Activity # 1- Assessing Horticultural Crop Suitability for the Queensland Murray Darling Basin Study Area

Biophysical Mapping

(1 August 2014 to 30 June 2016)

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Activity 1 — Project Team

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This publication has been compiled by David Carey of Agri-Science, Department of Agriculture and Fisheries.

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1. Weather data used for chill hour and temperature mapping

1.1 Introduction

Discrepancies between the observations reported by growers in the St George region and the data available from the Australian Bureau of Meteorology (BoM) prompted this analysis of the available data. In 1997, the official recording station for St George was moved from the Post Office (43034) to the Airport (43109). There was no overlap in temperature data so it becomes very difficult to compare the relative differences and bias between these sites. To date, data recorded by growers has not been found to match the time when the Post Office station was operational.

Gridded, daily data, provided by BoM, has been used as the basis for much of the analysis for the overarching project which covers a region from St George and Dirranbandi in the west to Toowoomba and Stanthorpe in the east. The question then arose as to the suitability of the gridded data to represent requirements and limitation for crop growth.

The available data come from two sources. Raw data from BoM is collected by DSITI and used to construct the patched point data set (PPD). The BoM also curate a high quality data set for 112 locations in Australia referred to as ACORN-SAT. The BoM and DSITI provide daily gridded data for Australia, but utilise different interpolation methods because the data is purposed for climate analysis in the former case and for modelling in the latter. To investigate the differences in the source data, interpolation techniques, and changes in station location comparisons have been undertaken between the methods for St George using data from both organisations.

1.2 Data sets

Data sets from DSITI

Patched Point Data set (PPD) — daily station based data that has been patched to eliminate missing values. Patching occurs at various levels depending on data availability at nearby stations. Originally developed for the AussieGrass project, this data set provides modellers with a clean data set without missing values, as missing values cause problems with process-based crop and pasture models. Observation data is derived from the BoM network and patched using algorithms that take into account topography and elevation. Any estimated values are in-filled with new observations as they come in. This happens to a greater extent with rainfall data where this is sometimes collected by hand.

For many stations, rainfall is the only variable that is recorded and temperature etc., must be estimated for all observations. The data are not controlled for changes in instrumentation and the environment of the recording station.

Data is available from 1 January 1889 to present. Naturally, the accuracy of the data declines rapidly prior to 1957 because of the lack of stations. To some extent it is declining again as stations are lost from the network.

Data Drill — the PPD is used to derive a set of surfaces, temperature, radiation, rainfall, evaporation and vapour pressure deficit. The grid size is 0.05° and is interrogated via a web interface whereby the user is asked to specify the latitude and longitude of the location of interest and the time span, from 1 January 1889 to present. The interpolation technique is based on thin-plate smoothing with longitude, latitude and elevation as independent variables.

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Data sets from BoM

Station data — raw, quality controlled for recording errors, but not changes in instrumentation and environment and referred to as AWAP. Data have missing values. This is the same data used to derive the PPD, but without in-filling. More or less variables will be available depending on the individual weather station.

ACORN-SAT - This data set includes data from 112 locations across Australia that provide homogenised, ground-based temperature records. The locations are chosen to maximise the length of record and network coverage across the country. Data is available for the St George Airport site (43109) from 1913. The impact of homogenisation was to adjust maximum temperatures by -0.61 °C and minimum temperatures by -1.05 °C when the station was moved from the Post Office to the airport. Three other adjustments were made:

Maximum temperature prior to 1991 +0.34 °C
Minimum temperature prior to 1936 +0.72 °C
Maximum temperature prior to 1924 +0.35 °C
These were derived from a statistical analysis and have no supporting metadata to indicate what changes took place that necessitated the adjustment.

Adjustments were made with reference to a number of surrounding stations (see bom station adjustment summary for details). The following is recorded in this document:

It is important to emphasise that both the much larger, raw (unadjusted) data set (known as AWAP) and the smaller (homogenised) ACORN-SAT data set show that Australia has been getting warmer since 1910 and that the two data sets indicate a very similar amount of warming overall.

BoM Gridded data — this data set contains interpolated, daily data across Australia and coincides with the Data Drill. The method of interpolation is different. This data tends to have a greater degree of smoothing than the Data Drill (Steve Jefferies DSITI, pers. comm.) and do not tend to reproduce the observed values for a given station.

Data availability for St George

The observational record on which the data sources are based are shown in Figure 2. The locations of the stations are shown in Figure 3. As noted above there is no overlap between the temperature records between the Post Office and the airport, probably because equipment was moved from one station to the other.

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Figure 2 - Data availability as percentage of year from 1957 onwards for St George stations.

