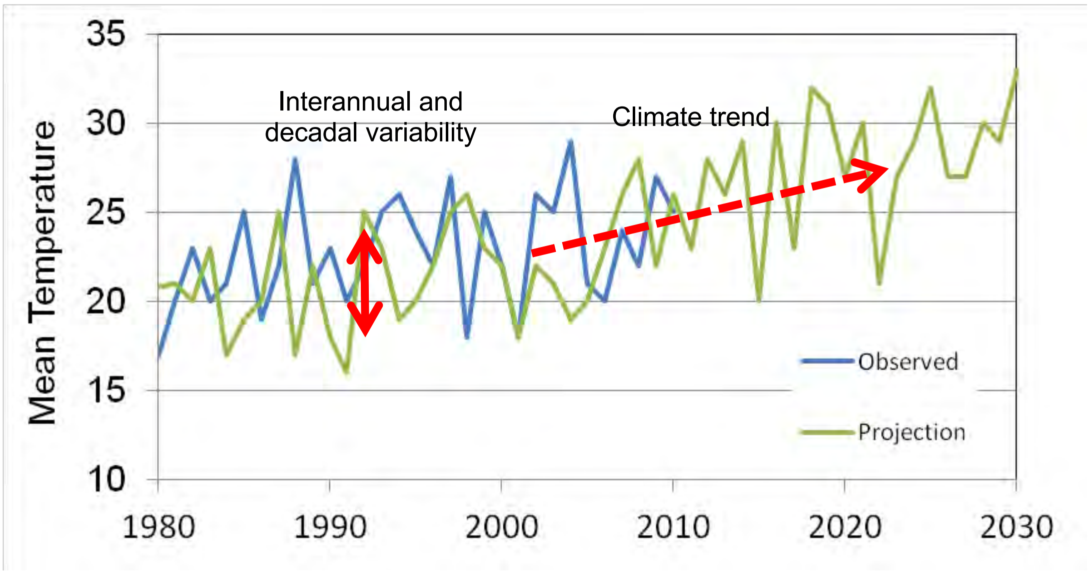


Figure 15. Confidence in climate change projections is based on the direction and size of the long-term trend, not the year-to-year variability. (Source: V Hernaman workshop presentation)

Future climate for the Northern Territory

- Average temperatures will continue to increase in all seasons (very high confidence)
- More hot days and warm spells are projected (very high confidence)
- Extreme temperatures - substantial increase in the temperature reached on hot days, the frequency of hot days, and the duration of warm spells
- Changes in average rainfall are possible, but uncertain (large decreases are less likely than increases or little change)
- Increased intensity of extreme short-duration (hourly, sub-daily) rainfall events (high confidence)
- In regions with abundant rain (e.g. Top End and the Kimberley), no change projected in fire frequency. In more southerly locations, changes to future rainfall will be determining factor of change to fire frequency. (The primary determinant of bushfire in the Monsoonal North is fuel availability.)
- Evaporation is projected to increase in all seasons as warming progresses (high confidence)
- Humidity is projected to decrease (medium confidence)
- Mean sea level will continue to rise and height of extreme sea-level events will also increase (very high confidence).

While we do not know exactly how the future will unfold in the decades out to 2100, we can draw on climate change science to tell us what the future climate might be like.

We can use science-based climate change information to provide the evidence for developing ‘climate smart’ policies and plans for sectoral adaptation and disaster risk management.

Using the latest climate science and modelling, climate projections can help us plan for a smaller range of options by narrowing down the range of possible future climates.

Australia’s national climate change projections

Australia’s national climate change projections[17] were developed by CSIRO and the Bureau of Meteorology in 2015 for the Commonwealth Natural Resource Management funded projections project. They are reported on the basis of clusters, which correspond to the broadscale climate and biophysical regions of Australia (Figure 16). Darwin and Katherine fall into the Monsoonal North (West) cluster.

