

Critical Temperature Thresholds (CTT).

Local weather conditions influence all stages of plant establishment, development and growth, ultimately determining crop productivity and marketability. Every crop has a unique range of optimum, and tolerable environmental conditions that favour its growth. Identifying and understanding the relationships between crop growth stages and ‘expected’ weather is very important in maximizing crop productivity. For a crop to be successfully grown and marketed in a region, the sequences of its growth phases must align with the climate, in order to maximise the potential of good growth, quality and marketable (harvestable) yield.

Grotjahn, R. (2021) demonstrates the effect of short durations of temperatures, above or below the optimum, which can have devastating consequences on horticultural crops and their produce. For high temperatures it may be measured in hours to days. Two days in a row, above the optimum, are more severe than one day. This makes the task of identifying Critical Temperature Thresholds difficult, and exacerbated by the fact that, “the thresholds have ranges due to the variation among cultivars and the conditions each plant experiences over time” (Grotjahn, R., 2021, p.40).

Introduction

The origin of the Mango (*Mangifera indica*) has been traced and has two major sites of evolution. One is in the mild, subtropical, northern Indian/Burmese region where mangoes have been cultivated for more than 4,000 years. Genetic material from this region has been used to produce varieties with a greater tolerance to low temperatures during both vegetative growth and fruit set. These monoembryonic varieties produce a single seedling from each seed and include the varieties Keitt, Kent, Palmer, Tommy Atkins and Irwin. A secondary site of Mango evolution developed around 2,000 years ago in the hot, humid, tropical areas of south-east Asia. This region is where the polyembryonic varieties have evolved. Polyembryonic varieties produce several seedlings from each seed. These south-east Asian varieties need higher temperatures for growth, and fruit set and are more susceptible to cold weather. This group includes varieties such as Nam Doc Mai (Thailand) and Carabao (Philippines). The shape, size and colour of mango fruit vary greatly with varieties. The fruit has a large seed enclosed in a fibrous coat and the fibres extend from the seed into the pulp.

Early sea travel and trade spread the fruit through almost every tropical and most subtropical regions of the world. The polyembryonic variety known as ‘Kensington Pride’, ‘Bowen’ or ‘Bowen Special’ still dominates the Australian fresh Mango market. The cultivar has distinctive flavour and aroma characteristics that distinguish it from the Florida-bred cultivars grown by many mango exporting countries (Whiley, et al., 1992).

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The cultivar Kensington is reputed to have arisen from seed given to George Sandrock, the Port Denison (now Bowen) harbourmaster between 1885 and 1889. Trade and shipping between north Queensland and south-east Asia were common at this time, so it is likely that the seed came into Australia this way. The seeds were grown by William Lott, and Lott's son, Harry who collected seeds from the best trees and planted them on his own property, 'Kensington', after which the cultivar is named (Meurant, 1986). Kensington mango trees were quickly introduced to the homesteads and household gardens and were generally referred to as the 'Bowen' or 'Bowen Special' mango.

There are a range of commercial mango varieties grown in Australia for the domestic and export markets. The main varieties and their respective approximate market share are: Kensington Pride (43%), Calypso™ (25%), R2E2 (19%), Honey Gold™ (8%), and other varieties (5%) ([Australian Mango Industry website accessed October 2024](#)).

The mango is considered one of the most important fruits in the world, grown in over 100 countries (Tharanathan, et al., 2006). Mango belongs to the family Anacardiaceae, with other cultivated trees in this family including the cashew and pistachio.

The major commercial mango-growing regions in Australia are located in Queensland the Northern Territory and Western Australia as detailed by Bally et al., (1999). In the 2022-23 season the Northern Territory was the largest producer, with Queensland a close second, while Western Australia, the third biggest production State, a considerably smaller growing region¹.

Production overview.

Queensland.

Queensland produces approximately 36,000 tonnes of mangoes a year from a cropped area of a little over 8,000 hectares. Queensland produces about 47% of Australia's total mango production, with the major growing locations being Mareeba and Dimbulah (55%), Bowen and the Burdekin (33%), central and south Queensland (11%) (Bally, et al., 1999). The Queensland mango harvest starts in North Queensland in late October and, in southern areas, ends in late March or early April.

The main varieties grown are Kensington Pride, B74 (marketed under the registered trademark CALYPSO®), R2E2, and Honey Gold®.

Most mangoes are sold directly into the supermarket distribution chain or through wholesale Market Agents in each capital city. Processors take fruit for juicing, canning, drying and for food manufacture.

¹ <https://www.horticulture.com.au/contentassets/a36fdfa2427d4ad284c426663b06f15c/hort-stats-fruit-22-23.pdf>

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Northern Territory.

In the Northern Territory mangoes are the largest horticultural commodity and the industry contributes over \$128 million to the economy.

Northern Territory (NT) growers produce 49% of Australia's crop and supply the first crop of the season to Australian consumers. This early fruit, the first fresh new season mangoes command a premium price.

NT mangoes are exported to key Asian markets as well as the United States of America. NT mangoes are attractive to export markets not only for their delicious taste and good size, but also because the Australian production season is counter cyclical to major northern hemisphere producers.

A significant number of mango farms are located close to Darwin but extend as far south as Mataranka. Approximately 40,000 tonnes of mangoes are produced from the NT's 6,350 hectares of mango plantations each year. The main mango varieties grown are Calypso®, R2E2, Kensington Pride, Mahachanok, Honey Gold®, Lady Jane, Lady Grace, NMBP1201, 1243, 4069, Falan and Nam Dok Mai².

Western Australia

In Western Australia Mangoes are a major horticultural crop. Mangoes are harvested from September through to April, due to the wide range of climates along the west coast. Kununurra in the north produces the first of the season followed by Broome, Carnarvon and then Gingin³. Mangoes can be grown around Perth, but careful management is necessary as they are susceptible to frost. The Perth growing area produces the last fruit of the Australian season and achieves high prices both in WA and interstate. The main commercial growing areas are Wanneroo, West Gingin, Gingin and Dandaragan. The main commercial variety grown around Perth is Kensington Pride, commonly known as "KP", but Haden, Namdok Mai, R2E2, and Kent are also grown⁴. The Australian Mango Association website lists the cropped mango area in WA to be around 980 hectares⁴.

Summary

Commercial mango production in Australia occurs predominantly in the northern tropical and sub-tropical regions. The majority of commercial production occurs in the Northern Territory, Queensland and Western Australia with niche plantings also in northern New South Wales, according to Bally et al., (1999).

² <https://ntfarmers.org.au/commodities/mangoes/>

³ [Foodhttps://www.agric.wa.gov.au/crops/horticulture/fruit/mangoes](https://www.agric.wa.gov.au/crops/horticulture/fruit/mangoes)

⁴ <https://www.industry.mangoes.net.au/resources/resources-library/national-mango-tree-crop-map-dashboard/>

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Most of mango cultivars exhibit some degree of irregular bearing (Singh, 1978). Low yields can be due to insufficient flower buds or to excessive fruit drop, but in all cases the relationship between vegetative and reproductive development is fundamental to achieving acceptable fruit load and yield (Chacko, 1986).

In the Northern Territory low yields in the major cultivar Kenningston Pride appear to be related to excessive vegetative vigour and poor flowering according to Schofield et al., (1986). Inconsistent floral induction (flowering), particularly in the tropics, is seen as a primary cause of poor yields. In contrast, flowering in the subtropics is reliable, but unsuccessful pollination is thought responsible for trees not meeting their fruiting potential (Whiley, et al., 1988 and Considine & Turner, 1991).

In their Australian research, Clonan et.al., (2021) documented how floral response to temperature varied among cultivars, with 'Calypso®', 'Kensington Pride', and 'NMBP 1201' having the greatest tolerance to high temperatures, followed by 'Honey Gold®', 'NMBP 1243' and 'NMBP 4069'. This work suggests that some cultivars are better adapted to flowering during warmer conditions, which they suggested would be an advantage under projected increased temperatures caused by climate change.

Erratic flowering and irregular fruiting have been recognised and documented in many mango cultivars (Chacko 1986; Pandey 1989; Chadha and Pal, 1993), including Kensington Pride (Beal, 1981). In the tropics, it is associated with year-to-year variation in the time of onset and duration of cool weather prior to flowering. This inconsistency of floral induction is believed to be the primary cause of poor yields from mango plantations grown in tropical northern Australia (Whiley, 1993).

In addition to nutritional and hormonal factors, crucial environmental factors like temperature and relative humidity influence the process of mango flowering (Parmar et al., 2012). Nunez-Elisea and Davenport (1994) state that in the subtropics, floral cell differentiation and development (morphogenesis) in mango trees, is initiated by cool weather. Temperatures of about 15°C or lower induce floral morphogenesis, whereas temperatures of about 20°C or higher promote vegetative growth.

Parmar et al., (2012) investigated the poor mango yield in the 2008-9 season in South Gujarat (India), which resulted from poor mango tree flowering in that year. The researchers compared maximum, minimum and average temperatures during the months of tree flowering (December to February) in that year, with those that occurred in the same flowering period of the previous 3 seasons (2005-2007) when expected (usual) tree yields occurred. The temperature and yield data analysis revealed that a 2°C higher average temperature during the 2008-9 flowering period resulted in an average fruit yield of 2.8 tonnes/ha while the average fruit yield for the previous 3 years at that site (2005-2008) was 7.3 tonnes/ha, a 62% yield loss.

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This detailed real-world analysis provides a powerful insight into the actual crop yield loss caused by temperatures that are above the mango trees Critical Temperature Threshold during the flowering period.

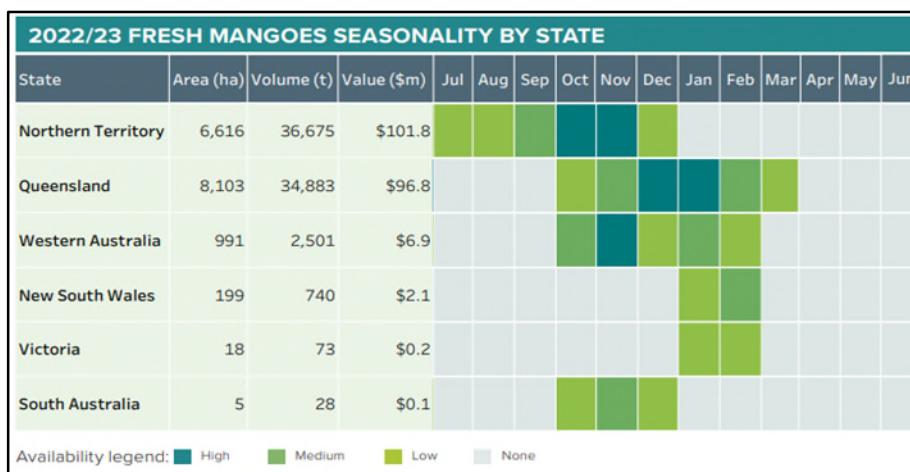


Figure 1. Australian fresh mango availability by month and production volume in each state (2022-23)

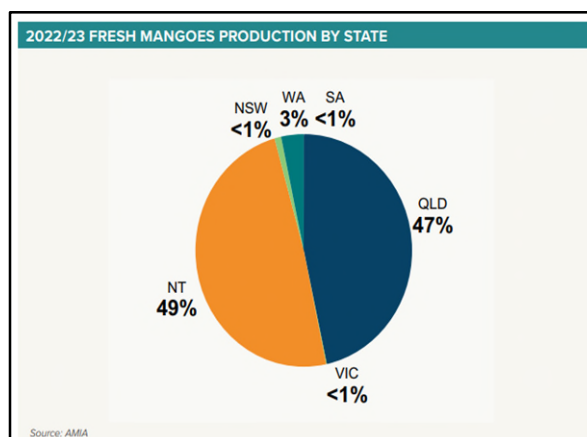
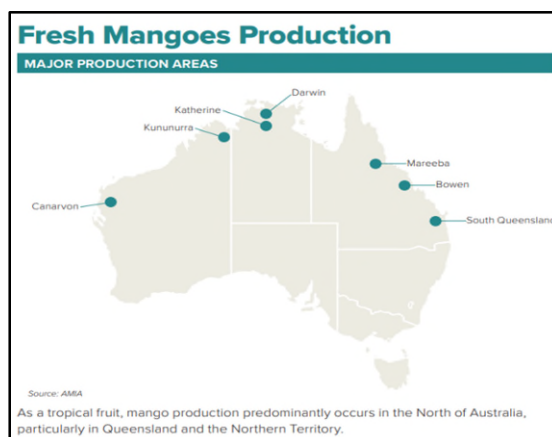


Figure 2. Commercial fresh mango production locations and their percentage of the national crop (2022-23)

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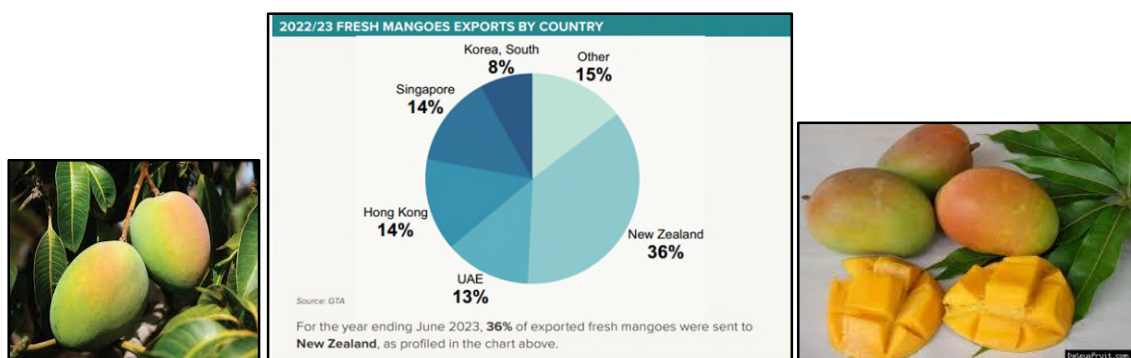


Figure 3. Australian fresh mango exports by country (2022-23)

Critical Temperatures and Growth Phases.

The Mango, once established has four distinct growth stages, as detailed by many researchers including Meurant et al., (1999). Air temperature and rainfall influence both the vegetative and phenological phases in mango and are two of the most important factors determining suitability of an area's climate for mango production, as reviewed and detailed by Makhmale, et al., (2016). The four annual growth stages of an established Mango tree are the vegetative, flowering, pollination and fruit set, and the fruit development stage.

Vegetative growth

In Australia, the mango tree usually has between one and four separate vegetative flushes during the year. In more mature fruiting trees, they are synchronised into fairly uniform flushes, and growth generally stops between each flush. According to Makhmale, et al., (2016) vegetative growth in mangoes coincides with a period in which the mean monthly temperature exceeds 15°C. This is backed up by controlled temperature studies carried out by Issarakraisila et al., (1989) in Australia, which revealed that mango shoot growth ceases when the mean daily temperature drops below 15 °C. Makhmale, et al., (2016) goes on to state that world-wide analysis shows that mango producing areas are distributed above and below the equator in latitudes where minimum temperature of the coldest month ranges from 6-22°C. Each vegetative growth flush starts from the terminal or axillary buds and develops into an elongation of the growing tip. Initially new leaves are often red or deep purple and change to green as they expand, harden and mature. The length of each growth flush is determined by individual tree vigour, crop load and temperature. The number of vegetative flushes also varies with variety, temperature and tree health.

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The most important growth flush is in summer after harvest, also referred to as the postharvest flush, which in Queensland occurs between January and April according to Meurant et al., (1999). The uniformity of the summer flush on individual branches and whole trees in a commercial crop is particularly important as this means that most of the terminals are of similar age and are ready to flower at the same time in the following season, so maximising crop uniformity (Meurant et al., 1999).



Figure 4. Mango vegetative growth flush images, with shoot and leaf expansion left, and young coloured leaves centre and right.

In bearing and vegetative mango trees, scorching of leaves and the dying of twigs are the main symptoms of heat stroke, as reported by Chawla et al., (2011).

The optimal temperature for growth of mango has been reported to be 23.8 - 29.4°C according to Nath et al., (2019), while Mukherjee (1953) determined the ideal temperature range for mango cultivation to be 24 – 30°C.

The estimated base temperature for vegetative growth across a number of Australian commercial mango cultivars examined by Whiley et al., (1989) was determined to be 15°C.

Laxman et al., (2016) in the chapter on mango in *Abiotic Stress Physiology of Horticultural Crops*, state that a temperature of 40°C is lethal to young (vegetative) Mango seedlings.

Optimal temperature for vegetative growth is >23°C & <30°C

The Critical Temperature Threshold for vegetative growth is ≥15°C & <38°C

Flowering

Temperature is a critical environmental stimulant of mango flowering, and the positive effect of cool temperatures is independent of daylength (Nunez-Elisea and Davenport, 1995). These researchers also state that floral initiation in mango is the result of complex interactions between shoot developmental stage and the prevailing environmental conditions. According to Clonan et al., (2021), there are three critical ingredients that underpin flower induction, viz. mature leaves, active growth and inductive temperatures during early stages of shoot development.

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Most mango varieties in Australia flower once a year during winter and early spring. Flower initiation is triggered during the cool dormant period by cool night temperatures and dry conditions. Núñez-Elisea and Davenport (1995) and Whiley (1997) investigated the effects of temperature and floral response in mango, establishing a general understanding that flowering in mango is initiated by cool temperatures, typically around 15°C and inhibited by temperatures, above 20°C.

In the Northern Territory, floral induction occurs when trees are exposed to cooler night-time temperatures that occur solely in the Dry Season (typically May to July). This season is also marked by a large difference between daily maximum and minimum temperatures. For example, the mean minimum for June in Katherine is 14.2°C and mean maximum is 30.1°C. To capitalise on this short mango induction window, commercial farmers use paclobutrazol (synthetic plant growth regulator) to reduce vegetative growth and potassium nitrate to promote flowering during inductive conditions. These management interventions act to enhance flowering by increasing flowering intensity, but cool temperatures are still required for floral induction to occur in the first instance (Blaikie et al., 2004; Whiley, 1993).