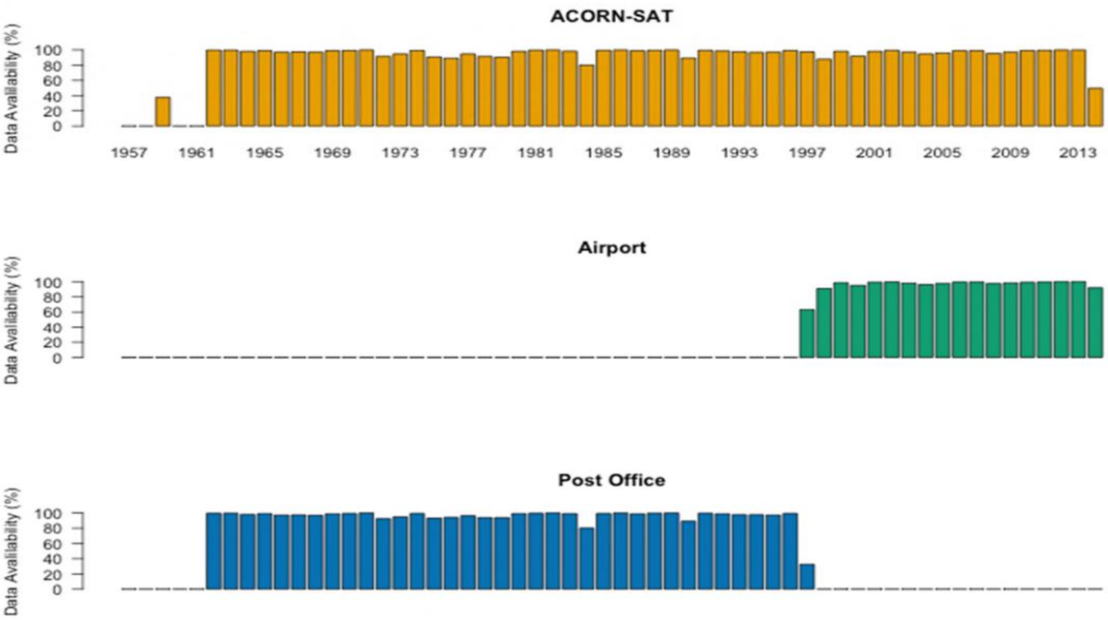

Figure 3 - Location of recording stations at St George. The white grid represents the Data Drill and BoM gridded data sets.

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1.3 Analysis of data

In order to understand the data from St George it is important to consider the relationships between the data sets. In Figure 4 the relationship between PPD, Data Drill, BoM Grid and ACORN-SAT are explored for the St George Airport site and includes the relationship between the Post Office and Airport in the PPD. The differences in methodology between the Data Drill and BoM grid are clearly shown in the Top-right figure of Figure 4. This becomes more obvious in the middle row and backs up Steve Jefferies assertion that the Data Drill more closely reproduces the station data (right) than does the BoM grid. In the bottom panel the comparisons are between the ACRON-SAT data for the Airport and the BoM grid (left) and the Data Drill (left). In both cases there appears to be something strange going on.