[17] Climate Change in Australia, www.climatechangeinaustralia.gov.au

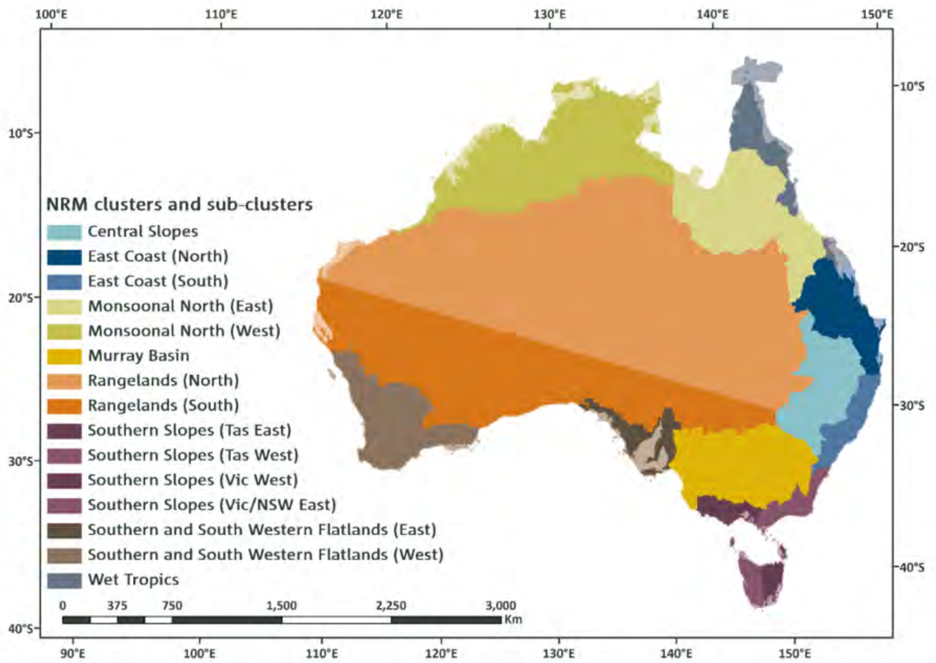
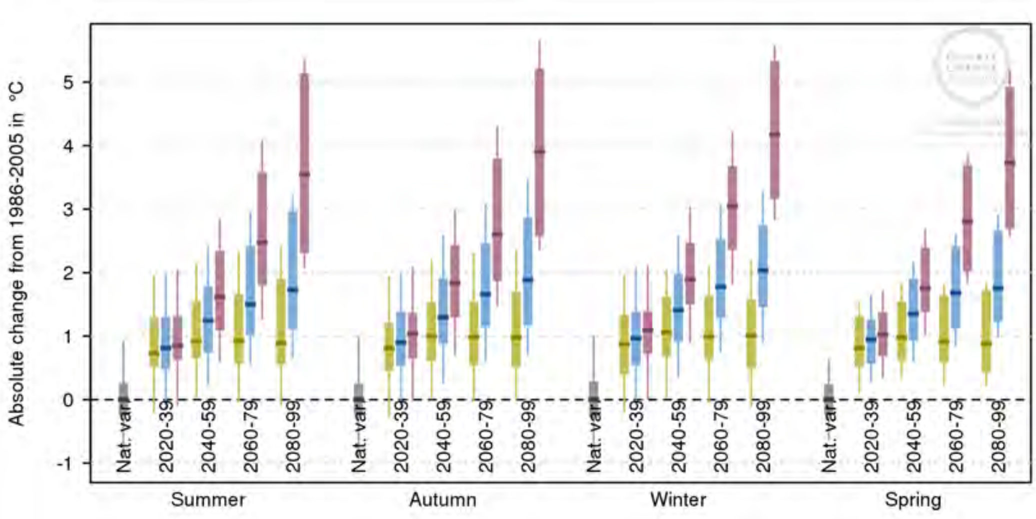


Figure 16. Clusters and sub-clusters used in Climate Change in Australia (Source: V Hernaman workshop presentation)

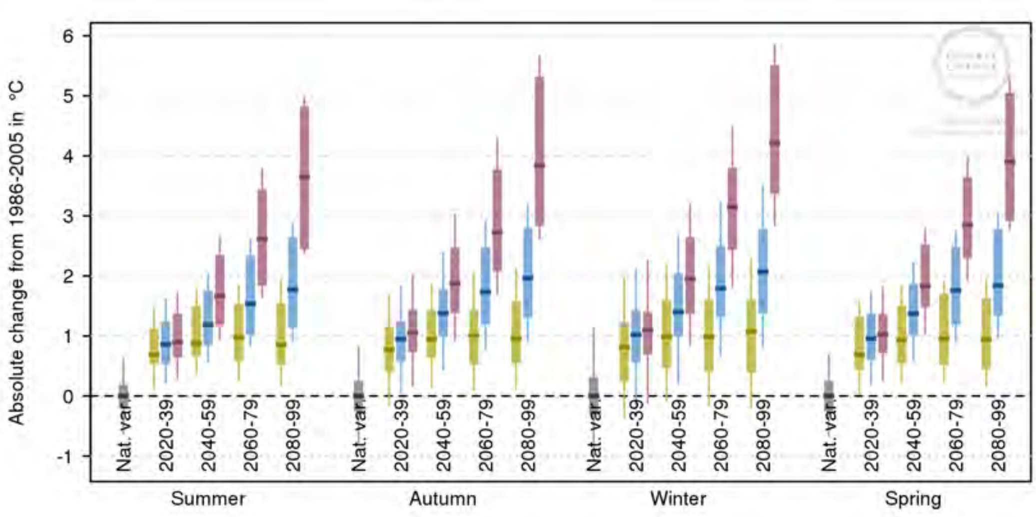
Mean temperature

Projected annual mean temperature change (ºC) relative to 1986–2005: median (10th–90th percentile)		RCP2.6	RCP4.5	RCP8.5
	2030	1.0 (0.5–1.2)	1.0 (0.6–1.3)	1.0 (0.7–1.3)
	2050	1.0 (0.7–1.3)	1.3 (0.9–1.9)	1.8 (1.4–2.4)
	2090	1.0 (0.5–1.6)	1.8 (1.3–2.7)	3.8 (2.8–5.1)