Terminal vegetative buds from the most recent mature shoots turn into floral buds shortly before flowering begins. Flower emergence continues for four to six weeks, and the intensity of flowering is influenced by the age of the terminals, the season and tree health. Temperature of the growing region and altitude influence the timing of flowering.

Flowering is earliest in the Northern Territory plantations, followed by trees along the northern coastal areas of Queensland. Trees in the Dry Tropics (Burdekin, Bowen) region flower in early July, followed by the Atherton Tableland, then Central Queensland and Bundaberg/Childers in September, and the drier areas of the Sunshine Coast in late September/October (Meurant et al., (1999).

Both the timing and intensity of flowering determine the trees potential crop load. In Kensington Pride, inconsistencies in flowering and fruit set are major limitations to production (Leonardi et al., 1999). The Australian mango industry provides a good example of how a variety preferred by consumers (Kensington Pride (**KP**)) may be less suited to some growing areas, but is still grown. The commercial production of KP in Northern Australia is challenged by a major flowering problem (Chapman, 1999). In the hotter tropical regions of North Queensland and the Northern Territory, mild winter temperatures during floral induction often lead to shoot growth at the expense of flowering, resulting in a low percentage of flowers and reduced yield. Kensington Pride is known to be excessively vigorous, favouring vegetative growth at the expense of flowering according to Bally, et al., (1999). Meurant et al., (1999) state that cool overnight minimum temperatures between 10°C and 12°C promote flower initiation, while Nunez-Elisea & Davenport (1994) and Whiley et al., (1989) demonstrated floral induction in potted mangos of various varieties, occurred at minimum (overnight) temperatures of 15°C.

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Issarakraisila et al. (1994) found that 'Kensington' trees produced abnormal flowers with shortened styles, smaller-sized ovaries and black anthers when the daily mean temperature of the orchard was below 15°C. These same researchers also concluded that development of 'Kensington' inflorescences only occurs when minimum temperatures are above 12-15°C. Minimum temperatures of 18 °C or less are considered to be favourable for the induction of flowering in mango according to Davenport and Nunez-Elisea, (1997). Clonan et al., (2021) determined that the cultivars Calypso®, Kensington Pride, and NMBP 1201 were found to be the least sensitive to high inhibitory temperatures, and also had the shortest delay between vegetative and subsequent floral growth. This means that these cultivars are better able to flower under high temperature tropical or changing climate conditions. In the Darwin mango production region in some years, flowering is limited by the number of days with minimum temperatures below 18°C and maximum temperatures above 32°C, as detailed in a NT Government mango industry analysis report published in June 2020.⁵

In the dry tropical regions, water stressing the trees for two or three months before flowering also improves floral induction by minimising late summer (vegetative) shoot growth. This crop management technique of holding-off irrigation (to induce water stress), in a dry climate ensures that terminal buds are at least three months old, so mature enough to produce flowers (Meurant et al.,1999).



Figure 5. Mango flower panicle.

Optimal minimum temperature for flower induction is $\geq 10^{\circ}\text{C}$ & $\leq 12^{\circ}\text{C}$

The Critical Temperature Threshold for flower induction is $\leq 18^{\circ}\text{C}$

Optimal temperature for flower development is $> 15^{\circ}\text{C}$ & $\leq 32^{\circ}\text{C}$

The Critical Temperature Threshold for flower development is $> 12^{\circ}\text{C}$ & $\leq 32^{\circ}\text{C}$

⁵ [Mango climate Impacts in Darwin | Earth Systems and Climate Change Hub \(nspclimate.com.au\)](https://nspclimate.com.au)

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Pollination and fruit set.

Pollinated mango flowers initially set many small pea sized fruit on each flower panicle, but the tree naturally sheds most of them, leaving on average less than one fruit per terminal by harvest time (Meurant et al., 1999). Any environmental stress will increase the number of young fruits dropped, as the tree balances its fruit load according to the prevailing growing conditions. Poor initial fruit set is usually due to poor pollination. Low day/night temperatures have a significant effect on the pollen characteristics and floral morphology of mango, as reported by Sukhvibul et al., (1999). Pollen viability is affected by night temperatures below 15°C and Issarakraisila and Considine (1994) found that exposure to temperatures below 15°C for 12 hours reduced pollen viability of 'Kensington' mango. Varieties vary in their sensitivity to cold as detailed by Sukhvibul et al., (1999), but flowers that open when night temperatures fall below 10°C are unlikely to set fruit (Meurant et al., 1999). Although low temperatures promote strong flowering in mangoes as detailed in the above section, fruit often fails to set because of low pollen viability or embryo death in the early stages of fruit development if temperatures are too low (Patel-Gaurang, 2015) & Meurant, et al., (1999). This is more common in the polyembryonic group of varieties, which includes Kensington Pride. Cool temperatures adversely affect both pollen germination and pollen tube growth, which is completely inhibited at temperatures below 15°C (Issarakraisila and Considine, 1994). Pollen germination and viability are highly dependent on temperature.

Warm temperatures tend to preserve pollen viability, but cool temperature conditions can negatively impact pollen development and growth of the pollen tube growth to the ovule (Davenport, 2009)

Temperatures <16°C cause flower deformation, delayed pollen germination, pollen tube growth and induce ovule abortion according to Ramirez & Davenport (2016). The cultivar 'Kensington' displayed high pollen viability (85%) when grown in 30°C day and 20°C night temperatures (Sukhvibul et al., 1999). Other Australian research found that the optimum temperature in 'Kensington' was between 15° and 33°C (Issarakraisila and Considine, 1994). The optimum temperature for pollen germination and, ovule penetration in the cultivar 'Kent' in Israel was 30°C according to Dag et al., (2000). While De Wet et al., (1986) found the most effective temperature for the pollination of the mango cultivar Hayden was between 25°C and 30°C.

In cooler subtropical mango production regions, lower overnight temperatures promote flower induction and ensure a high percentage of flowering terminals. However, if minimum temperatures regularly fall below 10°C, pollen viability as well as the number of hermaphrodite flowers on polyembryonic varieties (e.g. Kensington Pride) is greatly reduced. This results in poor fruit set as each inflorescence bears several thousand male and hermaphrodite (bisexual) flowers.

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In unusually cool seasons, a low number of hermaphrodite flowers results in poor yield. The flowers of most mango varieties are self-compatible, that is they can be fertilised by their own pollen, hence the importance of the number of hermaphrodite flowers as detailed by Sukhvibul et al., (1999).

Mango flowers are pollinated by wind and insects (Meurant et al., 1999) with the most common insect pollinators being wasps, bees and large flies (Anderson et al., (1982), Ramírez & Davenport, (2016)).

Tree nutrition plays a very important role in successful fruit set, with adequate levels of boron being essential for pollination and normal flower development.



Figure 6. Left, a fly standing on a pea sized mango, while feeding from and pollinating an adjacent flower. Right, a developing mango and open flower on the same panicle.

Optimal temperature for pollination and fruit set $>20^{\circ}\text{C}$ & $\leq 33^{\circ}\text{C}$

The Critical Temperature Threshold for pollination and fruit set is $>16^{\circ}\text{C}$ & $\leq 33^{\circ}\text{C}$

Fruit development

Mango fruit takes four to five months to mature (80 to 150 days after first flower bud burst), depending on the growing district (Meurant et al., 1999). Fruit growth and expansion is faster in the hotter regions of the Northern Territory and Nth Queensland than in the cooler subtropical, southern growing regions.

Research has demonstrated and confirmed that fruit maturity can be predicted by using a heat sum technique, highlighting the importance of temperature as a key determinant of fruit yield and timing. This fruit development estimate is based on accumulated growing degree days (GDD) beginning at the early stage of flowering. Calculating the Mango GDD total relies on the summing of “growth potential” across days. The average of daily minimum and maximum temperature minus a ‘minimum base temperature’ (T_b), which assumes fruit development halts below this temperature, and can involve a penalty for temperatures above a ‘maximum base temperature’ (T_B), which assumes fruit development slows at high temperatures. This established technique was found to provide a useful fruit maturity prediction indicator by Amaral et al., (2023).

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Research Team – David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF Qld & Peter Deuter, Horticultural Consultant, PLD Horticulture



These Australian researchers reviewed and analysed mango maturity times in multiple Australian locations and seasons and determined that a lower base temperature of 12°C, and an upper fruit development temperature of 32°C could effectively be used to predict mango maturity, beginning from the “asparagus” stage of flowering. These researchers determined that Growing Degree Day sum totals of 1600, 1728, 1740 and 2185, for the cultivars Kensington Pride, Calypso®, Honey Gold®, and Keitt, respectively, were useful predictors of fruit maturity.



Figure 7. Developing mango fruit at left, while on the right the several flower racemes are visible with a single fruit developing on each.

Makhmale et al., (2016) state that high temperatures cause physiological changes within mango fruit and that, “spongy tissue” is induced by high internal fruit temperatures causing severe tissue breakdown. Their research determined that low rates of fruit transpiration and high rates of respiration (when both artificially and naturally induced) resulted in the development of spongy fruit tissue, leading to fruit breakdown. The authors did not detail the exact temperatures, but did state that maintaining good soil moisture was also essential when trying to protect fruit from heat stress. Rajan (2012) states that the optimal maximum temperature for mango growth is 27°C – 35°C.

Fruit position in the tree canopy alters its daily exposure to high temperatures and intense light conditions. This can lead to metabolic and physiological disorders that affect both fruit yield and quality, as detailed by many researchers including Léchaudel et al., (2013). This research team examined the effect of temperature and light under field conditions by comparing well-exposed and shaded fruit. Results showed the fruit surface temperature was 1°C higher during the day on the shaded side of well-exposed fruit than it was on the surface of shaded fruit, and about 2 to 3°C higher on the sunny side of well-exposed fruit than on the surface of shaded fruit. This field work determined that the difference in fruit surface temperature could reach up to 7°C at midday on sunny days.

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Laxman et al., (2016), specialist authors of the Mango Chapter in the [Abiotic Stress Physiology of Horticultural Crops](#) textbook, state that abundant soil moisture and moderately hot temperatures (30–33°C) during fruit development are best for commercial mango production.

Optimal temperature for fruit development >27°C & ≤33°C

The Critical Temperature Threshold for fruit development is >12°C & ≤35°C

Future climate implications – crop performance and yield.

The Earth Systems and Climate Change Hub (2020), Mango Industry Northern Australian Workshop Fact Sheet Series, details the expected impact of climate change on mango production in the Northern Territory. The documents state that 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 maximum and minimum temperatures and the frequency of these events will affect flowering and fruit production in northern Australian mango production regions.

Roberts (2021) reflects that over the last decade in far northern Australia, commercial mangoes (Kensington Pride and R2E2) have been flowering later, and at a lower rate, than usual. This article goes on to state that as underlying temperatures increase due to climate change, and hotter weather arrives earlier in the year, the expectation is that the mango season will start earlier.

While this is true, the mango cropping and production cycle is also highly dependent on cooler minimum temperatures in winter months to induce flowering – and these too are arriving later and lasting for shorter periods in northern Australia. The increase in average temperatures in northern Australia and across the world, especially in some equatorial locations, means that summer is starting earlier, and winter is arriving later. Research detailed in the flower induction and flowering growth stage section above, demonstrates how flower number and development is induced by low temperatures at night and can be inhibited by high temperatures during the day.

This work shows that if cool durations are not long enough, trees can produce vegetative growth instead of flower panicles. Roberts (2021) stated that in the 2020 production year, flowering did not occur until August in the northwest of Australia. Typically, flower panicles appear on mango trees across tropical and subtropical Australia in late May and June each year.

Impacts from such climate driven changes are significant, as not only are tree yields decreasing, but mango fruit production costs are also rising.

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According to Roberts (2021) many northern Australian farmers are now questioning the economic viability of their mango orchards.

Australian research work and the mango industry focussed Fact Sheets produced by the Earth Systems and Climate Change Hub (2020), highlights the fact that the average temperature in the Northern Territory has increased by around 1°C over the past 100 years, with the number of extreme heat days also increasing.

As temperatures get warmer, important temperature thresholds for mango production will be crossed, including the threshold for flower induction. The Earth Systems and Climate Change Hub (2020) industry summary states that both minimum and maximum temperatures are projected to limit mango flower induction, but increases in maximum temperatures will be the most limiting.

Currently the Katherine production region (which includes the Katherine, Mataranka and Pine Creek commercial farms) averages around 74 days in the May to August period, with maximum temperatures below 32°C, and this could decline to just 7 days under the high emissions scenario. May and August are the most problematic months at this growing location, as autumn remains hotter for longer, and late winter temperatures increase. The months of May and August are projected to have fewer than five inductive days by 2090, meaning that flower induction may be restricted to, and concentrated in, June and July in the Katherine region.

In the high emissions future, all cultivars except Calypso® and Kensington Pride are expected to become vulnerable within the next decade⁶. By the end of the century, all cultivars could experience a 71% decrease in the number of inductive days between May and August, when compared to the current average.

Growers will need to consider on-farm adaptation actions to reduce the impacts of climate change and maintain the ongoing sustainability of mango production in the Northern Territory. This could include better canopy management, shifting to new cultivars (some of which have been identified), employing orchard cooling practices or relocating orchards.

As extreme heat becomes more prevalent, the health and safety of farm works will continue to present challenges during the harvest period. Night time harvests are already being carried out in some Northern Territory plantations.

Orchards positioned further south will be less vulnerable to these projected temperature changes, but may well see their fruiting and harvest season become earlier. Current production locations across Australia will be impacted differently due to their unique underlying historic climatic conditions.

⁶ https://nеспclimate.com.au/wp-content/uploads/2019/05/A4-2p-mango-IA-results-factsheet-Katherine_web.pdf

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Increasing maximum temperatures, warmer minimums, heatwaves, increased storm frequency, pollinator numbers and altered rainfall patterns, could all impact production viability, yield, quality and timing throughout Australia.

Queensland is already experiencing the impacts of climate change:

The Climate Change in Australia website, CSIRO and Bureau of Meteorology, Climate Change in Australia website (<http://www.climatechangeinaustralia.gov.au/>), cited [January 2023] contains the following statements⁷.

All of Queensland has warmed since 1910.

Average annual temperature has increased by 1.5°C since 1910.

Under a high emissions scenario (RCP8.5), by mid-century, Queensland can expect an average annual temperature increase of around 1.3 - 2.5°C (central **estimate of 1.9°C**).

These statements about Queensland's changing climate refer to annual average temperature increases (1.3 – 2.5°C), so they smooth out the usual fluctuations in daily, weekly and monthly temperature at any location. The State of the Climate 2022 Report⁸, Future Climate section states, "new research in Australia and around the world, together with the IPCC's Sixth Assessment Report, enhance understanding of the state of Australia's future climate. In coming decades, Australia is projected to experience continued warming, with more extremely hot days and fewer extremely cool days."

This has serious implications for horticultural production in Queensland and Australia. Higher temperatures will impact existing crops, production timing and locations. While some production may be able, or forced, to move to a new location, land suitability, water availability, workforce and supporting infrastructure (e.g. road networks and power availability) pose significant constraints.

⁷ <https://www.climatechangeinaustralia.gov.au/en/changing-climate/state-climate-statements/queensland/>

⁸ <https://www.csiro.au/en/research/environmental-impacts/climate-change/State-of-the-Climate>

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Mango -Critical Temperatures Thresholds (from published research).

Table 1 Mango critical temperatures by growth stage.

Growth Stage	Critical Temperature °C	
	Lower	Upper
Vegetative	≥15	<38
Flower Induction	>10	≤18
Flowering	>15	≤32
Pollination and Fruit Set	>16	<33
Fruit development & fill	>12	<35

It is important to realise that to achieve a mean monthly maximum of 30°C (for example), there will be a spread of cooler and hotter days. In a biological system, plant stress caused by several days in a row above a critical temperature, tends to tip the system into decline.

To simulate the effects of high temperatures on consecutive days, we have used the critical temperature +2°C for 3 days and applied this to each crops' threshold. So, for Mango at the flowering stage, the literature indicates the Critical Temperature Threshold is 32°C maximum temperature. To assess the effects of high temperatures, we have chosen **34°C as the Critical Temperature Threshold** for the **flowering** stage. This temperature is also just one degree below the upper CTT for fruit development and fill (33°C + 2°C) 35°C.

Commodity production data.

Australia produced around \$208 million dollars' worth of mangoes in the 2022-23 season from an area of around 15,903 ha. The majority of fruit is sold into the fresh market (82%) with the balance going to the food service sector 18%⁹. Mango is a tropical fruit, with most production occurring in Northern Australia dominated by the Northern Territory (49%) and Queensland (47%). Northern Western Australia (Kununarra and Katherine) accounts for around 3% of the national crop volume.

In the Northern Territory commercial mango plantations are situated around Darwin and Katherine, while in Queensland, production is spread from Cooktown in the north, west to Georgetown. The Atherton Tableland, Burdekin and Bowen are major production locations with fruit also being grown in the drier parts of south Queensland, such as Bundaberg, Gympie and the Sunshine Coast. There used to be a number of small commercial mango producers in the Esk/Gatton region. This is no longer the case, as this location produces fruit late in the summer season so attains lower prices than they once did. Increasing fruit volume from large, earlier fruiting northern production orchards that have developed in the last 20 years has now made this South-East Queensland location uneconomic.

⁹ <https://www.horticulture.com.au/contentassets/a36fdfa2427d4ad284c426663b06f15c/hort-stats-fruit-22-23.pdf>

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Major Australian mango varieties.