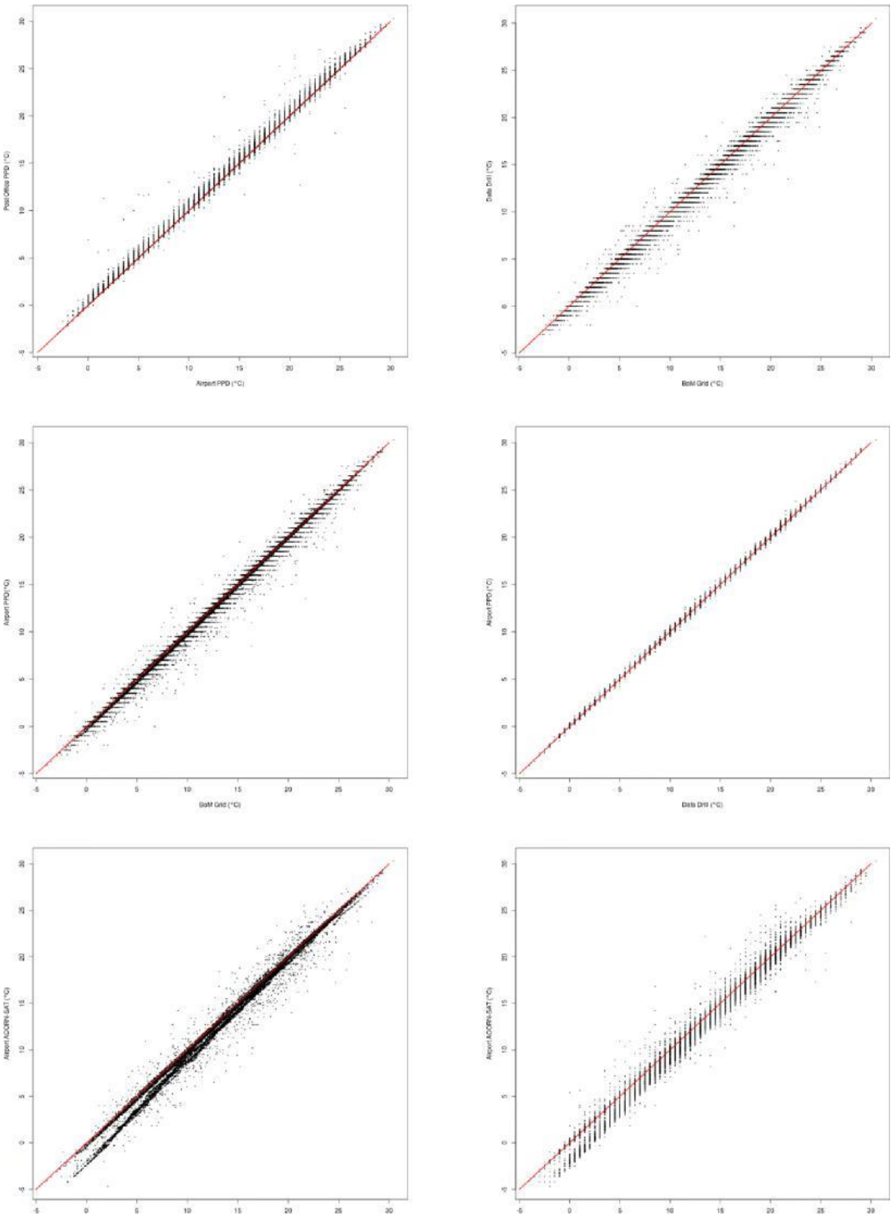

Figure 4 - Comparison between data sets for minimum temperature. Top —left: PPD data for Post Office and Airport. Top-right: Gridded data from Data Drill and BoM. Middle: Airport PPD versus BoM Grid (left) and Data Drill (right). Bottom: Airport data from ACORN-SAT versus BoM Grid (left) and Data Drill (right).

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To explore the ACORN-SAT data further, one can quickly show that until 10 May 1997, when the Airport site started, the difference in minimum temperatures had a median of -0.7 (meaning that the ACORN-SAT data is cooler) with extremes of -7.2 to 8.7 with an IQR of -2.3 to -0.4 (75% of differences are in this range). Once the Airport site came online the data sets are identical.

1.4 Translation from Data to Analyses

Construction of box plots for minimum and maximum temperature are not revealing. There are slight, but non-significant differences, Figure 5

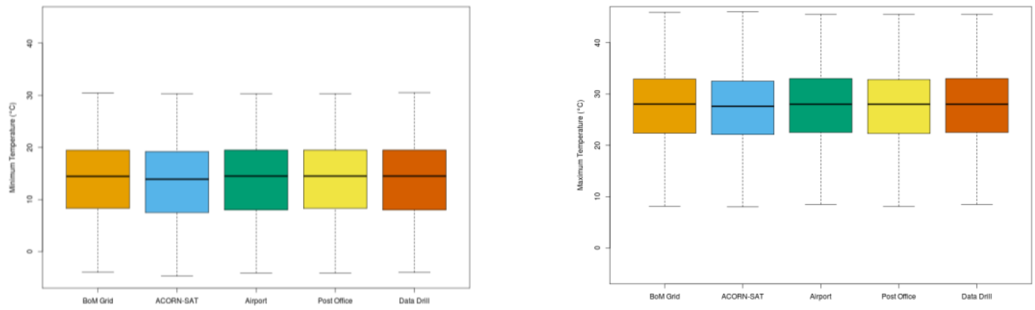

Figure 5 - Comparison between minimum (left) and maximum (right) temperatures from the data sets. This takes into account missing data ACORN-SAT data.

However, when a threshold is brought into the analysis the result is quite different, Figure 6. The impact is greatest on minimum temperature thresholds, than maximum temperature thresholds. Also, the differences between Airport and Post Office can be clearly seen with a greater incidence of frost recorded for the Airport. The ACORN-SAT site overestimates incidence of frost days per year, while the BoM grid underestimates frost days by 21% compared to the Airport data. The Data Drill more closely estimates the observed data with a 3% over-estimate of frost days.