MEAN TEMPERATURE



MINIMUM TEMPERATURE



MAXIMUM TEMPERATURE

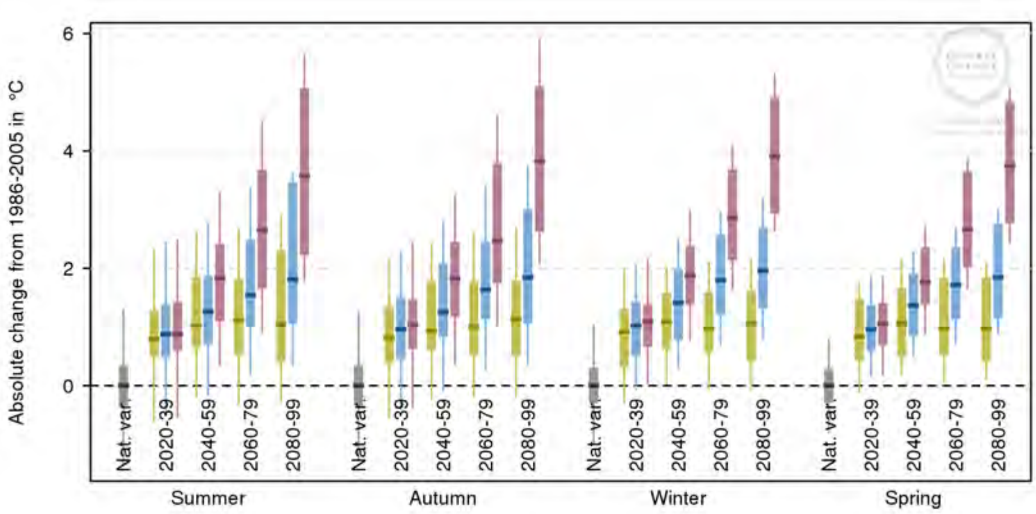


Figure 17. Projected increase in mean (top), minimum (middle) and maximum (bottom) temperature (ºC) relative to 1986–2005 for the Monsoonal North cluster. Grey: natural variability, green: RCP2.6, blue: RCP4.5, pink: RCP 8.5. Dark line in each bar is the median. Bar extent is the 10th to 90th percentile. (Source: V Hernaman workshop presentation)

Extreme temperature

Projected increase in annual average no. days max. temperature > 40ºC (range from eight GCMs)		Historic	RCP 4.5		RCP8.5	
		1981–2010	2050	2090	2050	2090
	Darwin	0	0	0	0	1–11
	Kununurra	30	45–81	52–99	52–106	90–194

Mean rainfall

Projections of rainfall for the Monsoonal North is difficult because GCMs offer diverse results and different processes (e.g. monsoon onset, MJO, tropical circulation) can have opposite impacts on model projected future rainfall.

Natural climate variability is projected to remain the major driver of rainfall changes in the next few decades.

Projected mean rainfall change (%) for 2090 relative to 1986–2005: (10th–90th percentile)		2090		
		RCP2.6	**RCP4.5**	**RCP8.5**
	Annual	–14% to +4%	–15% to +7%	–24% to +24%
	Summer	–14% to +4%	–17% to +9%	–20% to +20%
	Autumn	–20% to +13%	–19% to +15%	–31% to +32%
	Winter	–45% to +19%	–39% to +19%	–53% to +44%
	Spring	–31% to +14%	–30% to +29%	–46% to +30%

Extreme rainfall

Extreme rainfall is projected to intensify, even in regions where mean rainfall decreases.

Increases in rainfall extremes have already been observed for short duration (3-hour or less) rainfall.

As temperature rises, capacity of the air to hold water vapour also increases, providing a greater potential source of moisture for rain to form: for each 1°C increase in temperature, the water-holding capacity of air increases by approximately 7% (Clausius-Clapeyron rule).

The increase in intense rainfall can be even greater when the increased moisture in the air provides more energy for the storm. This is already evident in the most extreme hourly rainfall, particularly in summer storms.

Evapotranspiration

Evapotranspiration projections increase with emissions scenario and towards the end of the century (Figure 18).