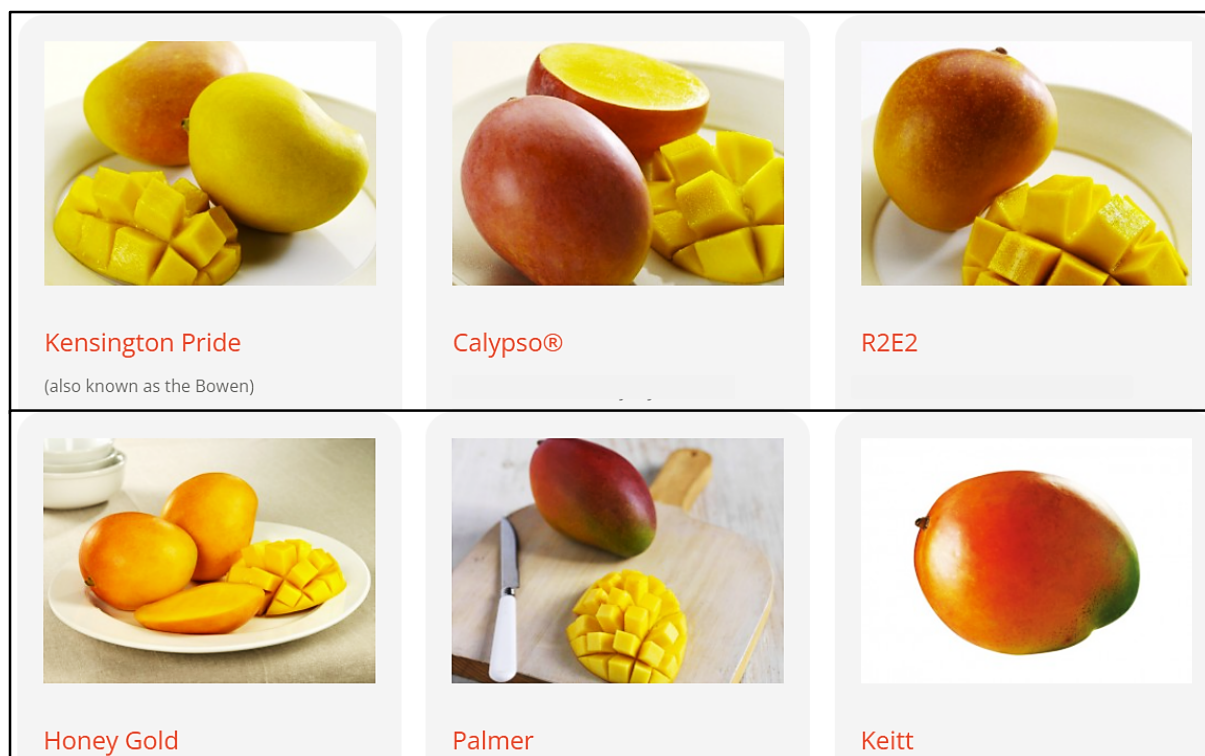


Figure 8. Major Australian commercial mango varieties. Source, Australian Mangoes, accessed November 2024¹⁰.

Mango's most critical growth stage.

Both the growth stage and Critical Temperature Threshold analysis section above, along with Australian and international mango industry production research and experience, highlights that mango yield potential is highly dependent on effective flower induction and pollination. This is the most crucial stage impacting yield potential in this tropical plants annual growth cycle. Being exposed to a specific minimum temperature range (10-18°C) prior to spring growth determines the plant's ability to produce flower buds and set fruit. Buds exposed to high maximum temperatures ($\geq 32^{\circ}\text{C}$) during early bud growth are less likely to develop floral panicles (Clonan et al., 2021).

¹⁰ <https://mangoes.net.au/about-australian-mangoes/australian-mango-varieties/>

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Industry specific research and Fact Sheets produced by Australia's Earth Systems and Climate Change Hub¹¹ highlight this issue that is currently challenging in some years and will increasingly impact production in Australia's more northern production locations as both minimum and maximum temperatures continue to slowly rise.

One of the Fact Sheets produced by Australia's Earth Systems and Climate Change Hub details that in Katherine for example, currently averages around 74 days in the May to August period with maximum temperatures below 32°C. This research showed that by the end of the century, this could well decline to thirty-two days under the lower emissions scenario (RCP4.5) and just seven days under the high emissions (RCP8.5) scenario. The most vulnerable mango development months are May and August, projected (by the above Fact Sheet) to have fewer than five inductive days by 2090. The main flower induction period in Katherine may be restricted to the cooler months of June and July.

Mango production locations

This map highlights the most northern, Northern Territory and Western Australian production locations. This interactive mango industry map is available at; <https://www.industry.mangoes.net.au/resources/resources-library/national-mango-tree-crop-map-dashboard/>

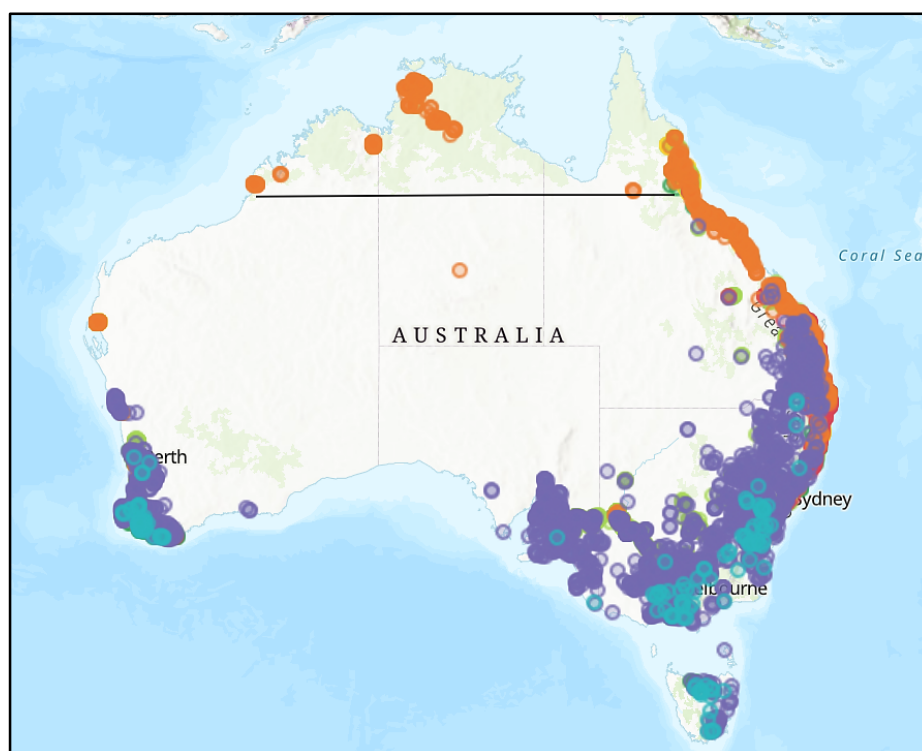


Figure 9. Commercial mango crop locations in Australia (Orange dots) with "northern production" above the line

¹¹ <https://nespclimate.com.au/?s=mango+fact+sheet>

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Production regions, seasons and critical temperature thresholds

Critical Temperature Thresholds - Climate Monitor** analysis/verification of annual historical temperatures at selected production areas.

I. Queensland

a) Bowen Queensland (November harvest).

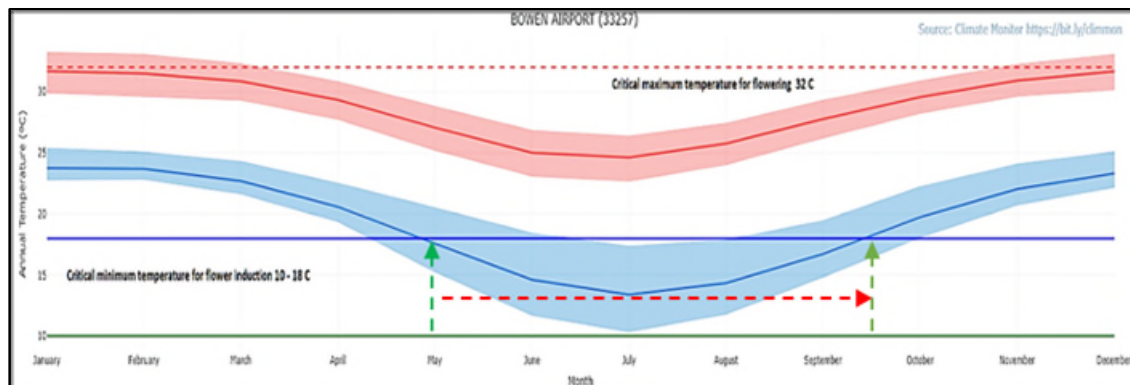


Figure 10. Climate Monitor monthly historical maximum (red) and minimum (blue) temperatures and mean temperatures (solid lines within each coloured band), at Bowen, with Mango tree critical flower induction temperatures overlaid. Green arrows indicate the start and end months when in many years to date (but not all) Bowen minimum temperatures fall within the flower induction range. The red dotted arrow indicates the length of the current flower induction period.

Note: The monthly temperature graph shows the 10th to 90th percentile, i.e., you expect the temperature to be in this range for 8 out of 10 years.

** Climate Monitor¹² is a Web Tool which allows the user to analyse and graph minimum and maximum temperature and rainfall for all available years, calculate thermal time (chill and heat units) and be able to retrieve, analyse and graph temperature thresholds (for any chosen Australian location).

Mangoes in the Bowen region receive cool, flower inductive minimum temperatures that favour flower bud production and flower development from May through until September in most years. Maximum daily temperatures are also well below 32°C at this time of year further enhancing flowering and pollination. Young fruit develop, fill and colour up as the warmer late spring and early summer temperatures drive fruit growth. Importantly minimum temperatures rarely drop below 10°C at this location. When mango trees would be flowering, this temperature is the lower mango CTT for the flowering stage. Research highlighted above determined that a minimum temperature of 14°C maximises mango flower production. The mean monthly minimum temperature in Bowen in June, July and August is 14.3°C, 13.4°C and 14.5°C respectively, maximising flower development, so enhancing yield potential at this prime Qld production location.

¹² <https://grf-smartfarm.daf.qld.gov.au/shiny/apps/climatemon/>

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When viewing Figure 10 above, remember that both the hottest and coldest 10% of years are not included in this graph. Both maximum and minimum temperatures at this growing location during the flower induction, pollination and the fruit development and fill stage, favour quality fruit production and high yields.

The graphic below shows the highest and lowest maximum temperature (upper and lower) for each month in 2018 ▲ and the average ● for each month in 2018 which was a “hot” year at Bowen. Minimum temperatures are indicated in the same manner by the blue symbols. This 2018 temperature information is overlaid onto Figure 10 above.

This analysis of a “hot year” at Bowen demonstrates how well suited to mango production this coastal location is. Mean monthly maximums and minimums in the critical flower induction, pollination and fruit set months of June, July, August and even the “hot” September in 2018 were still within the mango trees acceptable CTT range. The warmer maximums and minimums in September and October would have advanced fruit development and brought on an early harvest in that year.

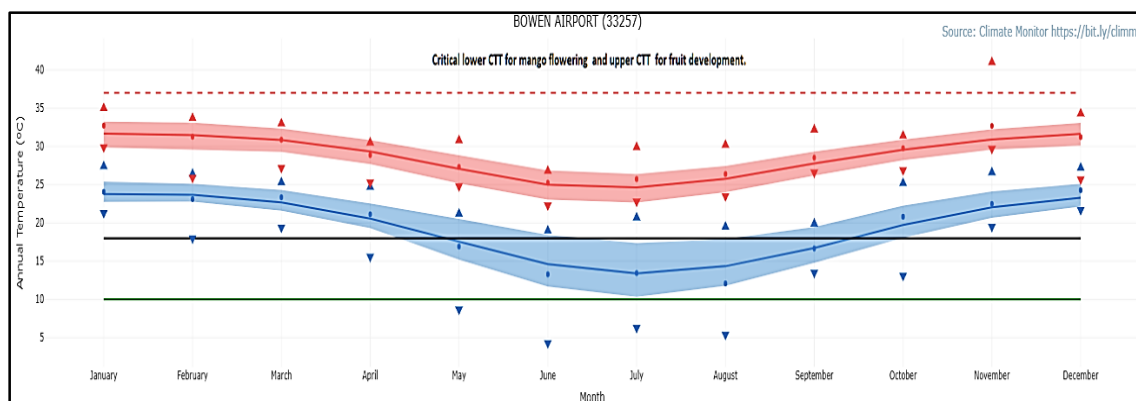


Figure 11. Highest and lowest maximum (red triangle) and minimum temperature (blue triangle) for each month in 2018 and the monthly average for that month (red and blue dots), overlaid on Figure 10 above.

Daily temperatures in the Bowen region in all years from 1957 – 2024 have been within the optimum mango fruit growth and development range (12 to 35°C) for 113 days (92%) of each season from August to November, based on BoM temperature data from 1957 to 2024, shown below.

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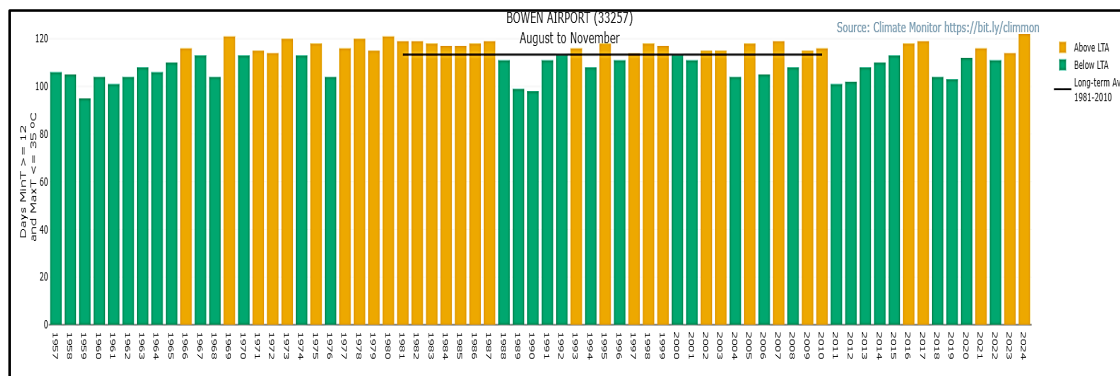


Figure 12. Number of days in each year (1957-2024) from August to November at Bowen that had a minimum of at least 12°C and a maximum of no more than 35°C.

Temperatures at Bowen during the mango fruit growth and development phase are close to ideal, with cool winter minimums followed by warm maximums that sit within the plants ideal fruit fill and development range. Harvest season usually commences in early November for the pre-Christmas premium price market window.

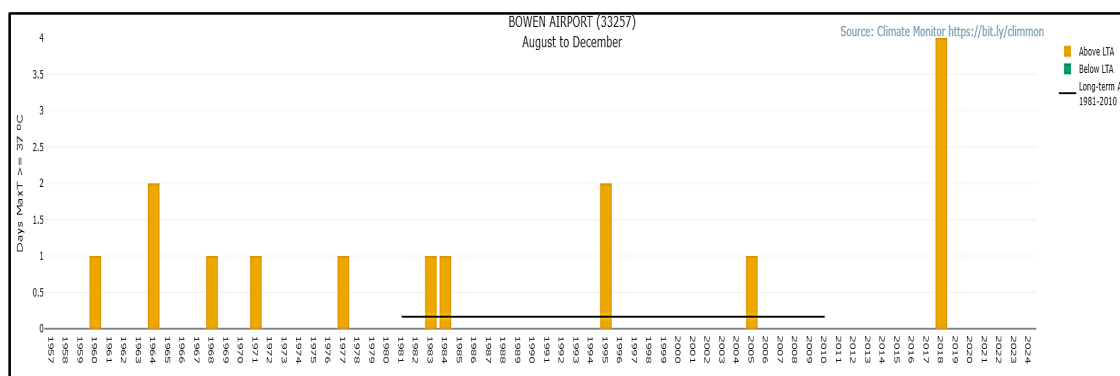


Figure 13. Number of days in each year since 1957 during August – November (inclusive) that Bowen has reached a maximum of at least 37°C.

This Climate Monitor analysis compares the number of days each year when the maximum temperature equalled or exceeded 37°C at Bowen, which is mangoes upper CTT during the fruit filling growth stage. The graph above shows that 2018 was a “hot” year at Bowen as highlighted in Figure 13 above, with a maximum temperature of 37°C or above, occurring on 4 days during the start of August and the end of November.

The historic temperature and mango CTT analysis above highlights that the potential for high quality mango production at Bowen is high. This explains the reason the industry has continued to thrive and develop in the Bowen region.

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Future temperature insight.

As underlying temperatures continue to rise¹³ at Bowen, both the projected annual mean minimum and mean maximum temperatures will increase by around 1.5°C by the 2050's, based on My Climate View data. These projected increases still sit well within the Mango plants physiological Critical Temperature Thresholds. Mango production in Bowen will be only slightly affected in some years with projected minimum temperatures during the plants flower induction period, which will result in a slight delay the start of the flower induction period.

The Representative Concentration Pathways scenario RCP8.5 (Schwalm, et al., 2020), has been chosen in this study to represent a future climate (2050's average), in an effort to understand the impacts on each of the current production locations.

a) Bowen

Projected future (2050's) and current climate data for Bowen.

Table 2. Projected future temperature comparison for Bowen under high emissions scenario RCP 8.5, where cumulative global emissions are currently tracking¹⁴.

Time Period	Annual Average T Max °C	Annual Average T Min °C	Annual Heat Risk Days. Based on the crop specific upper CTT T Max ≥37°C	Annual Cold Induction Days. Based on the crop specific lower CTT T Min ≤14°C Note 14°C is mid-range of 10 to 18°C needed for flower induction.
1964-1993 Past Average	28.5	19.9	0	40
1994 -2023 Recent Average	28.8	20.2	0	42
2030's High Emissions - Future Average	29.6	21.0	1	30
2050's High Emissions - Future Average	30.3	21.7	2	25
Difference from Past Average	+1.8	+1.8	+2	-15

¹³ <http://www.bom.gov.au/state-of-the-climate/australias-changing-climate.shtml>),

¹⁴ <https://myclimateview.com.au/>

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The high emissions pathway model indicates a temperature shift, showing a 1.8°C increase in maximum temperatures and a 1.8°C increase in minimum temperatures by the 2050's. The number of days when the maximum temperature in Bowen exceeds 37°C is projected to increase from 0 to 2 days, however this is likely to occur in mid-summer after fruit has been harvested. The crop specific number of cold induction days decreases by 17 to just 25 days, when compared to the recent past.