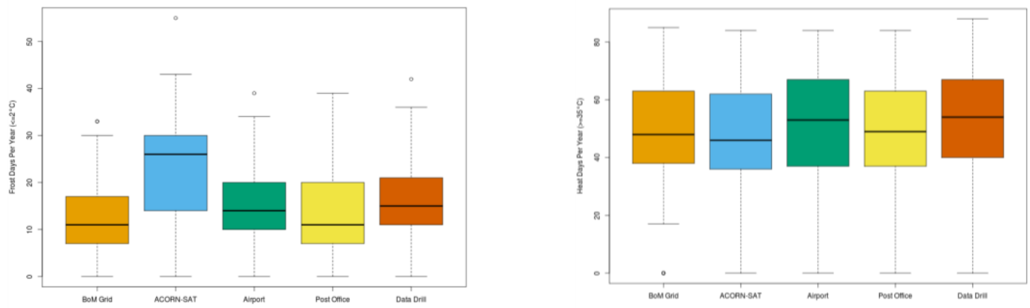

Figure 6 - Comparison between frost days per year, i.e. <=2 °C (left) and heat days per year, i.e. >= 35 °C (right) for the data shown in Figure 5.

With respect to the calculation of chill hours per year, Figure 7 suggests that the effect of switching from BoM Grid to Data Drill should be minimal, -4.6% underestimate using BoM Grid. This will be relatively quick to examine across the region once the Data Drill becomes available.

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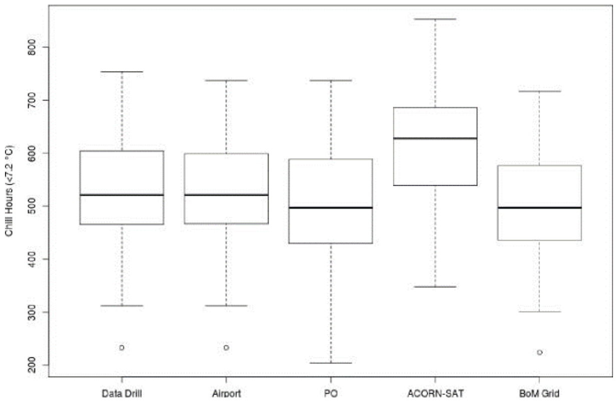

Figure 7 - Chill hours per year (1963-2013) using the different data sources for St George. ACORN-SAT has been in-filled to provide a continuous data series.

1.5 Conclusions

- It would seem that the DSITI gridded data is more suitable for these analyses than the BoM gridded data.
- Note that the chill hour percentages that have been calculated to date have used the BoM data and so probably underestimate chilling. But the effect should be small
- The disparity in the historical observations between growers and the pre-1997 Post Office data is obviated to some extent by the use of the PPD data for the Airport, but not completely. This is to be expected and unless the process is highly sensitive to departures at a point scale then it is unlikely that an incorrect conclusion would be drawn.
- It would be very useful to have data recorded by a grower near St George to explore the relationship between that and the Post Office site.
- The ACORN-SAT data appears to be meteorologically accurate, but unsuitable for modelling. It no doubt has greater application in climate trend analysis.

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2. Mapping the QMDB Study Area for temperature, irrigation and soil suitability

2.1 Mapping of Regional Temperatures

Mean temperatures

Mean monthly minimum and mean monthly maximum temperatures across the region can give an indication of which parts of the QMDB Study Area and which months are unsuitable for particular crops. However it is important to be aware that actual daily, weekly or monthly maximum or minimum temperatures may be much higher or lower than the long term average. Figure 8 below shows the mean monthly minimum temperatures based on data from 1957 to 2014 across the study area.

The coolest months are June to August but the impacts of low temperatures may need to be considered from May to September. The coolest parts of the region are around the Granite Belt and the South East corner of the study area. Generally minimum temperatures increase to the West of the region.

Figure 9 shows mean monthly maximum temperatures across the QMDB study area. The hottest months are December to February but impacts of high temperatures on certain crops may need to be considered from November to March for large parts of the region. St. George and areas further west have mean temperatures of 29°c or higher from October to March.

Whilst mean monthly temperatures can give a useful overview of temperature trends across the region it is important to also look at how frequently temperatures below or above critical crop growth thresholds occur. See specific examples for broccoli and sweet corn which are examined in detail below.

When viewing maps and considering the temperature data it is important to remember that all data is sourced from official Bureau of Meteorology sites. Actual temperatures at a specific location may vary according to local topography and prevailing wind patterns.

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Figure 8— Mean monthly minimum temperatures in the study area.