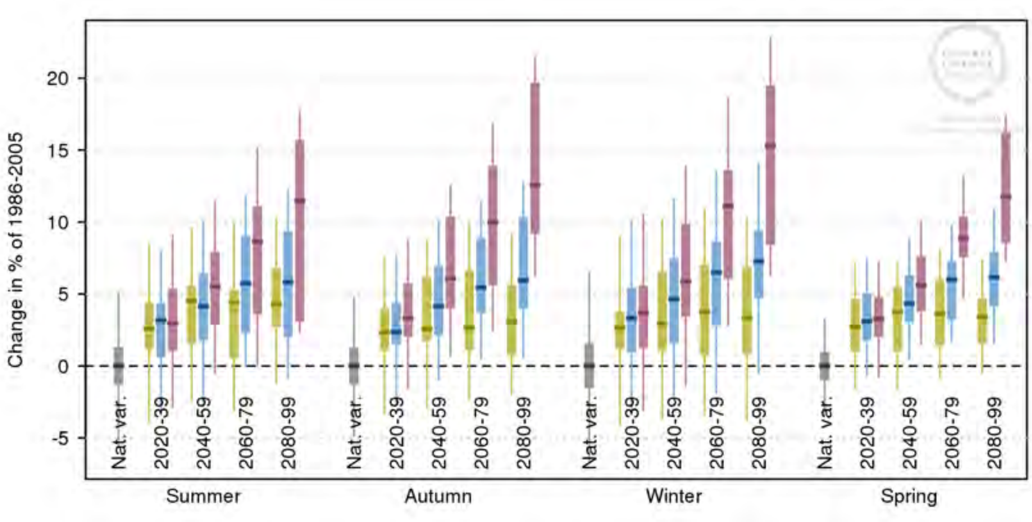


Figure 18. Projected increase in mean evapotranspiration (%) relative to 1986–2005 for the Monsoonal North cluster. Grey: natural variability, green: RCP2.6, blue: RCP4.5, pink: RCP 8.5. Dark line in each bar is the median. Bar extent is the 10th to 90th percentile. (Source: V Hernaman workshop presentation)

Solar radiation

Generally little change in solar radiation is projected (Figure 19).

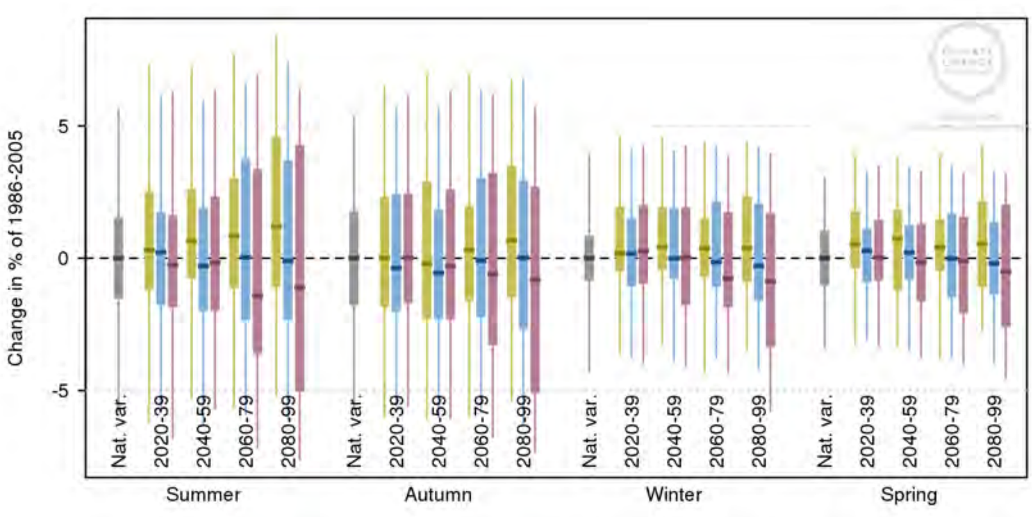


Figure 19. Projected change in mean solar radiation (%) relative to 1986–2005 for the Monsoonal North cluster. Grey: natural variability, green: RCP2.6, blue: RCP4.5, pink: RCP 8.5. Dark line in each bar is the median. Bar extent is the 10th to 90th percentile. (Source: V Hernaman workshop presentation)

Relative humidity

Little change in relative humidity is projected until later in the century when a decrease is projected under mid–high emissions scenarios, but there are seasonal differences (Figure 20).