Data source: Climate Services for Agriculture output, [My Climate View](#)

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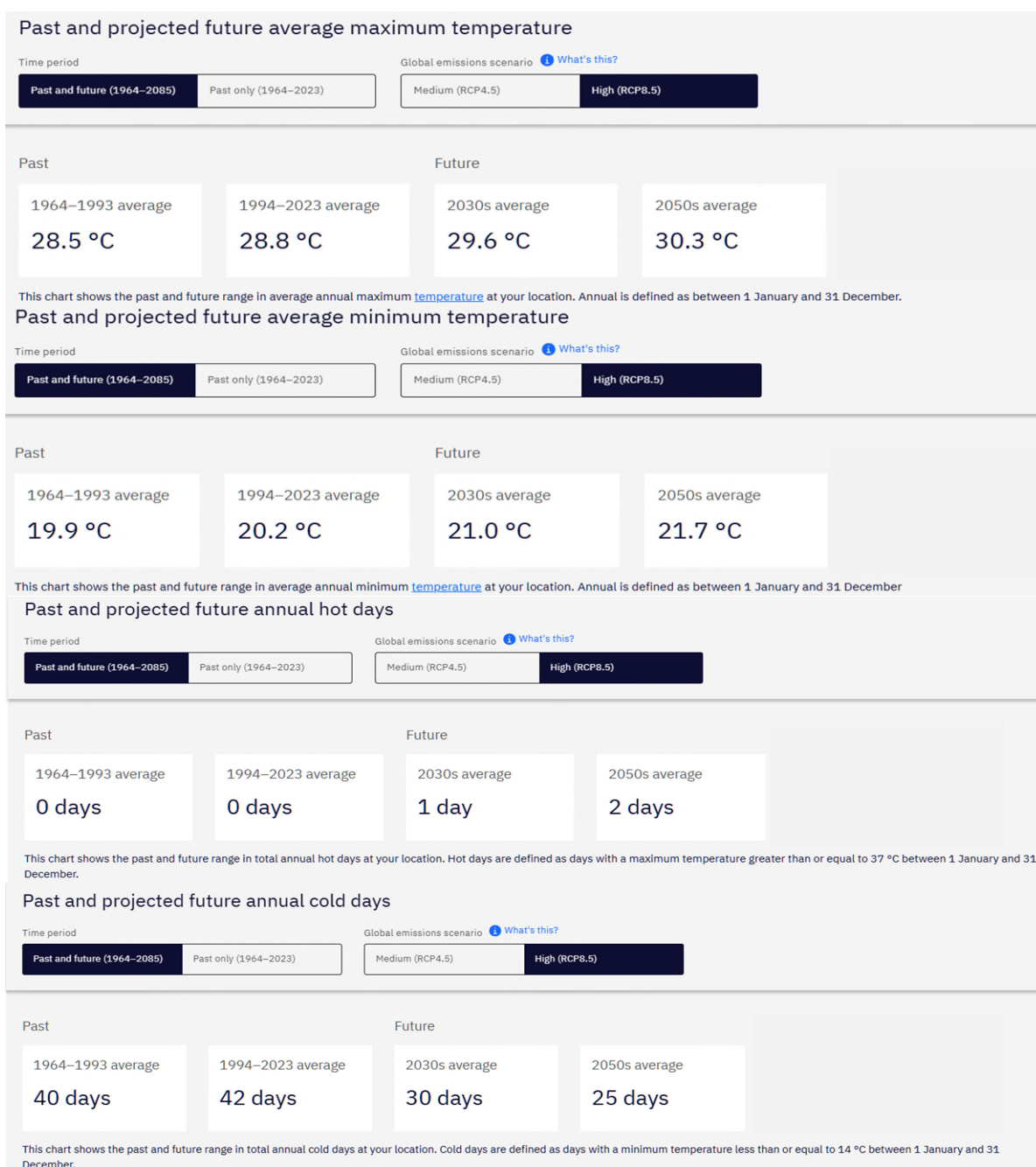


Figure 14. Projected future temperature outlook for Bowen under high emissions scenario RCP 8.5, where cumulative global emissions are currently tracking (Schwalm, et al., 2020). The graphic uses 1964 – 1993 for comparison of the 2030 to 2050 average temperature shift.

The high emissions pathway model indicates a temperature shift, showing a 1.8°C increase in average annual maximum temperatures and a 1.8°C increase in average annual minimum temperatures by the 2050's, when compared to the 1964-93 base period.

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Projected 2050's maximums and minimum temperatures both increase by 1.5° C compared to the 1994-2023 recent past averages.

The annual number of hot days at Bowen increases from 0 days to an average of 2 days $\geq 37^{\circ}\text{C}$ each year, however this is most likely to occur during mid-summer after fruit have been harvested. Crop specific cold days needed for mango flower induction 10°C to 18°C (14°C Optimum) are projected to decrease from 42 days to 25 days (Figure 14) when compared the recent past.

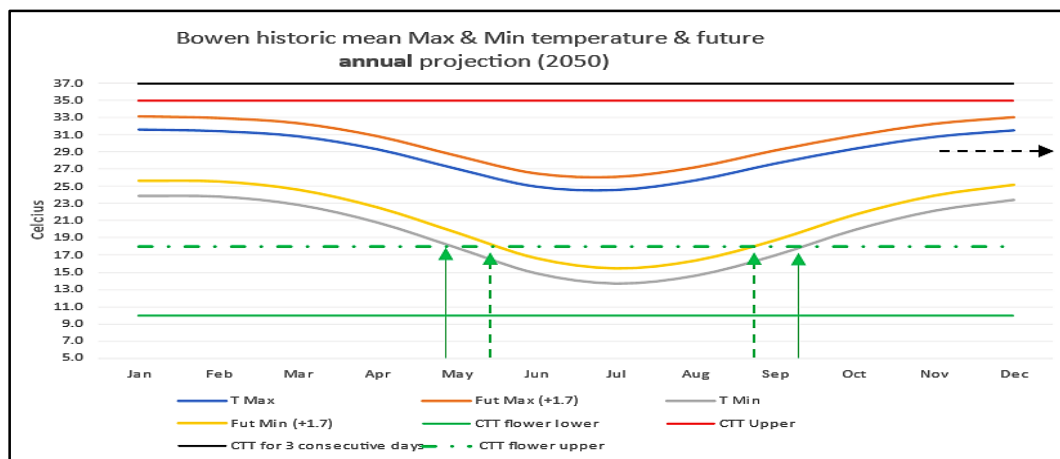


Figure 15. Current mean monthly temperatures at Bowen, mango tree upper CTT (37°C), lower flower induction CTT (10°C – 18°C) & the impact of projected future mean annual temperature shifts (2050's) on the optimum growing season. Green solid arrows and the green dotted arrows define the current and future flower bud induction and flower production window, due to warmer minimums.

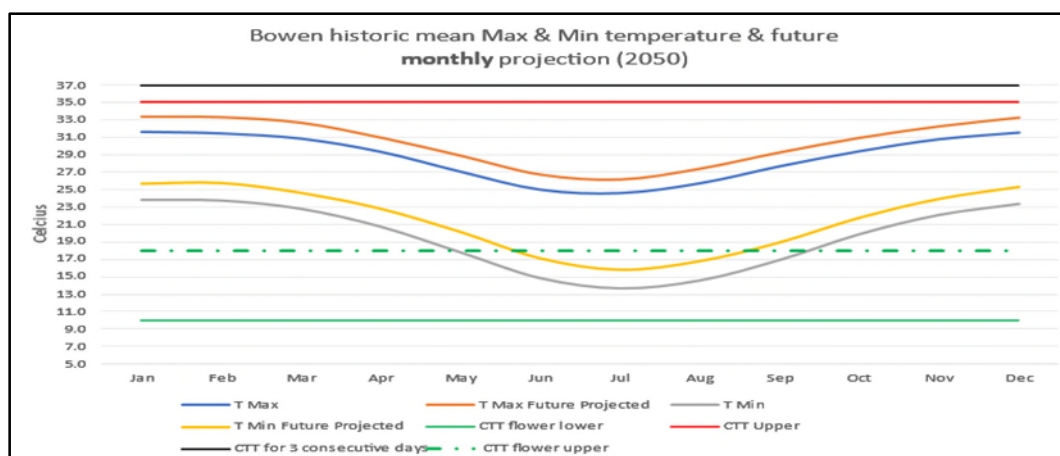


Figure 16. Current mean monthly temperatures at Bowen, mango tree upper CTT (37°C), lower flower induction CTT (10°C – 18°C) & the impact of projected future mean monthly temperature shifts (2050's) on the flower induction and flowering period. Note, the projected monthly future climate data displayed here reflects the individual monthly changes that underpin the projected annual changes in maximum and minimum temperatures. The green dotted line represents 18°C , above which mango flower induction declines. The projected 2050 changes to minimum temperature should have only a slight effect at this location.

Data source: Climate Services for Agriculture output, [My Climate View](#)

The projected future climate data used in this CTT document are sourced from the most recent (September 2024) My Climate View website (formerly CSA). The site has undergone a number of changes over the last 18 months. The data and graphics format used in each individual crop CTT document in this series of DCAP and FBRP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The location specific, high quality, historic climate information used herein, is sourced from [Climate Monitor](#), a free, publicly available DCAP (Qld Government) web-tool.

Mango Critical Temperature Thresholds

Research Team – David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF Qld & **Peter Deuter**, Horticultural Consultant, PLD Horticulture



Current maximum and minimum temperatures at Bowen during the mango plants flower induction and fruit development months of May – November, are within both the lower and upper Critical Temperature Thresholds. The projected 2050 annual mean maximum will see a 1.5°C increase, when compared to the recent past (1994-2023). This projected increase is still well below the mango plants upper CTT so there should be no impact on fruit fill and maturation. In fact, the higher daily maximum temperatures could well hasten fruit fill and development – as long as other growth inputs such as nutrition and water are adequate.

The projected 1.5°C increase in annual minimum temperatures by 2050 will, in the winter months, lead to both a slight increase in, and a delay of the arrival of overnight temperatures that are essential for flower bud induction and flower development. However as can be seen in **Error! Reference source not found.** and **Error! Reference source not found.** above, commercial mango crops will still be exposed to sufficiently cool temperatures (10-18°C) during June, July and August to achieve current flower induction levels on average in 2050. Warmer minimum temperatures in May and early September will mean in many years that these months will no longer significantly contribute to flower induction. Warmer May minimums in some years could delay “traditional” flower induction timing, slightly delaying early flower development. This should not lower flower number or potential total fruit number or yield each year but could delay pollination and fruit formation. Current harvest times may not change as both warmer daily minimums and maximums will enhance the fruit fill and maturation growth phase.

Bowen Queensland (November harvest).

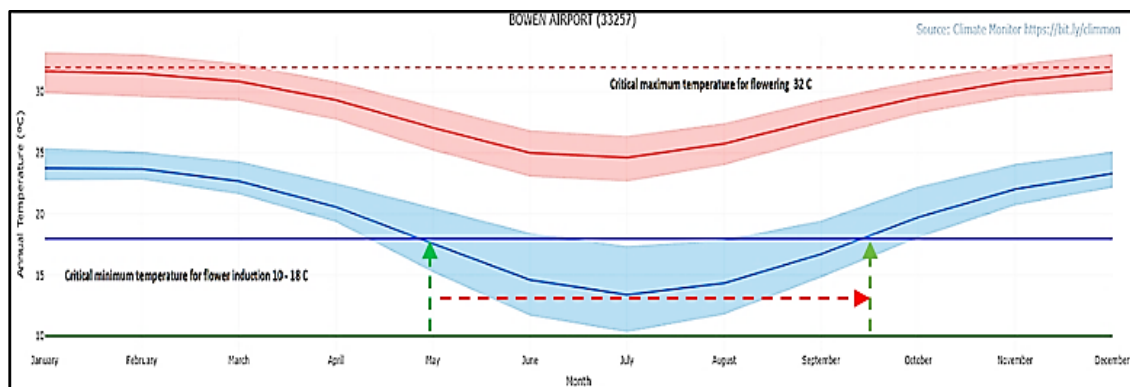


Figure 17. Climate Monitor monthly historical maximum (red) and minimum (blue) temperatures and mean temperatures (solid lines within each coloured band), at Bowen, with Mango tree critical flower induction temperatures – overlaid. Green arrows indicate the months in most years (but not all) when Bowen minimum temperatures fall within the flower induction range. The red dotted arrow indicates the length of the current flower induction period.

Note: The monthly temperature graph shows the 10th to 90th percentile, i.e., you expect the temperature to be in this range for 8 out of 10 years.

The projected future climate data used in this CTT document are sourced from the most recent (September 2024) My Climate View website (formerly CSA). The site has undergone a number of changes over the last 18 months. The data and graphics format used in each individual crop CTT document in this series of DCAP and FBRP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

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Mango Critical Temperature Thresholds

Research Team – David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF Qld & **Peter Deuter**, Horticultural Consultant, PLD Horticulture



**** Climate Monitor¹⁵** is a Web based Tool which allows the user to analyse and graph minimum and maximum temperature and rainfall for all available years, calculate thermal time (chill and heat units) and be able to retrieve, analyse and graph temperature thresholds (for any chosen Australian location).

Mangoes in the Bowen region receive cool, flower inductive minimum temperatures that favour flower bud production and flower development from May through until September in most years. Maximum daily temperatures are also well below 32°C at this time of year, so ideal for flowering and pollination. Young fruit develop, fill and colour up as the warmer late spring and early summer temperatures drive fruit growth.

Importantly minimum temperatures rarely drop below 10°C, at this location when mango trees would be flowering, this temperature is the lower mango CTT for the flowering stage. Research highlighted above determined that a minimum temperature of 14°C maximises mango flower production. The mean monthly minimum temperature in Bowen in June, July and August is 14.3°C, 13.4°C and 14.5°C respectively, maximising flower development and enhancing yield potential at this prime Qld production location. When viewing Figure 17 above, remember that both the hottest and coldest 10% of years are not included in this graph. Both maximum and minimum temperatures at this growing location during flower induction, fruit development and the fruit fill stage, favour quality fruit production and high yields.

The graphic below shows the highest and lowest maximum temperature (upper and lower) for each month in 2018 ▲ and the average ● maximum for that month in 2018 (a “hot” year at Bowen), as well as the minimums (blue symbol’s) overlaid onto Figure 17 above. This analysis of a “hot year” at Bowen demonstrates how well suited this coastal location is to mango production. Mean monthly maximums and minimums in the critical flower induction, pollination and fruit set months, June, July, August and even the “hot” September in 2018, were still within the mango trees acceptable CTT range. The warmer maximums and minimums in September and October would have advanced fruit development and brought on an early harvest in that year.

¹⁵ <https://grf-smartfarm.daf.qld.gov.au/shiny/apps/climatemon/>

The projected future climate data used in this CTT document are sourced from the most recent (September 2024) My Climate View website (formerly CSA). The site has undergone a number of changes over the last 18 months. The data and graphics format used in each individual crop CTT document in this series of DCAP and FBRP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The location specific, high quality, historic climate information used herein, is sourced from [Climate Monitor](#), a free, publicly available DCAP (Qld Government) web-tool.

Mango Critical Temperature Thresholds

Research Team – David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF Qld & Peter Deuter, Horticultural Consultant, PLD Horticulture

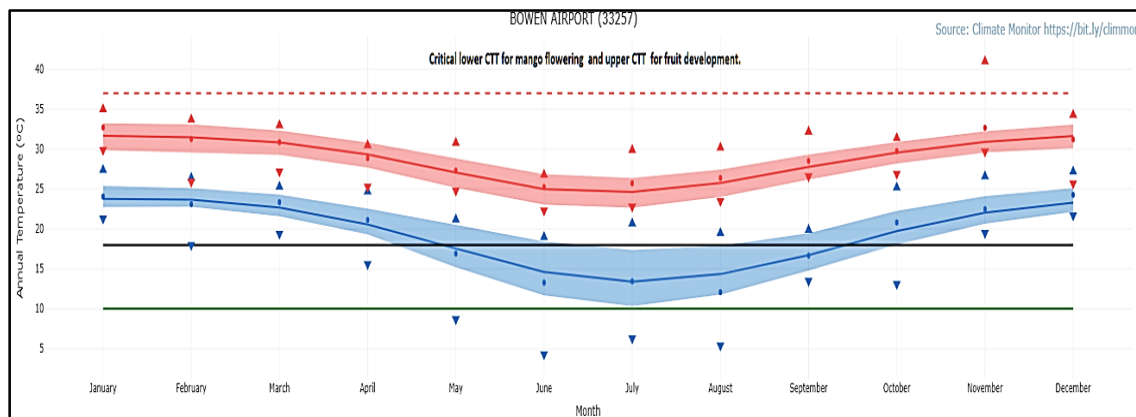


Figure 18. Highest and lowest maximum (red triangle) and minimum temperature for each month in 2018 and the monthly average for that month (red and blue dots), overlaid on Figure 17 above.

Daily temperatures in the Bowen region in all years from 1957 – 2024 have been within the optimum mango fruit growth and development range (12 to 35°C) for 113 days (92%) of each season from August to November, based on BoM temperature data from 1957 to 2023, shown below.