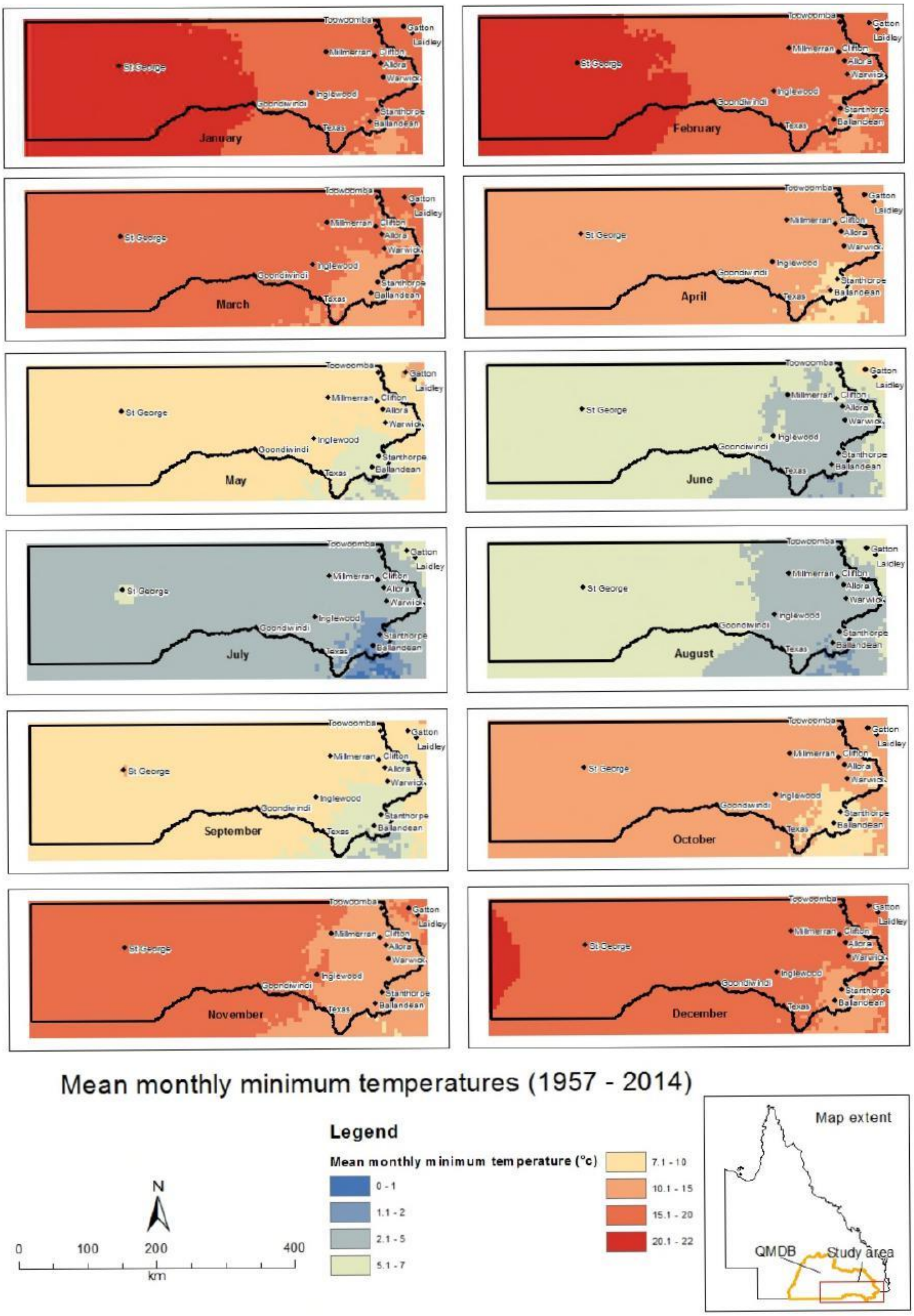

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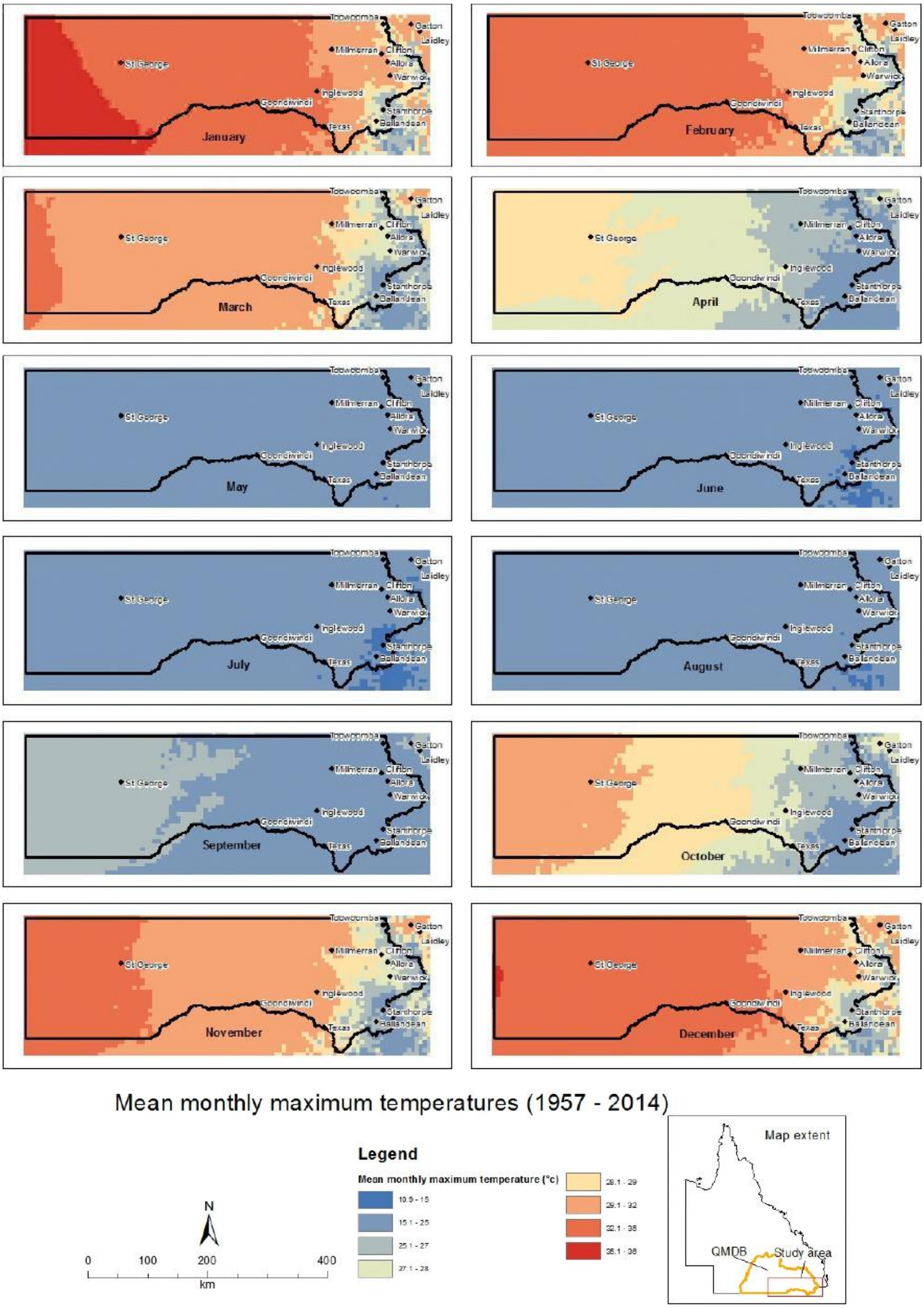
Figure 9— Mean monthly maximum