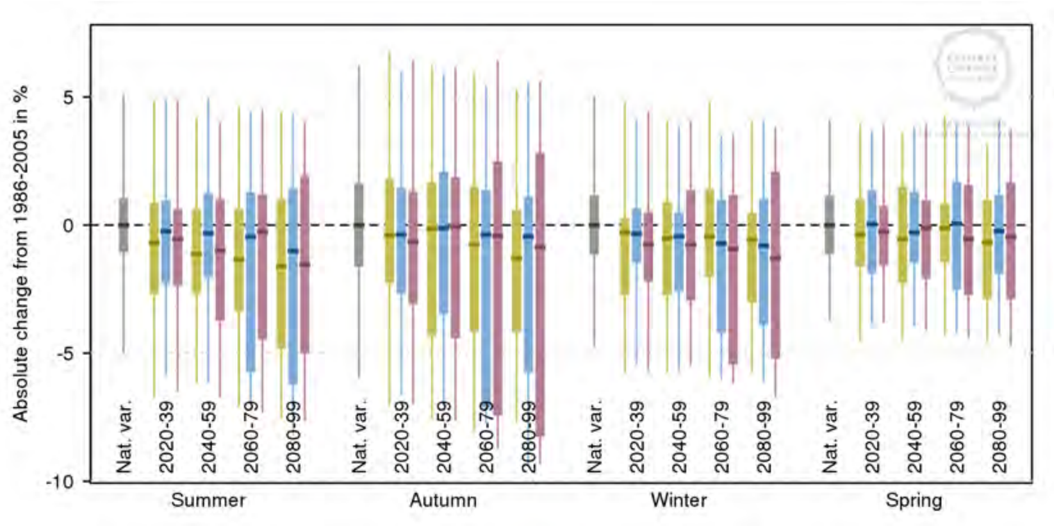


Figure 20. Projected change in mean relative humidity (%) relative to 1986–2005 for the Monsoonal North cluster. Grey: natural variability, green: RCP2.6, blue: RCP4.5, pink: RCP 8.5. Dark line in each bar is the median. Bar extent is the 10th to 90th percentile. (Source: V Hernaman workshop presentation)

Wind

There are season differences in wind projections (Figure 21).

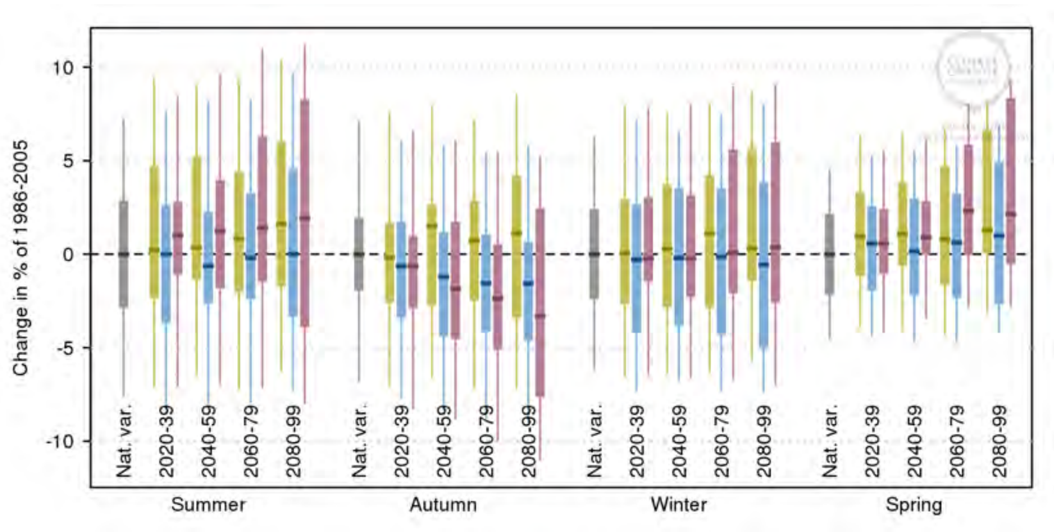


Figure 21. Projected change in wind (%) relative to 1986–2005 for the Monsoonal North cluster. Grey: natural variability, green: RCP2.6, blue: RCP4.5, pink: RCP 8.5. Dark line in each bar is the median. Bar extent is the 10th to 90th percentile. (Source: V Hernaman workshop presentation)

Using climate change information to plan ahead

Using climate change information and projections

Vanessa Hernaman, ESCC Hub/CSIRO

- The Northern Territory Government has been supplied with projected temperature threshold datasets out to 2090.
- In addition to this data, there are a number of relevant tools and datasets on the *Climate Change in Australia* website.
- A useful tool is the Analogues Explorer, which equates the future climate at a location to the current climate at another location.

Datasets given to the Northern Territory Government

CSIRO has supplied datasets for the average number of days below 14°C, 16°C, 18°C and 20°C under two future scenarios (RCP4.5 and RCP8.5) for four time slices: 2030, 3050, 2070 and 2090. Annual data is available, as is data for the tropical seasons (May–Oct; Nov–Apr). Monthly data or data for other seasons can be supplied.

This is gridded data in netCDF files that can be visualised using Panopoly[18] or ArcGIS[19]/QGIS[20].

This data is from three global climate models representing a much hotter/drier future (ACCESS1-0), a hotter/much wetter future (NorESM1-M) and a 'middle of the road' future (HadGEM2-CC). (Data from the other five models used in *Climate Change in Australia* can be supplied.)

Australian Water Availability Project (AWAP) historical data for the four thresholds has also been supplied.

Projected temperature threshold datasets

The projected temperature threshold datasets were prepared by obtaining the projected change between the baseline (1986–2005) and the future (e.g. 2040–2059) for each month for each model. The projected change was applied to a 30-year (1981–2010) daily time-series from the AWAP gridded observed dataset.