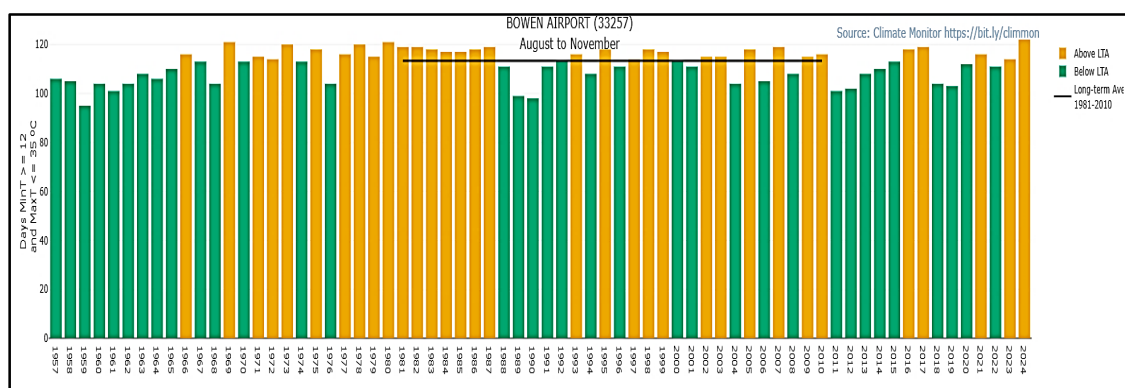


Figure 19. Number of days in each year (1957-2024) from August to November at Bowen that had a minimum of at least 12°C and a maximum of no more than 35°C.

Temperatures at Bowen during the mango tree fruit growth and development phase are close to ideal, with cool winter minimums followed by warm maximums that sit within the ideal fruit fill and development range. Harvest season usually commences in early November, ideal for the pre-Christmas premium price market window.

The projected future climate data used in this CTT document are sourced from the most recent (September 2024) My Climate View website (formerly CSA). The site has undergone a number of changes over the last 18 months. The data and graphics format used in each individual crop CTT document in this series of DCAP and FBRP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The location specific, high quality, historic climate information used herein, is sourced from [Climate Monitor](https://climate.monitor.gov.au/), a free, publicly available DCAP (Qld Government) web-tool.

Mango Critical Temperature Thresholds

Research Team – David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF Qld & Peter Deuter, Horticultural Consultant, PLD Horticulture

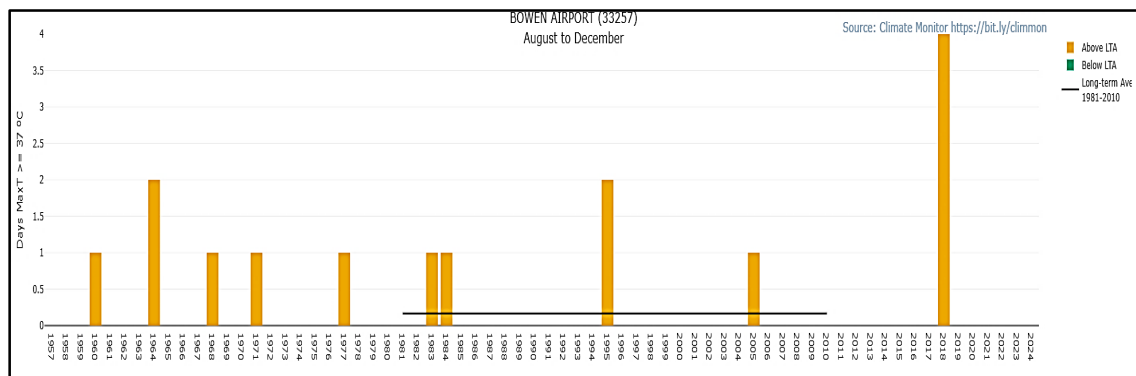


Figure 20. Number of days in each year since 1957 during August – November (inclusive) that Bowen has reached a maximum of at least 37°C.

This Climate Monitor analysis compares the number of days each year (1957-2024) from August to the end of November at Bowen, when the maximum temperature equalled or exceeded 37°C. This is the mango plants upper CTT during the fruit filling growth stage. The graphic above highlights that even though 2018 was a “hot” year at Bowen (as analysed and discussed in Figure 18 above) during the fruit fill and development stage, a maximum temperature of 37°C, or above only occurred on 4 days between the start of August and the end of November in that year.

The temperature analysis above demonstrates why a commercial mango industry exists at Bowen. Importantly temperature projections for the 2050’s reveal that the current high quality mango fruit grown at this location will be largely unaffected in future years.

The projected future climate data used in this CTT document are sourced from the most recent (September 2024) My Climate View website (formerly CSA). The site has undergone a number of changes over the last 18 months. The data and graphics format used in each individual crop CTT document in this series of DCAP and FBRP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The location specific, high quality, historic climate information used herein, is sourced from [Climate Monitor](#), a free, publicly available DCAP (Qld Government) web-tool.

Mango Critical Temperature Thresholds

Research Team – David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF Qld & Peter Deuter, Horticultural Consultant, PLD Horticulture



b) Cooktown

Projected future (2050's) and current climate data for Cooktown.

Table 3. Projected future temperature comparison for Cooktown under high emissions scenario RCP 8.5, where cumulative global emissions are currently tracking¹⁶.

Time Period	Annual Average T Max °C	Annual Average T Min °C	Annual Heat Risk Days. Based on the crop specific upper CTT T Max ≥37°C	Annual Cold Induction Days. Based on the crop specific lower CTT T Min ≤14°C <i>Note 14°C is mid-range of 10 to 18°C needed for flower induction.</i>
1964-1993 Past Average	29.0	22.2	1	6
1994 -2023 Recent Average	29.5	22.6	1	6
2030's High Emissions - Future Average	29.6	22.9	2	5
2050's High Emissions - Future Average	30.3	23.5	4	4
Difference from Past Average	+1.3	+1.3	+3	-2

The high emissions pathway model indicates a temperature shift, showing a 1.3°C increase in maximum temperatures and a 1.3°C increase in minimum temperatures by the 2050's. Importantly the number of days when the maximum temperature in Cooktown exceeds 37°C is projected to increase from 1 to 4 days, though this is likely to occur in mid-summer after fruit has been picked. The crop specific number of cold induction days decreases by 2 to just 4 days, when compared to the recent past.

Data source: Climate Services for Agriculture output, [My Climate View](#)

¹⁶ <https://myclimateview.com.au/>

The projected future climate data used in this CTT document are sourced from the most recent (September 2024) My Climate View website (formerly CSA). The site has undergone a number of changes over the last 18 months. The data and graphics format used in each individual crop CTT document in this series of DCAP and FBRP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The location specific, high quality, historic climate information used herein, is sourced from [Climate Monitor](#), a free, publicly available DCAP (Qld Government) web-tool.

Mango Critical Temperature Thresholds



Research Team – David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF Qld & Peter Deuter, Horticultural Consultant, PLD Horticulture

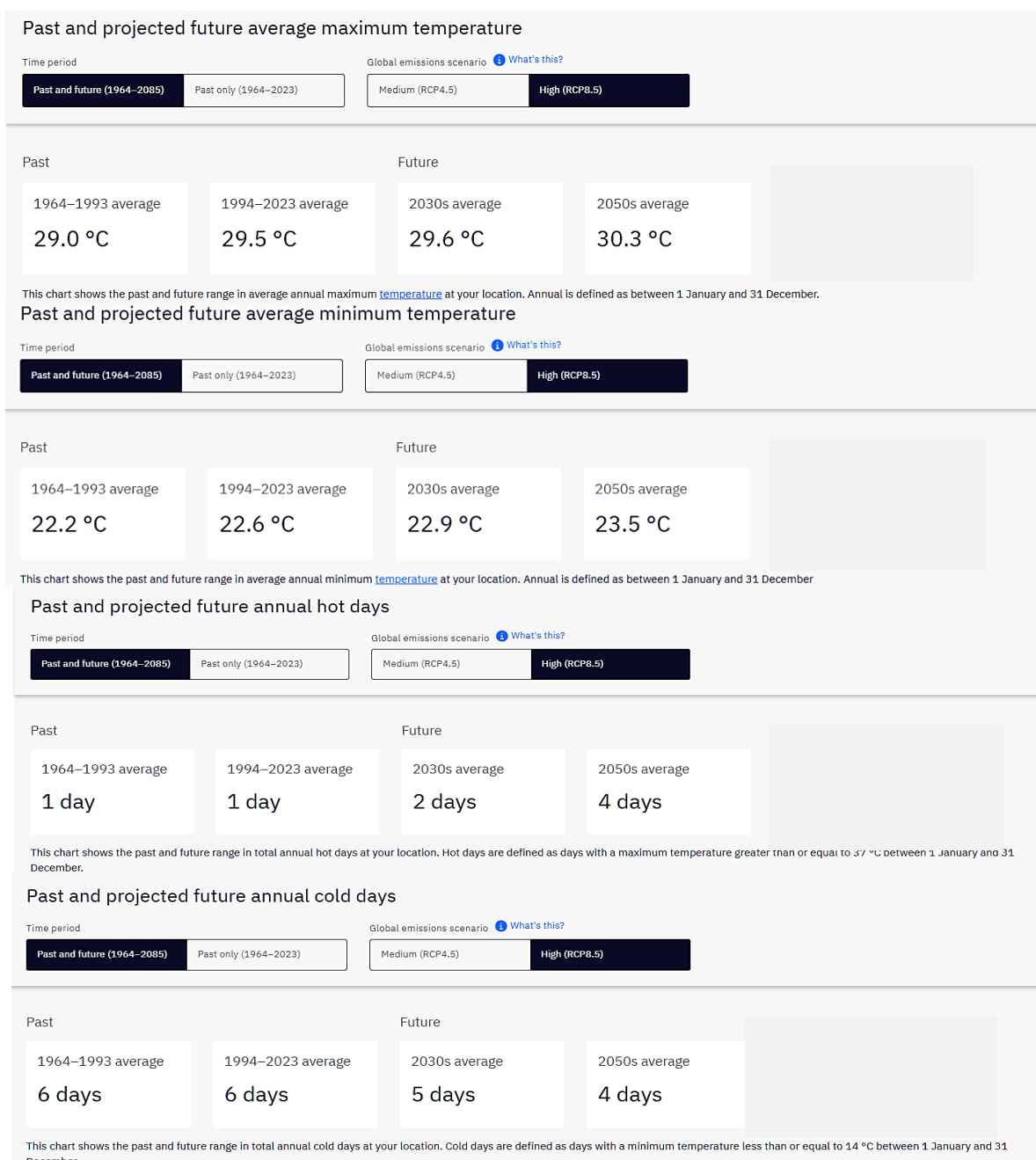


Figure 21. Projected future temperature outlook for Cooktown under high emissions scenario RCP 8.5, where cumulative global emissions are currently tracking (Schwalm, et al., 2020). The graphic uses 1964 – 1993 for comparison of the 2030's to 2050's average temperature shift.

The high emissions pathway model indicates a temperature shift, showing a 1.3°C increase in average annual maximum temperatures and a 1.3°C increase in average annual minimum temperatures by the 2050's, when compared to the 1964-93 base period.

The projected future climate data used in this CTT document are sourced from the most recent (September 2024) My Climate View website (formerly CSA). The site has undergone a number of changes over the last 18 months. The data and graphics format used in each individual crop CTT document in this series of DCAP and FBRP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

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Mango Critical Temperature Thresholds

Research Team – David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF Qld & Peter Deuter, Horticultural Consultant, PLD Horticulture



Projected 2050's maximums and minimum temperatures increase by 0.8°C and 0.7°C respectively compared to the 1994-2023 recent past averages. The annual number of hot days at Cooktown increases from 1 day to an average of 4 days $\geq 37^\circ\text{C}$ each year, however this is most likely to occur during mid-summer after fruit have been harvested.

Crop specific cold days required for mango flower induction 10°C to 18°C (14°C optimum) are projected to decrease from 6 days to 4 days (Figure 21) when compared the recent past.

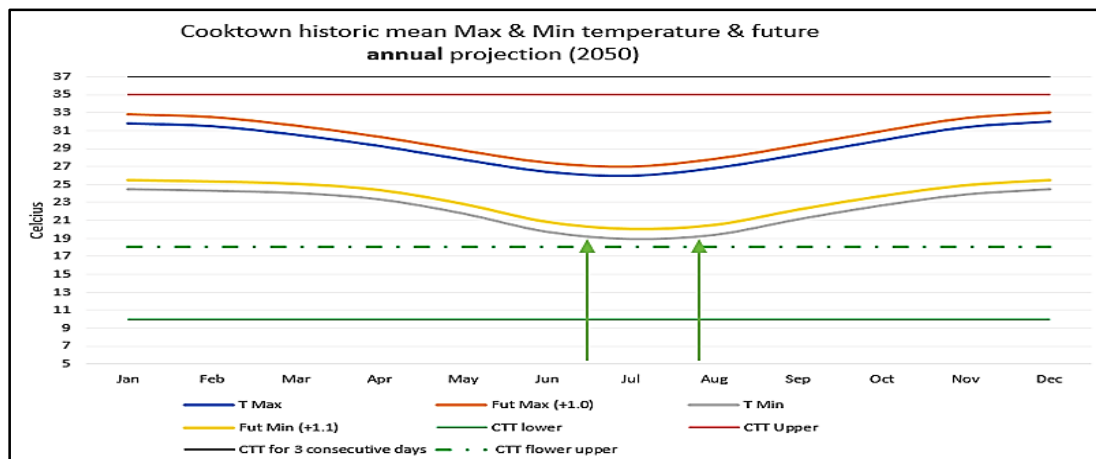


Figure 22. Current mean monthly temperatures at Cooktown, mango tree upper CTT (37°C), lower flower induction CTT ($10^\circ\text{C} - 18^\circ\text{C}$) & the impact of projected future mean annual temperature shifts (2050's) on the optimum growing season. Green solid arrows define the current problematic flower bud induction and flower production window. Minimum temperatures at this location already hamper flower induction and yield potential.

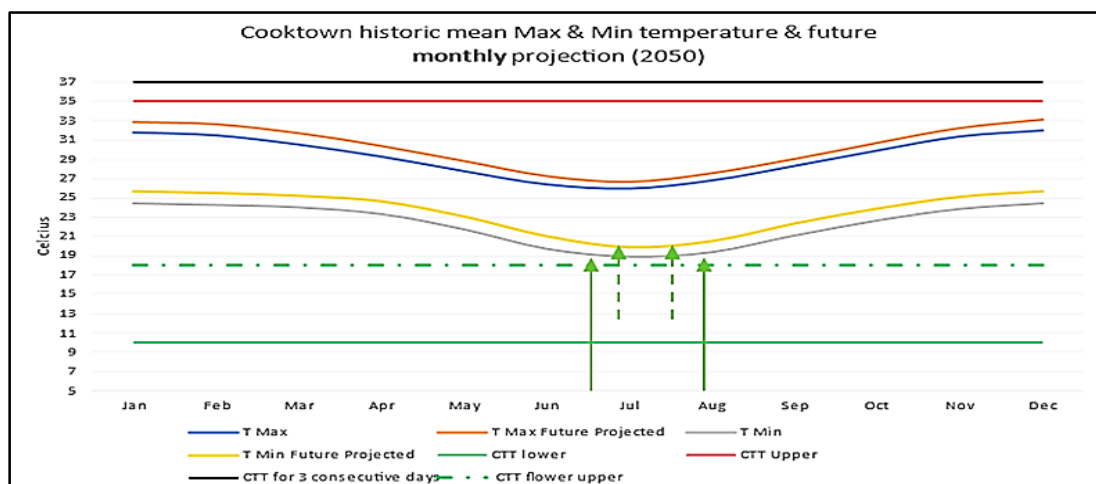


Figure 23. Current mean monthly temperatures at Cooktown, mango tree upper CTT (37°C), lower flower induction CTT ($10^\circ\text{C} - 18^\circ\text{C}$) and the impact of projected mean monthly temperature shifts (2050's) on the flower induction and flowering period. Note the projected monthly future climate data displayed here reflects the individual monthly changes that underpin the projected annual changes in maximum and minimum temperatures. The horizontal green dotted line represents 18°C , above which mango flower induction declines.

The projected future climate data used in this CTT document are sourced from the most recent (September 2024) My Climate View website (formerly CSA). The site has undergone a number of changes over the last 18 months. The data and graphics format used in each individual crop CTT document in this series of DCAP and FBRP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The location specific, high quality, historic climate information used herein, is sourced from [Climate Monitor](#), a free, publicly available DCAP (Qld Government) web-tool.

Mango Critical Temperature Thresholds

Research Team – David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF Qld & Peter Deuter, Horticultural Consultant, PLD Horticulture



The projected 2050 increases in minimum temperature will further reduce flower numbers and yield potential at this location. The further reduction in low temperature exposure is shown by the solid green and dotted green arrows.

Site specific mean temperature data source, DCAP [Climate Monitor](#)

Current minimum temperatures at Cooktown are above the minimum temperatures needed for effective flower induction in many years. The projected 0.9°C increase in annual minimum temperatures, compared to the recent past as displayed in Figure 22, will further reduce yield potential in most years.

Maximum temperatures at Cooktown during the mango plants flower pollination and fruit development months of July – November, are within the upper Critical Temperature Threshold. The projected 2050 annual mean maximum will see a 0.8°C increase, when compared to the recent past (1994-2023). This projected increase will still be below the mango plants upper CTT so there should be no impact on fruit fill and maturation. In fact, the higher daily maximum and minimum temperatures could speed up the fruit fill and development stage of any developing fruit– as long as other growth inputs such as nutrition and water are adequate.