temperatures for the study area



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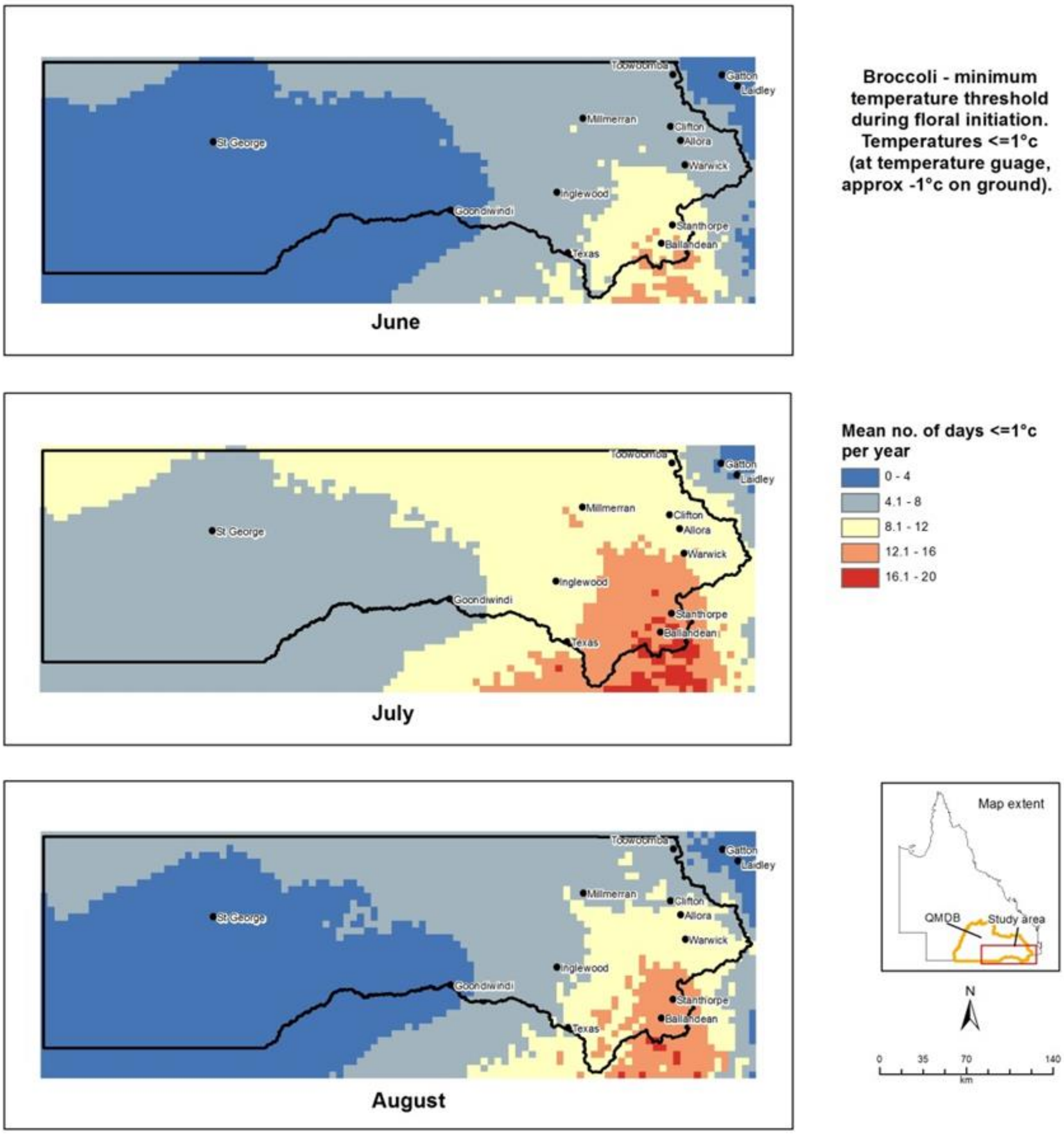
2.2 Minimum Temperature Thresholds - Broccoli