This method, known as the 'delta change' or 'change factor' method applies 20-year average monthly change factors to each day of the corresponding months in the observed 30-year

[18] https://panoply.io/
[19] https://www.arcgis.com/index.html
[20] https://www.qgis.org/en/site/

time-series. This produces a 30-year plausible future time-series which is then analysed for days above or below the selected threshold.

Considerations

Scaling

- Resultant future data are highly realistic looking because they preserve the spatial and temporal patterns present in the historic dataset but scaling does not capture future changes in variability.

Gridded observation data

- The observation data to which the change factor is applied are gridded product from BoM (AWAP).
- AWAP data are gridded at a spacing of 0.05 degrees longitude and latitude (approximately equal to 5 km). The density of stations varies geographically.
- The gridded product is created from observations from high-quality station data. Gaps between the stations are filled in by interpolation (statistical methods). The interpolation process smooths extremes and so is a conservative dataset.
- It is important to examine the results to ensure they make sense in light of what is known of the local climate, including how it compares to that of the surrounding areas.

Extracting point locations

- Location data are calculated from the 0.05° gridded future dataset, by querying the nearest available grid cell.
- These location data are not calculated from station data, there may be differences between the results obtained from this tool and the station-based data available from BoM.
- BoM data typically represent days greater/less than or equal to the relevant threshold whereas *Climate Change in Australia* data (e.g. the thresholds calculator and associated datasets) reports days greater/less than.

Datasets available on the *Climate Change in Australia* website

The *Climate Change in Australia* website[21] has data from eight global climate models. These eight models were selected because they:

- perform well for the Australian region compared to historical climate from observations
- Model independence?
- are representative of the range of change in temperature, rainfall and wind.

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[21] www.climatechangeinaustralia.gov.au

This data is available via a number of tools:

- Climate Analogues
- Regional Climate Change Explorer
- Summary Data Explorer
- Extremes Data Explorer
- Marine Explorer
- Thresholds Calculator
- Map Explorer
- Gridded Data Download
- Station Data Download.

Climate Analogues

The Analogues Explorer tool provides the ability to gain a clearer understanding of what the future climate at a location is expected to be by equating it to the current climate at another location (Figure 22). Users can explore a location under different emissions scenarios and time periods under preset scenarios. The options pane allows for additional queries.

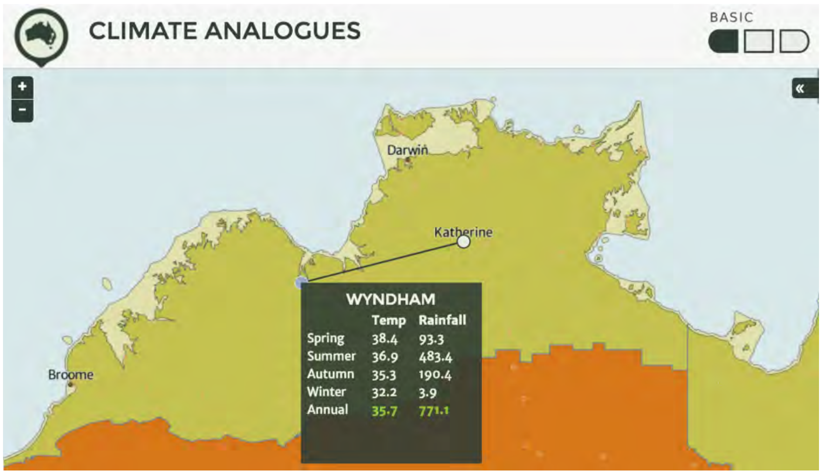

Figure 22. Climate analogue for Katherine in 2050 under RCP8.5 emissions scenario using maximum model consensus. (Source: *Climate Change in Australia* analogues explorer[22])

Thresholds Calculator

The thresholds calculator on *Climate Change in* Australia has recently been revised, with new thresholds prepared for the Northern Territory Government now added. Data is available for all eight global climate models as well as historical AWAP data for RCP4.5 and RCP8.5 for four time periods. The tool now displays a table giving the range and mean for a location (Figure 23); however, users are advised against using the mean given in the table, which is just provided as a guide. Instead, users are strongly encouraged to use the Climate

[22] https://www.climatechangeinaustralia.gov.au/en/climate-projections/climate-analogues/analogues-explorer/

Futures approach of worst, best and consensus cases. Data downloads will soon be available from this tool.