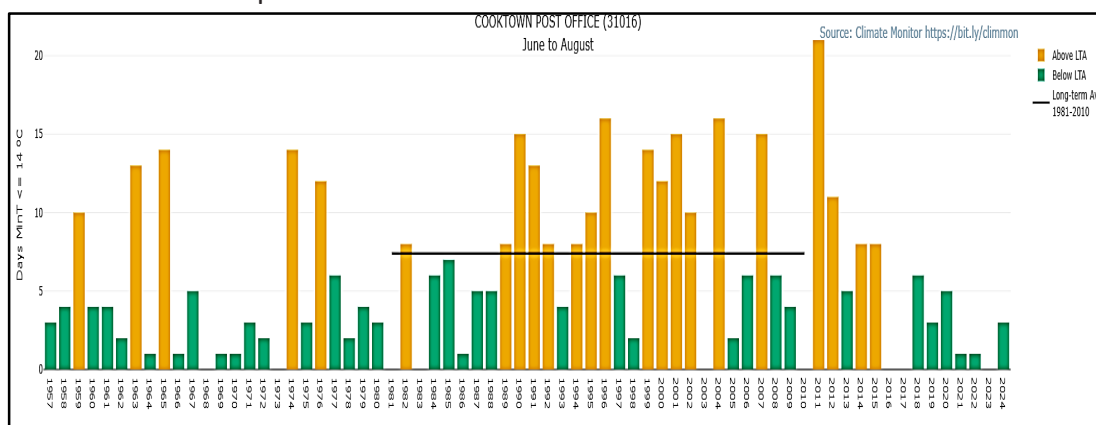


Figure 24. Number of days in each year at Cooktown from June to August that had had minimums of 14°C or below. Mango flower induction range is 10-18°C with 14°C optimal.

The projected 1.3°C increase in annual minimum temperatures by 2050, in the winter months, will lead to a further reduction of minimum temperatures that are essential for flower bud induction and flower development. Minimum temperatures at Cooktown are already marginal, at best, as can be seen in Figure 22, Figure 23 & Figure 24 above.

Cooktown mango crops will experience a further decline in and exposure to sufficiently cool temperatures (10-18°C) during July and August. This will cause a further reduction in

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Mango Critical Temperature Thresholds

Research Team – **David Carey**, Senior Horticulturist, Horticulture and Forestry Science, DAF Qld & **Peter Deuter**, Horticultural Consultant, PLD Horticulture



current and historic flower production levels, by the 2050's. Warmer mean minimum temperatures in July and August will, in many years no longer significantly contribute to

flower induction. This lower flower number will further reduce total fruit number and yield each year and also delay the "historic" fruiting season. As minimum temperatures increase, the underlying historic climatic conditions that supported the establishment of the current small mango industry in Cooktown will be altered, both flower production and subsequent yield will be greatly reduced.

c) Mareeba

Projected future (2050's) and current climate data for Mareeba.

Table 4. Projected future temperature comparison for Mareeba under high emissions scenario RCP 8.5, where cumulative global emissions are currently tracking¹⁷.

Time Period	Annual Average T Max °C	Annual Average T Min °C	Annual Heat Risk Days. Based on the crop specific upper CTT T Max ≥37°C	Annual Cold Induction Days. Based on the crop specific lower CTT T Min ≤14°C <i>Note 14°C is mid-range of 10 to 18°C needed for Flw induction.</i>
1964-1993 Past Average	28.3	17.3	0	75
1994 -2023 Recent Average	28.7	17.7	1	66
2030's High Emissions - Future Average	29.4	18.5	2	51
2050's High Emissions - Future Average	30.1	19.1	4	42
Difference from Past Average	+1.8	+1.8	+4	-33

The high emissions pathway model indicates a temperature shift, showing a 1.8°C increase in maximum temperatures and a 1.8°C increase in minimum temperatures by the 2050's. The number of days, when the maximum temperature in Mareeba exceeds 37°C, is

¹⁷ <https://myclimateview.com.au/>

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Mango Critical Temperature Thresholds

Research Team – David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF Qld & Peter Deuter, Horticultural Consultant, PLD Horticulture



projected to increase from 0 to 4 days, though this is likely to occur in mid-summer after fruit has been picked. The crop specific number of cold induction days decreases from 66 to 42 days, when compared to the recent past.

Data source: Climate Services for Agriculture output, [My Climate View](#)

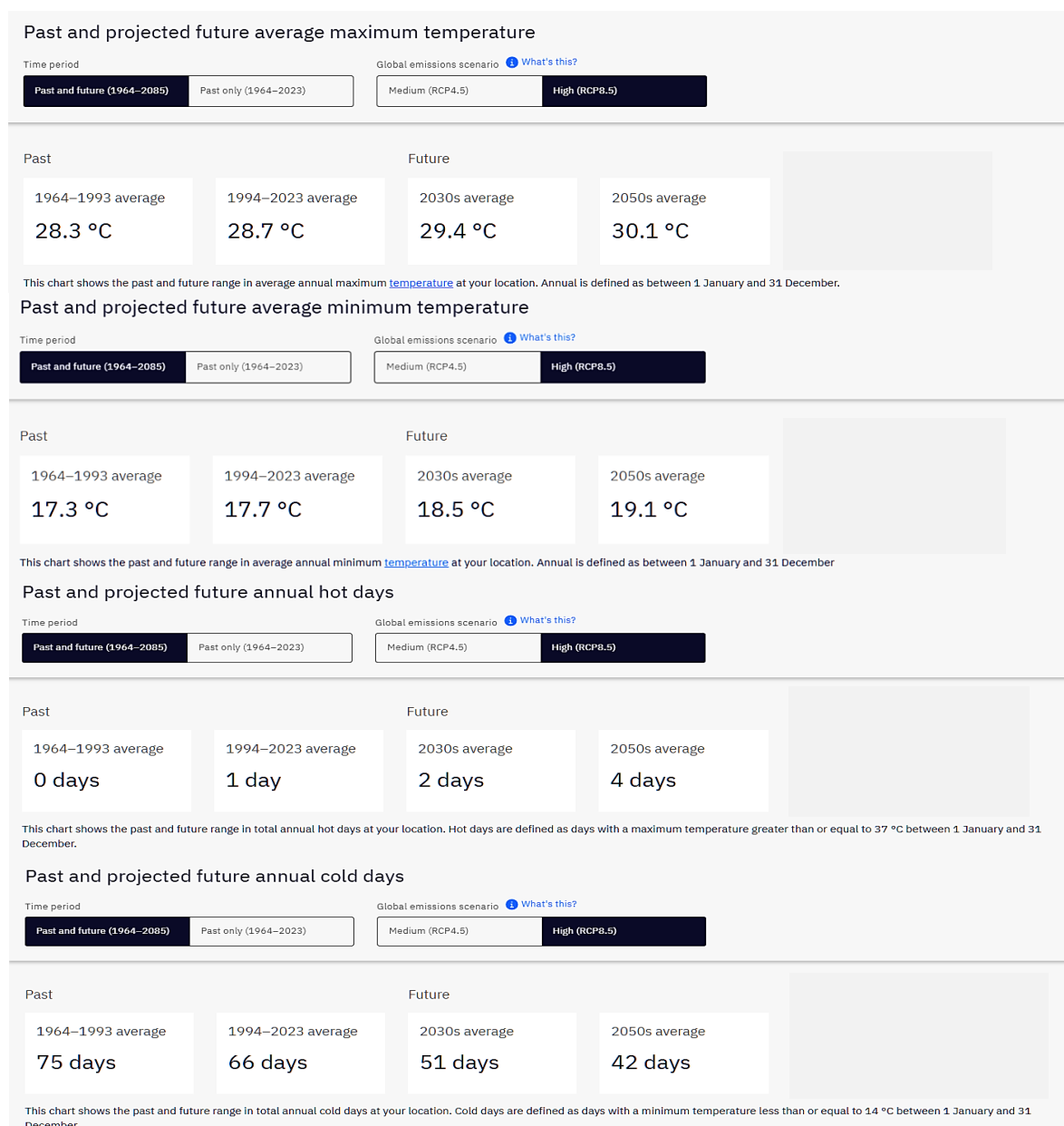


Figure 25. Projected future temperature outlook for Mareeba under high emissions scenario RCP 8.5, where cumulative global emissions are currently tracking (Schwalm, et al., 2020). The graphic uses 1964 – 1993 for comparison of the 2030 to 2050 average temperature shift.

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Mango Critical Temperature Thresholds

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The high emissions pathway model indicates a temperature shift, showing a 1.8°C increase in average annual maximum temperatures and a 1.8°C increase in average annual minimum temperatures by the 2050's, when compared to the 1964-93 base period. Projected 2050's maximums and minimum temperatures increase by 1.4°C compared to the 1994-2023 recent past averages. The annual number of hot days at Mareeba increases from 0 to an average of 4 days $\geq 37^{\circ}\text{C}$ each year, however this is most likely to occur during mid-summer after fruit have been harvested. Crop specific cold days required for mango flower induction 10°C to 18°C (14°C mid-point) are projected to decrease from 66 days to 42 days (Figure 25) when compared the recent past.

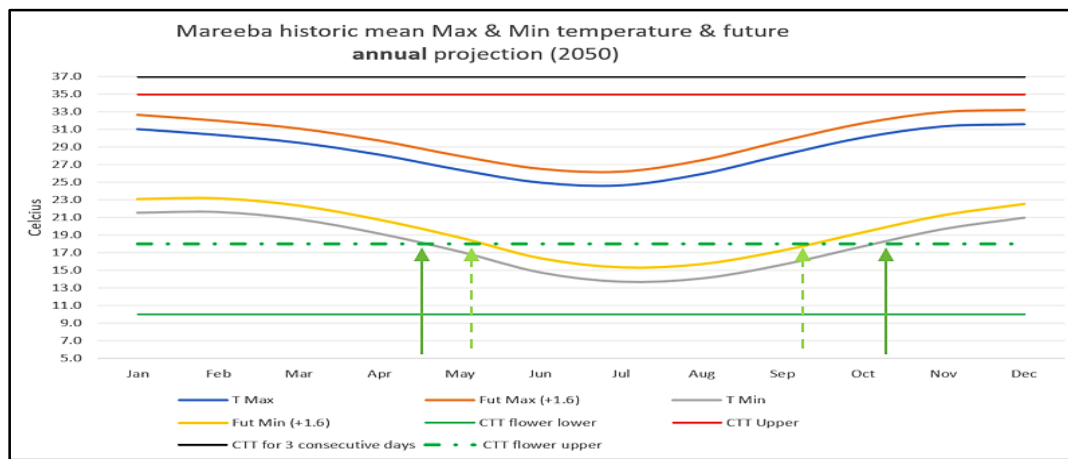


Figure 26. Current mean monthly temperatures at Mareeba, mango tree upper CTT (37°C), lower flower induction CTT ($10^{\circ}\text{C} - 18^{\circ}\text{C}$) & the impact of projected future mean annual temperature shifts (2050's) on the optimum growing season. Green solid arrows and the green dotted arrows define the current and future flower bud induction and flower production window.

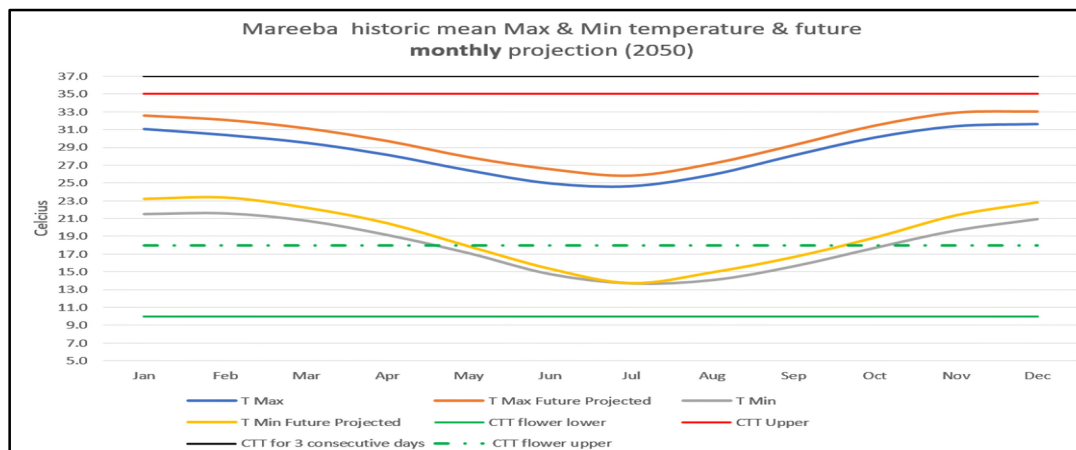


Figure 27. Current mean monthly temperatures at Mareeba, mango tree upper CTT (37°C), lower flower induction CTT ($10^{\circ}\text{C} - 18^{\circ}\text{C}$) & the slight impact of projected future mean monthly temperature shifts (2050's) on the flower induction and flowering period. Note, the projected monthly future climate data displayed here reflects the individual monthly changes that underpin the projected annual changes in maximum and minimum temperatures. The green dotted line represents 18°C , above which mango flower induction declines. The projected 2050 changes to minimum temperature will have negligible impact on flower induction and yield potential. Site specific mean temperature data source, DCAP Climate Monitor

The projected future climate data used in this CTT document are sourced from the most recent (September 2024) My Climate View website (formerly CSA). The site has undergone a number of changes over the last 18 months. The data and graphics format used in each individual crop CTT document in this series of DCAP and FBRP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

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Mango Critical Temperature Thresholds

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Current maximum and minimum temperatures at Mareeba during the mango plants flower induction and fruit development months of late April – early December, are within the upper Critical Temperature Threshold. The projected 2050 annual mean maximum will see a 1.4°C increase, when compared to the recent past (1994-2023). This projected increase is still well below the mango plants upper CTT, so there will be no impact on fruit fill and maturation. In fact, the higher daily maximum temperatures could well hasten fruit fill and development – as long as other growth inputs such as nutrition and water are adequate.

The projected 1.4°C increase in annual minimum temperatures by 2050, in the winter months, will have little effect in this high-altitude production location. Minimum temperatures at Mareeba will still remain well within the mango plants flower induction CTT for several months, as can be seen in Figure 26 and **Error! Reference source not found.** above.

Commercial mango crops will continue to be exposed to sufficiently cool temperatures (10-18°C) during June, July and August, ensuring excellent flower and fruit production at this location. The slight increase in both minimum and maximum temperatures could see fruit mature a little earlier, bringing the harvest season forward, as long as plant water availability and nutrition are not limiting.

The mango plants inherent CTT's are only one climate related component required for successful production. Other variables also need to be examined and considered in order to fully assess both future temperature and climate impacts. For example, insect activity, disease pressure, water availability and storm severity all impact potential yield.

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Interstate production – future insights.

Future climate data analysis for all locations (2050's) is based on current projections sourced from Australias, Climate Services for Agriculture website, My Climate View.

Note; due to the current impact of temperature on commercial mango yields in Northern Australia, a complete graphed analysis of past and projected temperatures has been completed and included here for all major interstate production sites.

ii) Northern Territory (Katherine)

Table 5. Projected future temperature comparison for Katherine under high emissions scenario RCP 8.5, where cumulative global emissions are currently tracking¹⁸.

Time Period	Annual Average T Max °C	Annual Average T Min °C	Annual Heat Risk Days. Based on the crop specific upper CTT T Max ≥37°C	Annual Cold Induction Days. Based on the crop specific lower CTT T Min ≤14°C Note 14°C is mid-range of 10 to 18°C needed for flower induction.
1964-1993 Past Average	34.3	20.4	78	49
1994 -2023 Recent Average	34.5	20.4	84	56
2030's High Emissions - Future Average	35.3	21.8	121	35
2050's High Emissions - Future Average	36.1	22.6	160	29
Difference from Past Average	+1.8	+2.2	+82	-20

Data source: Climate Services for Agriculture output, [My Climate View](#)

¹⁸ <https://myclimateview.com.au/>

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The location specific, high quality, historic climate information used herein, is sourced from [Climate Monitor](#), a free, publicly available DCAP (Qld Government) web-tool.

Mango Critical Temperature Thresholds

Research Team – **David Carey**, Senior Horticulturist, Horticulture and Forestry Science, DAF Qld & **Peter Deuter**, Horticultural Consultant, PLD Horticulture



The high emissions pathway model indicates a temperature shift, showing a 1.8°C increase in maximum temperatures and a 2.2°C increase in minimum temperatures by the 2050's.

The number of days when the maximum temperature in Katherine exceeds 37°C is projected to increase from 84 to 160 days, some of which will to be in the mango season.

The crop specific number of cold flower induction days decreases from 56 to 29, when compared to the recent past.

These are all significant changes that are projected to occur in a location that currently experiences varying yield and yield loss due to warm minimums in some years during both the flower induction, flowering and pollination growth stages.