Broccoli is a temperate vegetable crop, which is grown in Queensland mainly during the winter.

Floral Initiation is a critical development phase in broccoli, during this phase, temperatures above or below a threshold will affect head development and subsequently head quality. Only high quality broccoli heads are acceptable on the market.

Figure 10 maps the average number of occurrences of minimum temperatures equal to or less than 1 C (at the temperature gauge which equates to around -1°C on the ground) in the study area. At or below -1 C ground temperature, broccoli floral initiation is affected, and yield is reduced as the resulting broccoli heads are misshapen, with uneven bead size. As the number of days at or below -1 C on the ground increases, the negative impacts become more pronounced.

Figure 10 — Average number of occurrences of =<1°C



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Number of days below a Temperature Threshold (monthly assessment)

Broccoli is a temperate vegetable crop, which is grown in the Lockyer and Fassifern Valley's mainly during the winter and on the Easter Darling Downs and Granite Belt in summer. Figure 11 to Figure 14 map the number of occurrences of minimum temperatures (on a monthly basis for all the years from 1957 to 2014) equal to or less than -3 C, in the QMDB Study Area.

At or below -3°C (at the level of the temperature gauge which is approximately -5 °C on the ground), broccoli floral initiation is significantly affected with some shoot apices killed. Yield is significantly reduced. As the number of days at or below -3 C (-5 C ground temperature) increases, the negative impacts on broccoli yield and quality become more pronounced.

The first map for each month (max no. of days <=-3°C) shows the highest number of days less than or equal to -3 C recorded in that month for any one year between 1957 and 2014. This is the worst case scenario. The next map (min no. of days <=-3 .C) shows the lowest number of days less than or equal to -3 C recorded in that month for any one year between 1957 and 2014. This is the best case scenario.

The mean, median and standard deviation of the number of occurrences of minimum temperatures equal to or less than -3 C for that month are also shown. This gives an idea of the average conditions that can be expected for that month across the QMDB Study Area and how much variation from the mean can be expected. The `range of no of days <=-3 C' map, shows the maximum number of occurrences minus the minimum number of occurrences, so also gives an idea of how much variation in number of days with temperatures of less than or equal to -3 C occurs across the region. The total number of occurrences shows the total number of times between 1957 and 2014 that temperatures less than or equal to -3 C have occurred in that month.

Figure 11 shows that temperatures of less than or equal to -3°C occur infrequently in May. In the worst year on record the Granite Belt area had several days that were under -3 C but median occurrences are 0 across the region. Figure 12 shows that the number of days less than or equal to -3 C increases from May to June and that the variability in number of low temperature days from year to year is quite noticeable. This shows a higher risk in planting broccoli, particularly in the Eastern part of the region in June. July (Figure 13) has the highest number of days less than or equal to -3 C. The mean number of days less than or equal to -3 C in the QMDB study area is between 1 and 4 for most of the region and higher for the Granite Belt ¬indicating a high risk in planting broccoli or other crops (see Crop Suitability Matrix ¬Appendix 1) sensitive to frost and low temperatures. The number of days when minimum temperatures drop below -3 C are slightly lower in August (Figure 14) than July but most of the region apart from St. George and the western part of the study area have an average (mean) of 1-4 days that drop below the critical low temperature threshold for broccoli

The floral initiation stage of broccoli growth is most sensitive to freezing. Low temperatures during buttoning tend not to reduce head yield but may produce low quality heads. As shown in the 'seasonal production windows table' on Page 73, broccoli is best planted between March and May in the study area to avoid lower temperatures.