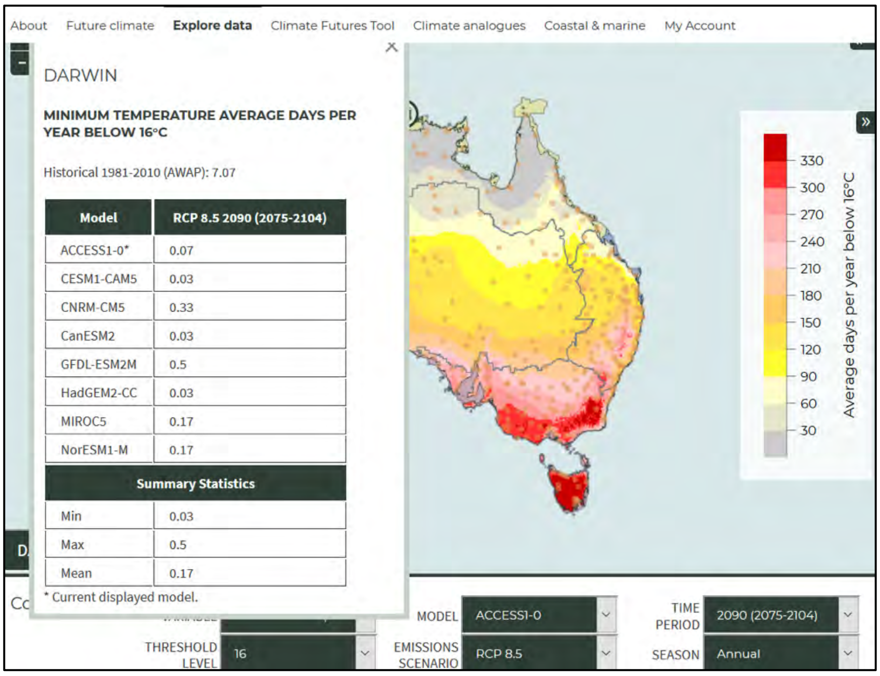

Figure 23. Screenshot of the *Climate Change in Australia* thresholds calculator showing the annual average number of days per year with minimum temperature below 16ºC for Darwin for 2090 (2075–2104) using RCP8.5 from the ACCESS1-0 global climate model.

Demonstrating the utility of climate change projections

The ESCC Hub's mandate is to ensure that Australia's policies and management decisions are effectively informed by climate change science. However, climate change information is often not readily accessible, conceptually and physically.

The Hub is working with a number of stakeholders to develop guidelines to assist with the uptake and application of climate change information. Key in this process are a series of case studies demonstrating how climate change information can be applied to assist with sectoral decision making and planning. One of these case studies will be undertaken with the Northern Territory Government and mango industry.

Case study

The impact of climate change on flowering induction in mango in the Northern Territory

The ESCC Hub is working with the Northern Territory Government (Department of Primary Industry and Resources, DPIR), the Australian Mango Industry Association and NT Farmers Association to demonstrate the utility of climate change information for planning and management decisions in the Northern Territory mango industry. This document provides details of the technical scope for the case study.

Flowering induction in mangoes is dependent on minimum and maximum temperatures. Timing of flowering has implications for fruit set and so is commercially important. Understanding how temperatures will change in the future will support the mango industry to minimise risks and identify opportunities as they plan for the future.

Mango cultivars

- Kensington Pride
- Honey Gold
- B74
- 3 x cultivars from the National Mango Breeding Program

Regions of interest

Northern half of Northern Territory, as well as three specific growing regions (including Kununurra in Western Australia).[1]

Relevant climate variables

Temperature thresholds[2]

- Days under 16ºC, 18ºC
- Days over 32ºC, 35ºC

Time frame of interest

- 2030 – for current planting
- 2050 – for next planting
- 2070 and 2090 – for breeding program

Time step

Monthly data for May, June, July and August (when flowering occurs) – i.e. number of days per month under/over thresholds.

Observations

Historical trends in maximum and minimum temperature and the four temperature thresholds will be included for the region. BoM will provide climatology information associated with particular good/poor production events where possible.

Emissions scenarios

The case study will use RCP4.5 and RCP8.5, as these are the scenarios that the temperature thresholds are available for.

Projections

Climate change projections will be constructed as days over or under the identified thresholds.

Data availability

- DPIR will contribute mango physiology understanding from recent research.
- BoM has observed maximum and minimum temperature data.
- CSIRO has temperature threshold projections data.

Data collection and analysis timeline

28 Feb 2019	Expert meeting
1 Mar 2019	Case study scoping meeting
Mar–Aug 2019	Climate team to collect and process observed data and climate model output; Mango team to conduct literature review, prepare gap analysis and analyse mango flowering data for the varieties in the case study
Sep 2019–Jan 2020	Synthesis – drafting of technical report and peer review
18–19 Feb 2020	Synthesis workshop
31 Mar 2020	Publication of final report

Notes

1. NT DPIR to provide bounding box (latitude and longitude for each corner) for the three regions.
2. Temperature thresholds to be confirmed by DPIR by end April 2019.
3. Stakeholder engagement and communication activities and products are documented in the case study stakeholder communication and engagement plan.

Engagement and communication

An engagement and communication plan will be prepared to support the case study goals:

- To provide industry-relevant information about the impact of climate change on flower induction
- To improve the level of climate change literacy in the Northern Territory mango sector[23]
- To demonstrate the process for turning climate change science into useful industry information
- To raise awareness of the utility of existing climate change information
- To encourage the use of climate change information in other primary production systems.