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Mango Critical Temperature Thresholds

Research Team – David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF Qld & Peter Deuter, Horticultural Consultant, PLD Horticulture

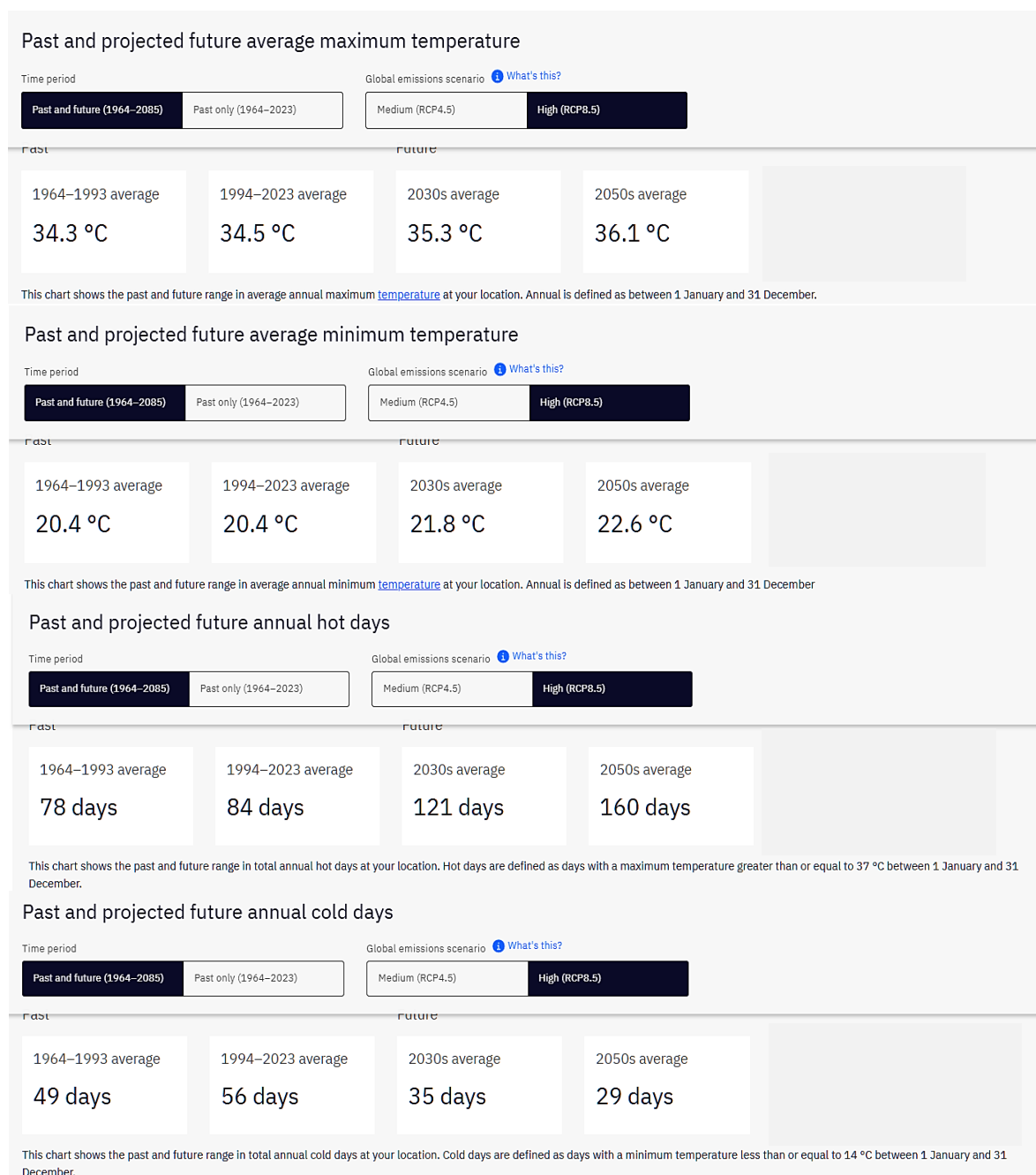


Figure 28. Projected future temperature outlook for Katherine under high emissions scenario RCP8.5, where cumulative global emissions are currently tracking (Schwalm, et al., 2020). The graphic uses 1964 – 1993 for comparison of the 2030 to 2050 average temperature shift.

The projected future climate data used in this CTT document are sourced from the most recent (September 2024) My Climate View website (formerly CSA). The site has undergone a number of changes over the last 18 months. The data and graphics format used in each individual crop CTT document in this series of DCAP and FBRP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The location specific, high quality, historic climate information used herein, is sourced from [Climate Monitor](#), a free, publicly available DCAP (Qld Government) web-tool.

Mango Critical Temperature Thresholds

Research Team – David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF Qld & Peter Deuter, Horticultural Consultant, PLD Horticulture



The high emissions pathway model indicates a temperature shift, showing a 1.8°C increase in average annual maximum temperatures and a 2.2°C increase in average annual minimum temperatures by the 2050's, when compared to the 1964-93 base period. Projected 2050's maximums and minimum temperatures increase by 1.6°C and 2.2°C respectively when compared to the 1994-2023 recent past averages.

The annual number of hot days at Katherine increases considerably, while the crop specific cold days required for mango flower induction 10°C to 18°C (14°C optimum) are projected to decrease from 56 days to just 29 days (Figure 28) when compared to the recent past.

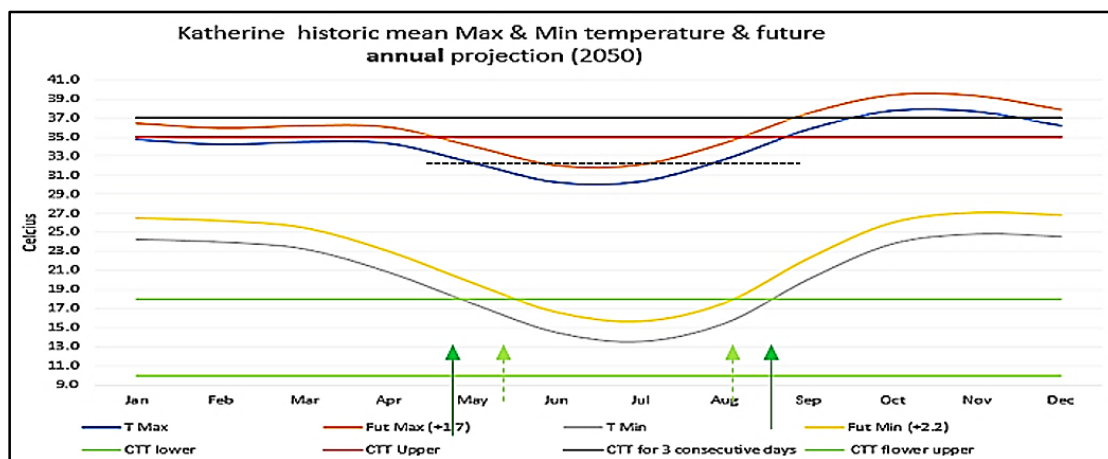


Figure 29. Current mean monthly temperatures at Katherine, mango tree upper CTT (37°C), lower flower induction CTT (10°C – 18°C) & the impact of projected future mean annual temperature shifts (2050's) on the optimum growing season. Green solid arrows and the green dotted arrows define the current and future flower bud induction and flower production window. The upper CTT for flower development is 32°C marked by the black dotted line and the upper CTT for flower pollination is 33°C.

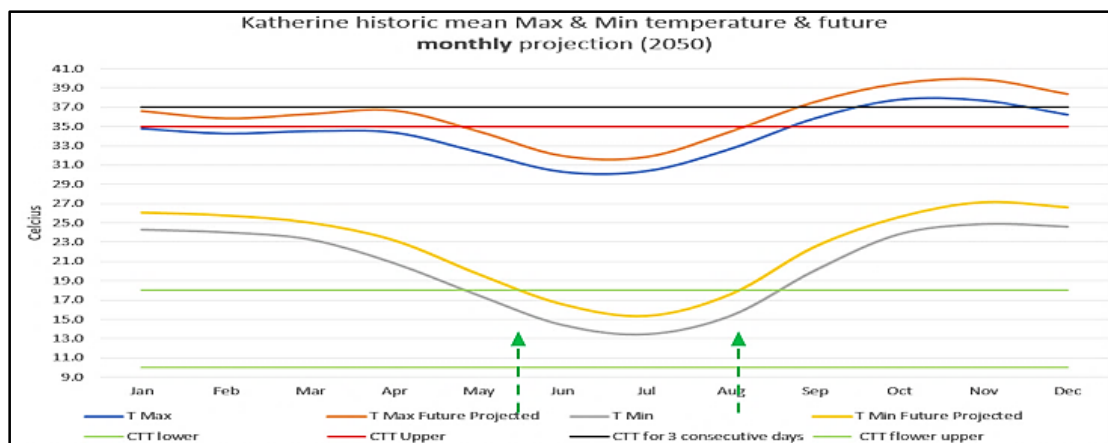


Figure 30. Current mean monthly temperatures at Katherine, mango tree upper CTT (37°C), lower flower induction CTT (10°C – 18°C) & the impact of projected future mean monthly temperature shifts (2050's) on the flower induction and flowering period. Note, the projected monthly future climate data displayed here reflects the individual monthly changes that underpin the projected annual changes in maximum and minimum temperatures. The upper green line represents 18°C, above which mango flower induction declines. The projected 2050 changes to both minimum and maximum temperature will impact flower induction, pollination and yield potential.

The projected future climate data used in this CTT document are sourced from the most recent (September 2024) My Climate View website (formerly CSA). The site has undergone a number of changes over the last 18 months. The data and graphics format used in each individual crop CTT document in this series of DCAP and FBRP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The location specific, high quality, historic climate information used herein, is sourced from [Climate Monitor](#), a free, publicly available DCAP (Qld Government) web-tool.

Mango Critical Temperature Thresholds

Research Team – David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF Qld & **Peter Deuter**, Horticultural Consultant, PLD Horticulture



Site specific current and historic mean temperature data source, DCAP Climate Monitor

Projected increases in both maximum and minimum temperatures at Katherine during the mango plants flower induction period (10-18°C), in combination with the upper CTT for flower development and pollination (32°C), will result in a further decrease in crop yield in future years. This analysis result agrees with a June 2020 report published by the Earth Systems and Climate Change Hub that states, “both minimum and maximum temperatures are projected to limit mango flower induction; however, higher maximum temperatures are the most limiting”¹⁹, at both Katherine and Darwin.

Figure 29 above depicts the projected 2050 changes to both maximum and minimum temperatures at Katherine. Not only will flower induction be limited by warmer minimum temperatures that will delay the inductive period, but flower development and pollination will also be impacted by maximum daily temperatures above 32°C, which will also occur earlier in Spring. Both these projected temperature increases will cause a further decline in yield potential in “average years” and in a “hot year” this impact will be amplified. To highlight these conditions, the impact of a “hot year” is explored using actual temperature data from 2018, in Figure 31 below.

The projected 1.8°C and 2.2°C increase in average maximum and minimum temperatures respectively by 2050 will impact commercial mango production at Katherine.

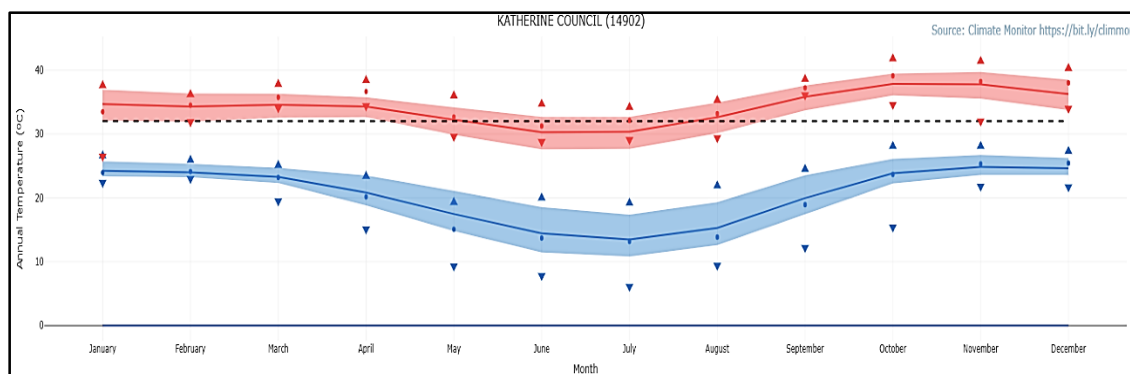


Figure 31. Climate Monitor analysis showing the annual historic monthly maximum (red), minimum (blue) temperatures and mean temperatures (solid lines within each coloured band), with mango tree upper critical temperature for flowering and pollination overlaid, at Katherine. The upper flowering CTT of 32°C, is overlaid and used in this analysis. 2018 was a warm year in this location, as the graph above shows. The highest and lowest maximum (red triangles) and minimum temperatures (blue triangles) for each month in 2018 as well as the monthly average for 2018 (red and blue dots) overlaid on the long-term annual average).

¹⁹ https://nеспclimate.com.au/wp-content/uploads/2019/05/A4-2p-mango-IA-results-factsheet-Katherine_web.pdf

The projected future climate data used in this CTT document are sourced from the most recent (September 2024) My Climate View website (formerly CSA). The site has undergone a number of changes over the last 18 months. The data and graphics format used in each individual crop CTT document in this series of DCAP and FBRP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The location specific, high quality, historic climate information used herein, is sourced from [Climate Monitor](#), a free, publicly available DCAP (Qld Government) web-tool.

Mango Critical Temperature Thresholds

Research Team – David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF Qld & **Peter Deuter**, Horticultural Consultant, PLD Horticulture



Figure 31 above illustrates how in some years and months (2018 overlay used here), the hottest daily maximums for the month (upper red triangles) and minimums (upper blue

triangles) in June, July and August 2018 were well above the average annual 90th percentile maximum and minimum temperature for a given month across all years. The red and blue circles in this graph represent the actual monthly mean recorded in 2018.

The projected future climate data used in this CTT document are sourced from the most recent (September 2024) My Climate View website (formerly CSA). The site has undergone a number of changes over the last 18 months. The data and graphics format used in each individual crop CTT document in this series of DCAP and FBRP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The location specific, high quality, historic climate information used herein, is sourced from [Climate Monitor](#), a free, publicly available DCAP (Qld Government) web-tool.

Mango Critical Temperature Thresholds

Research Team – David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF Qld & Peter Deuter, Horticultural Consultant, PLD Horticulture



iii) Western Australia (Kununurra)

Table 6. Projected future temperature comparison for Kununurra under high emissions scenario RCP 8.5, where cumulative global emissions are currently tracking²⁰.

Time Period	Annual Average T Max °C	Annual Average T Min °C	Annual Heat Risk Days. Based on the crop specific upper CTT T Max ≥37°C	Annual Cold Induction Days. Based on the crop specific lower CTT T Min ≤14°C <i>Note 14°C is mid-range of 10 to 18°C needed for flower induction.</i>
1964-1993 Past Average	34.9	21.4	118	30
1994 -2023 Recent Average	34.9	20.8	115	50
2030's High Emissions - Future Average	35.9	22.4	155	22
2050's High Emissions - Future Average	36.8	23.3	188	15
Difference from Past Average	+1.9	+1.9	+70	-15

Data source: Climate Services for Agriculture output, [My Climate View](#)

The high emissions pathway model indicates a temperature shift, showing a 1.9°C increase in both maximum temperatures and minimum temperatures by the 2050's. The number of days when the maximum temperature in Kununurra exceeds 37°C is projected to increase from 118 to 188 days, though some of these days will occur in mid-summer after fruit has been picked.

The crop specific number of cold induction days decreases from 50 to 15 days, when compared to the recent past, a significant change.

²⁰ <https://myclimateview.com.au/>

The projected future climate data used in this CTT document are sourced from the most recent (September 2024) My Climate View website (formerly CSA). The site has undergone a number of changes over the last 18 months. The data and graphics format used in each individual crop CTT document in this series of DCAP and FBRP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The location specific, high quality, historic climate information used herein, is sourced from [Climate Monitor](#), a free, publicly available DCAP (Qld Government) web-tool.

Mango Critical Temperature Thresholds



Research Team – David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF Qld & Peter Deuter, Horticultural Consultant, PLD Horticulture

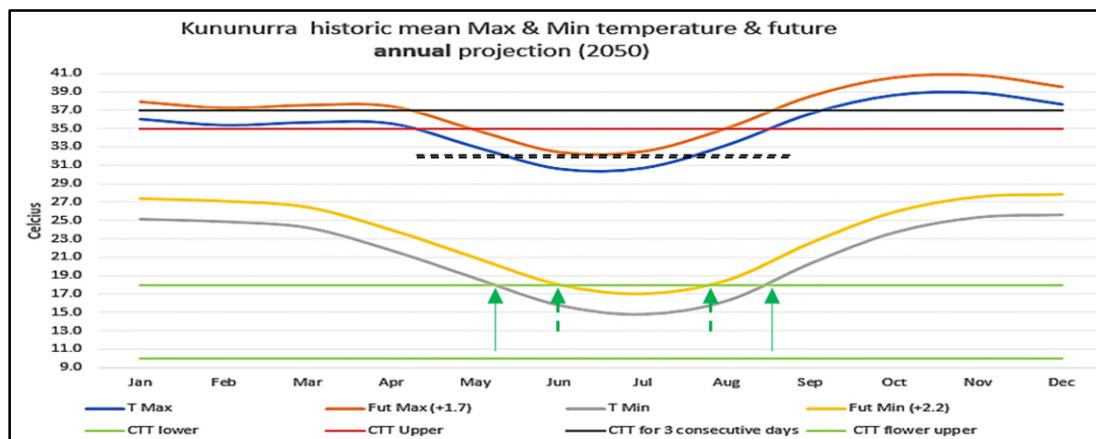


Figure 32. Current mean monthly temperatures at Kununurra, mango tree upper CTT (37°C), lower flower induction CTT (10°C – 18°C) & the impact of projected future mean annual temperature shifts (2050's) on the optimum growing season. Green solid arrows and the green dotted arrows define the current and future flower bud induction and flower production window. The upper CTT for flower development is 32°C marked by the black dotted line, the upper CTT for flower pollination is 33° C.

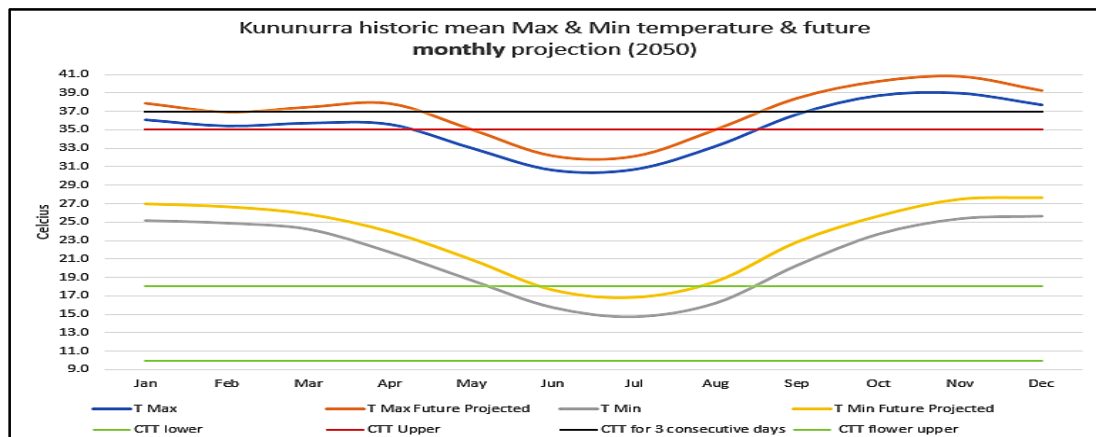


Figure 33. Current mean monthly temperatures at Kununurra, mango tree upper CTT (37°C), lower flower induction CTT (10°C – 18°C) & the projected future mean monthly temperature shifts (2050's). Note, the projected monthly future climate data displayed here reflects the individual monthly changes that underpin the projected annual changes in maximum and minimum temperatures displayed in Error! Reference source not found. The projected 2050 changes to both minimum and maximum temperature will impact flower induction, pollination, and yield potential.

Site specific current and historic mean temperature data source, DCAP Climate Monitor

Current maximum and minimum temperatures at Kununurra during the mango plants flower induction period (lower CTT, 10-18°C), as well as the upper CTT for flower development and pollination 32°C result in decreased crop yield in some years.

Figure 32 and Figure 33 above display the projected 2050 changes to both maximum and minimum temperatures at Kununurra.

The projected future climate data used in this CTT document are sourced from the most recent (September 2024) My Climate View website (formerly CSA). The site has undergone a number of changes over the last 18 months. The data and graphics format used in each individual crop CTT document in this series of DCAP and FBRP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The location specific, high quality, historic climate information used herein, is sourced from [Climate Monitor](#), a free, publicly available DCAP (Qld Government) web-tool.

Mango Critical Temperature Thresholds

Research Team – David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF Qld & Peter Deuter, Horticultural Consultant, PLD Horticulture



Not only will flower induction be limited by warmer minimum temperatures that will delay the inductive period, but in addition, flower development and pollination will also be further impacted by maximum daily temperatures above 32°C, which will also occur earlier.

Both these projected temperature increases will cause a further decline in yield potential in “average years” and in a “hot year” this impact will be amplified.

The projected 1.9°C and 2.5°C increase in average maximum and minimum temperatures respectively by 2050, compared to the recent past, is a significant shift and will impact commercial mango production.

iv) Western Australia (Carnarvon)

Table 7. Projected future temperature comparison for Carnarvon under high emissions scenario RCP 8.5, where cumulative global emissions are currently tracking²¹.

Time Period	Annual Average T Max °C	Annual Average T Min °C	Annual Heat Risk Days. Based on the crop specific upper CTT T Max ≥37°C	Annual Cold Induction Days. Based on the crop specific lower CTT T Min ≤14°C <i>Note 14°C is mid-range of 10 to 18°C needed for flower induction.</i>
1964-1993 Past Average	27.5	17.4	17	102
1994 -2023 Recent Average	28.2	17.8	19	97
2030's High Emissions - Future Average	28.6	18.6	20	78
2050's High Emissions - Future Average	29.5	19.2	25	68
Difference from Past Average	+2.0	+1.8	+8	-34

Data source: Climate Services for Agriculture output, [My Climate View](#)

²¹ <https://myclimateview.com.au/>

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The location specific, high quality, historic climate information used herein, is sourced from [Climate Monitor](#), a free, publicly available DCAP (Qld Government) web-tool.

Mango Critical Temperature Thresholds

Research Team – David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF Qld & **Peter Deuter**, Horticultural Consultant, PLD Horticulture



The high emissions pathway model indicates a temperature shift, showing a 2.0°C increase in maximum temperatures and a 1.8°C increase in minimum temperatures by the 2050's. While the number of days when the maximum temperature in Carnarvon exceeds 37°C is projected to increase from 19 to 25 days, this is most likely to occur in mid-summer after fruit has been harvested. The crop specific number of cold induction days decreases from 97 to 68 days, when compared to the recent past.

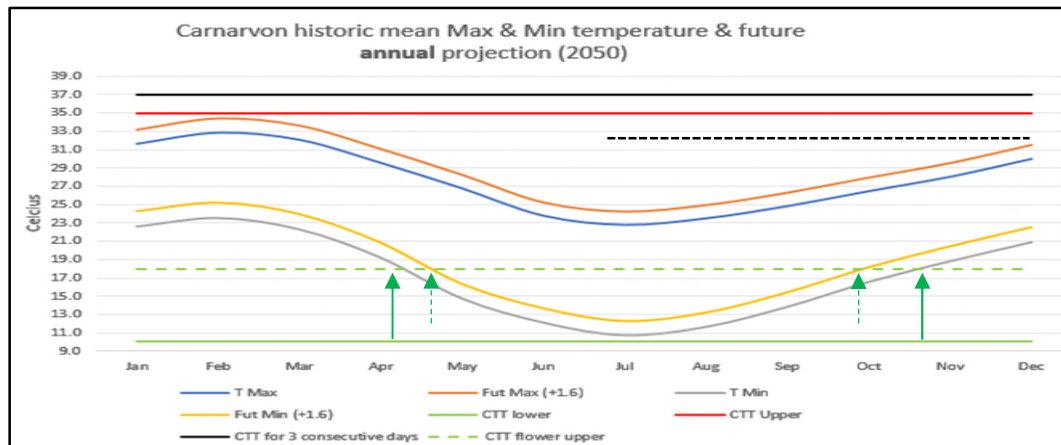


Figure 34. Current mean monthly temperatures at Carnarvon, mango tree upper CTT (37°C), lower flower induction CTT (10°C – 18°C) & the impact of projected future mean annual temperature shifts (2050's) on the optimum growing season. Green solid arrows and the green dotted arrows define the current and future flower bud induction and flower production window. The upper CTT for flower development is 32°C marked by the black dotted line and the upper CTT for flower pollination is 33° C.

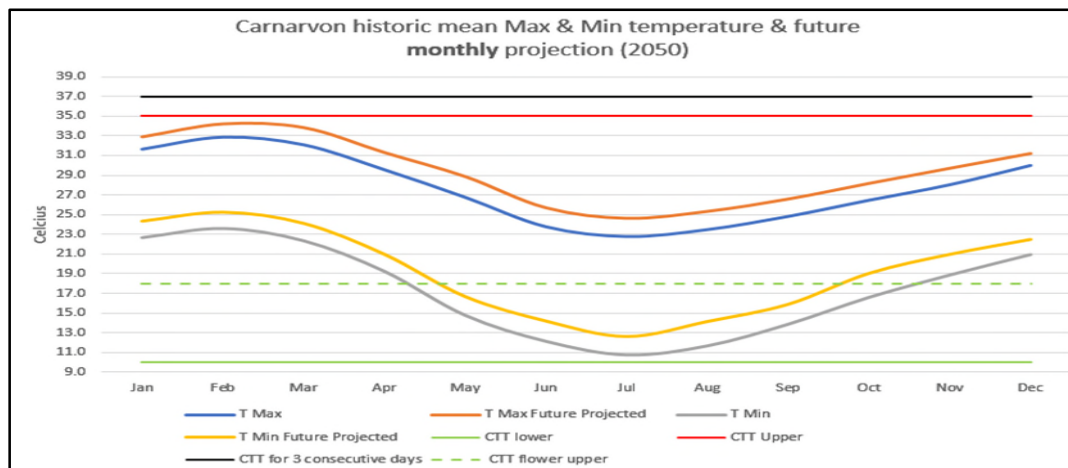


Figure 35. Current mean monthly temperatures at Carnarvon, mango tree upper CTT (37°C), lower flower induction CTT (10°C – 18°C) & the projected future mean monthly temperature shifts (2050's). Note, the projected monthly future climate data displayed here reflects the individual monthly changes that underpin the projected annual changes in maximum and minimum temperatures displayed in

Site specific current and historic mean temperature data source, DCAP Climate Monitor.

The projected future climate data used in this CTT document are sourced from the most recent (September 2024) My Climate View website (formerly CSA). The site has undergone a number of changes over the last 18 months. The data and graphics format used in each individual crop CTT document in this series of DCAP and FBRP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

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Mango Critical Temperature Thresholds

Research Team – **David Carey**, Senior Horticulturist, Horticulture and Forestry Science, DAF Qld & **Peter Deuter**, Horticultural Consultant, PLD Horticulture



Current maximum and minimum temperatures at Carnarvon during the mango plants flower induction period (lower CTT, 10-18°C), as well as the upper CTT for flower development and pollination 32°C are close to ideal in most years.

Figure 34 and Figure 35 above highlight the projected 2050 changes to both maximum and minimum temperatures at Carnarvon. Mango flower induction, flowering and pollination at this location will be relatively unaffected by the projected temperature changes, though the onset of flower induction may be slightly delayed.

Warmer minimums and maximums may enhance fruit development and fill, advancing the historic harvest period slightly.

The projected 1.3°C increase in average maximum and 1.4°C in minimum temperatures respectively by 2050, compared to the recent past, will not negatively impact fruit production and could bring forward the historic mango harvest season.

The mango plants inherent CTT's are only one climate related component required for successful production. Other variables also need to be examined and considered in order to fully assess both future temperature and climate impacts. For example, insect activity, disease pressure, water availability and storm severity all impact potential yield.

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Annual maximum, minimum, hot and cold days, by the 2050's, for mango production at reviewed locations in Australia.

Growing Location	Current Max Temp °C	Projected Max temp change °C by 2050's	Current Min Temp °C	Projected Min temp change °C by 2050's	Current number of hot days ≥37° C	Projected number of hot days ≥37° C by 2050's	Current number of cold induction days ≤14° C	Projected number of cold induction days ≤14° C by 2050's
Bowen (Qld)	28.8	+1.5	20.2	+1.5	0	2	42	25
Cooktown (Qld)	29.5	+0.8	22.6	+0.9	1	4	6	4
Mareeba (Qld)	28.7	+1.4	17.7	+1.4	1	4	66	42
Katherine (NT)	34.5	+1.6	20.4	+0.2	84	160	56	29
Kununurra (WA)	34.9	+1.9	20.8	+2.5	115	188	50	15
Carnarvon (WA)	28.2	+1.3	17.8	+1.4	19	25	97	68

Data source: Climate Services for Agriculture location specific output, [My Climate View](#) .

The projected future climate data used in this CTT document are sourced from the most recent (February 2024) My Climate View website (formerly CSA). The updated site underwent some changes, it now displays the 2030 and 2050 average projections. The data and graphics format used in each individual crop CTT document in this DCAP & FBRP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The location specific, high quality, historic climate information use herein, is sourced from [Climate Monitor](#), a free, publicly available DCAP web-tool.

Mango Critical Temperature Thresholds

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Do your own analysis.

If you are interested in other production locations within Australia, you can evaluate a location yourself.

1. Use Climate Monitor to easily analyse and graph the location of interest.
Access Climate Monitor at
<https://www.longpaddock.qld.gov.au/dcap/horticulture-industry/>
Click on the **Go Climate Monitor** button.
2. Use the My Climate View website to explore the projected temperature, rainfall and evaporation changes at your chosen location.
Access Climate Services for Agriculture future climate projections at
<https://myclimateview.com.au/>

Appendix I

<https://www.climatechangeinaustralia.gov.au/en/changing-climate/future-climate-scenarios/greenhouse-gas-scenarios/>

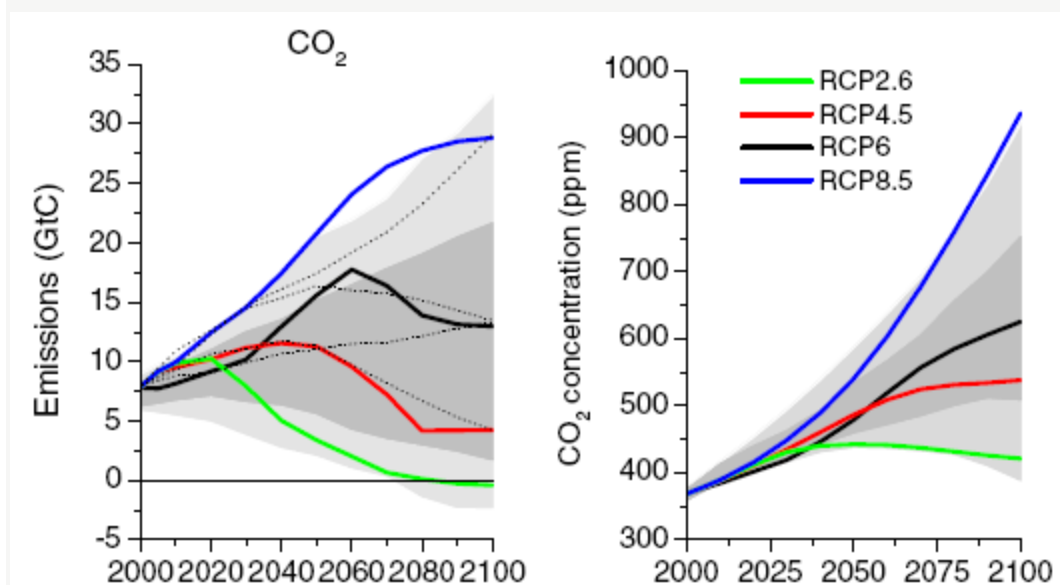
GREENHOUSE GAS SCENARIOS

(REPRESENTATIVE CONCENTRATION PATHWAYS - RCPs)

The future of anthropogenic greenhouse gas and aerosol emissions (and hence their resultant radiative forcing) is highly uncertain, encompassing substantial unknowns in population and economic growth, technological developments and transfer, and political and social changes.

The climate modelling community has developed Representative Concentration Pathways (RCPs) to explore credible future options. The Australian climate change projections found on this site are derived from climate models forced by the RCPs.

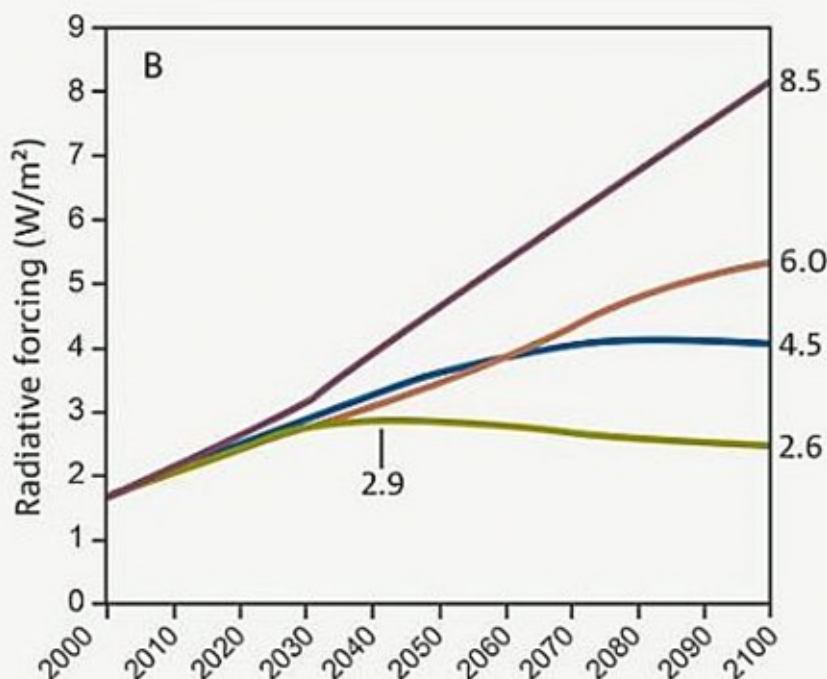
These scenarios span the range of plausible global warming scenarios. They provide a range of options for the world's governments and other institutions for decision making.



Emissions of CO₂ across the RCPs (left), and trends in concentrations of carbon dioxide (right). Grey area indicates the 98th and 90th percentiles (light/dark grey) of the values from the literature). The dotted lines indicate four of the SRES marker scenarios.

SOURCE: van Vuuren et. al., (2011)

Research Team – David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF Qld & Peter Deuter, Horticultural Consultant, PLD Horticulture.



Radiative forcing for the different RCPs. The numbers on the right show the final radiative forcing at 2100 and give each scenario its name (8.5, 6.0, 4.5 and 2.6 W/m²)

SOURCE: Climate Change in Australia Technical Report

RCPs are prescribed pathways for greenhouse gas and aerosol concentrations, together with land use change, which are consistent with a set of broad climate outcomes used by the climate modelling community. The pathways are characterised by the radiative forcing produced by the end of the 21st century. Radiative forcing is the extra heat the lower atmosphere will retain as a result of additional greenhouse gases, measured in Watts per square metre (W/m²).

The RCPs represent a wider set of futures that the previous emissions scenarios used by climate modelling community (SRES), and now explicitly include the effect of mitigation strategies. As with SRES, no particular scenario is deemed more likely than the others, however, some require major and rapid change to emissions to be achieved.

THERE ARE FOUR RCPS

RCP8.5– a future with little curbing of emissions, with a CO₂ concentration continuing to rapidly rise, reaching 940 ppm by 2100.

RCP6.0– lower emissions, achieved by application of some mitigation strategies and technologies. CO₂ concentration rising less rapidly (than RCP8.5), but still reaching 660 ppm by 2100 and total radiative forcing stabilising shortly after 2100.

RCP4.5- CO₂ concentrations are slightly above those of RCP6.0 until after mid-century, but emissions peak earlier (around 2040), and the CO₂ concentration reaches 540 ppm by 2100.

RCP2.6 - the most ambitious mitigation scenario, with emissions peaking early in the century (around 2020), then rapidly declining. Such a pathway would require early participation from all emitters, including developing countries, as well as the application of technologies for actively removing carbon dioxide from the atmosphere. The CO₂ concentration reaches 440 ppm by 2040 then slowly declines to 420 ppm by 2100).

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Mango Critical Temperature Thresholds

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