The plan will be based around three core principles:

- Relevance – framing (economic), timing (mindful of production), relatable (local/industry examples)
- Repetition – often and in many formats – person, print, screen
- Resourcefulness – making use of existing channels and multi-use products.

It will be implemented between February 2019 and May 2020, with three clear periods of activity:

- **Pre-season (Feb–Jun 2019):** The focus in this period is building climate literacy and raising project awareness (noting that without the climate literacy, the value of the project is not fully understood), taking advantage of the AMIA conference (May).
- **During season (Jul–Dec 2019):** The focus in this period is maintaining the momentum in climate change awareness within the industry built up in the pre-season, taking advantage of existing industry communication channels (e.g. AMIA and/or NT Farmers newsletters).
- **Post-season (Jan–May 2020):** The focus in this period is on the impact assessment results, which will not be available until March 2020.

[23] This goal was added after the project inception workshop, where discussions with grower representatives highlighted a low level of climate change literacy. Adding this element is essential for the full value of the project to be realised, and meets a general industry need that was not understood in the initial project scope.

Appendix 1: Workshop agenda

Earth Systems and Climate Change Hub

Experts meeting for case study 5.1 - Impact of climate change of mango production in the Northern Territory – preliminary review and scoping

28th of February and 1st of March

Banyan Room, CSIRO Darwin

Background

Projected increases in minimum and maximum temperatures will potentially affect flowering and production of mango cultivars. This case study will investigate the application of climate change information to the NT mango industry so effects of minimum and maximum temperatures for current cultivars can be identified. This will allow the industry to consider development of appropriate management and developed needs.

Outputs from this case study are expected to:

- assist in identifying pathways to obtain spatially and temporally explicit data to support adaptation planning for mango production, and
- raise awareness of the key climate impacts or opportunities that could potentially influence the mango industry.

Objectives

- To raise awareness of the utility of existing climate change information
- To trial draft Hub guidelines for using climate change science to support decision and policy making
- To provide industry-relevant information about the impact of climate change on mango growth, harvesting and yield.
- To explore how this information may be used to plan appropriate industry short and long-term responses

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AGENDA
Day 1

Item	Description	Responsible	Time (mins)	Start
•	Welcome: • Introductions • Welcome	Chair: Mandy Hopkins Roundtable Phil Hausler	30	09.30
•	NT Climate Change	Mila Bristow, NT Government	15	10.00
•	Overview of the NT Mango Industry	Leo Skliros, NT Mango Industry Association	15	10.15
	Morning tea break		30	10.30
•	Environmental limits to mango production in Northern Australia	Peter Johnson, Western Australia	30	11.00
•	Relationship between temperature and mango flower induction	Cameron McConchie, NT Government	30	11.30
•	Industry panel discussion	Industry representatives	30	12.00
	Lunch		30	12.30
•	Past climate trends and drivers for northern Australia	Greg Browning, BOM	30	13.00
•	Climate Changes Projections for northern Australia	Vanessa Hernaman – ESCC Hub	45	13.30
•	Using climate change information and projections when determining thresholds	Vanessa Hernaman – ESCC Hub	45	14.15
	Afternoon tea break		30	15.00
•	Discussion around the table		30	15.30
•	Day 1 concludes			16.00

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Day 2

Item	Description	Responsible	Time (mins)	Start
1.	Key points from yesterday	Mandy Hopkins	30	09.30
2.	Introduction to the guidelines	TBC	60	10.00
	Morning tea break		30	11.00
3.	Working with the group on the use of these guidelines in an impact study:- - Useful - Not Useful - Changes required		90	11.30
	Lunch break		30	13.00
4.	Any further business		30	13.30
5.	Wrap up and next steps		30	14.00
6.	Close			14.30

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Appendix 2: Workshop participants

• Mila Bristow*	NT Government – DPIR*
• Greg Browning*	Bureau of Meteorology (via telephone)
• Pieter Claassen	Bureau of Meteorology
• Maddison Clonan	NT Government – DPIR
• Sarah Hain	Australian Mango Industry Association
• Matt Hall	NT Government – DPIR
• Phil Hausler	NT Government – DPIR
• Mark Hearnden	NT Government – DPIR
• Vanessa Hernaman*	ESCC Hub/CSIRO
• Mandy Hopkins	ESCC Hub/CSIRO
• Peter Johnson*	Consultant (via telephone)
• Martina Matzner	Acacia Hills
• Cameron McConchie*	NT Government – DPIR
• Karen Pearce	ESCC Hub/Bloom Communication
• Tanh Pham	NT Golden Mango
• Camilla Philip	NT Farmers Association
• Wayne Quach	Pine Creek Mangoes
• Leo Skliros*	NT Mango Industry Association
• Bruce Toohill	Landmark
• Nghi	Bees Nees

* = workshop presenter

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