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Figure 11- number of occurrences of minimum temperatures (for the month of May for all the years from 1957 to 2014) =<-3°C

May

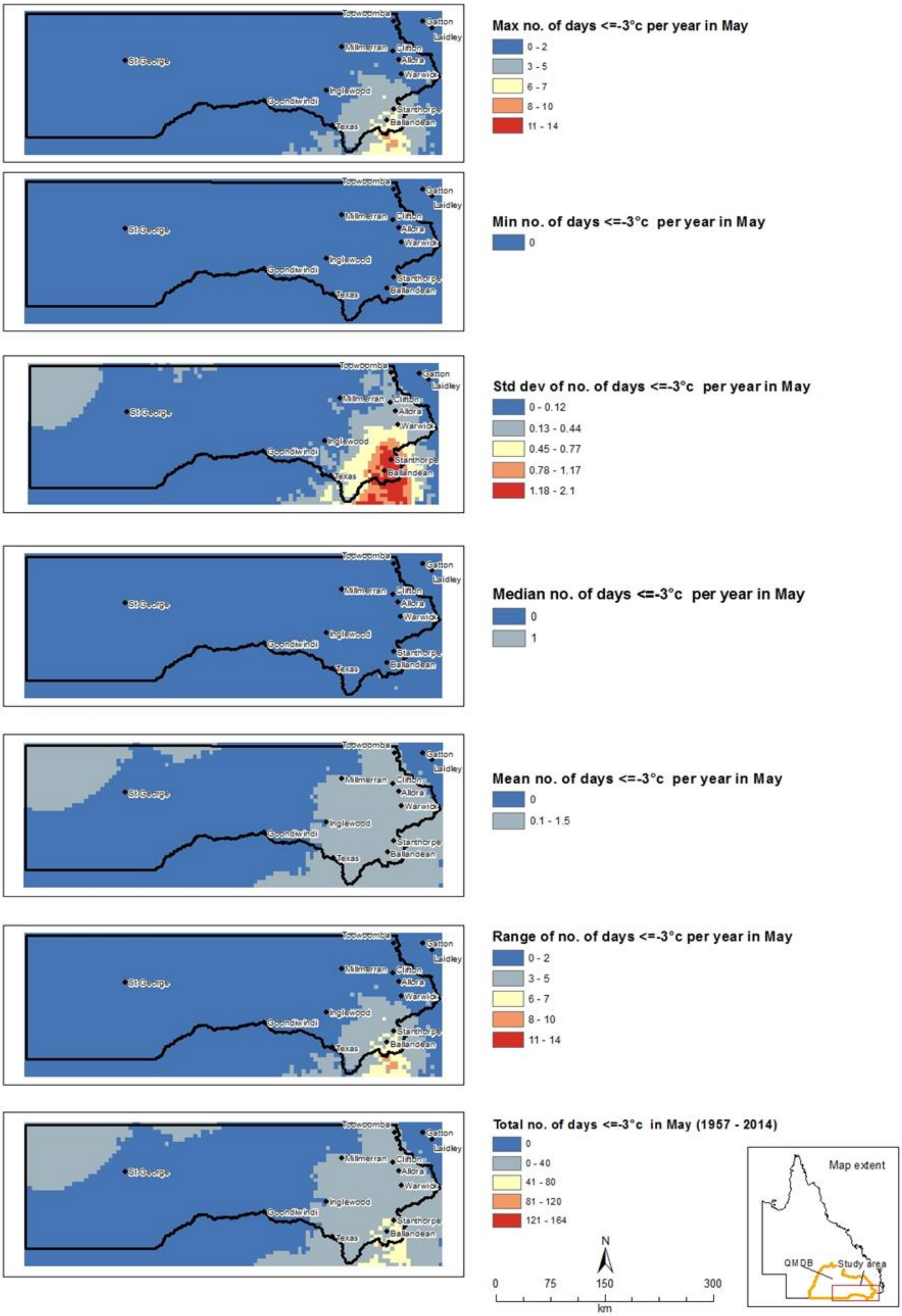

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Figure 12 - number of occurrences of minimum temperatures (for the month of June for all the years from 1957 to 2014) =< -3°C.

June

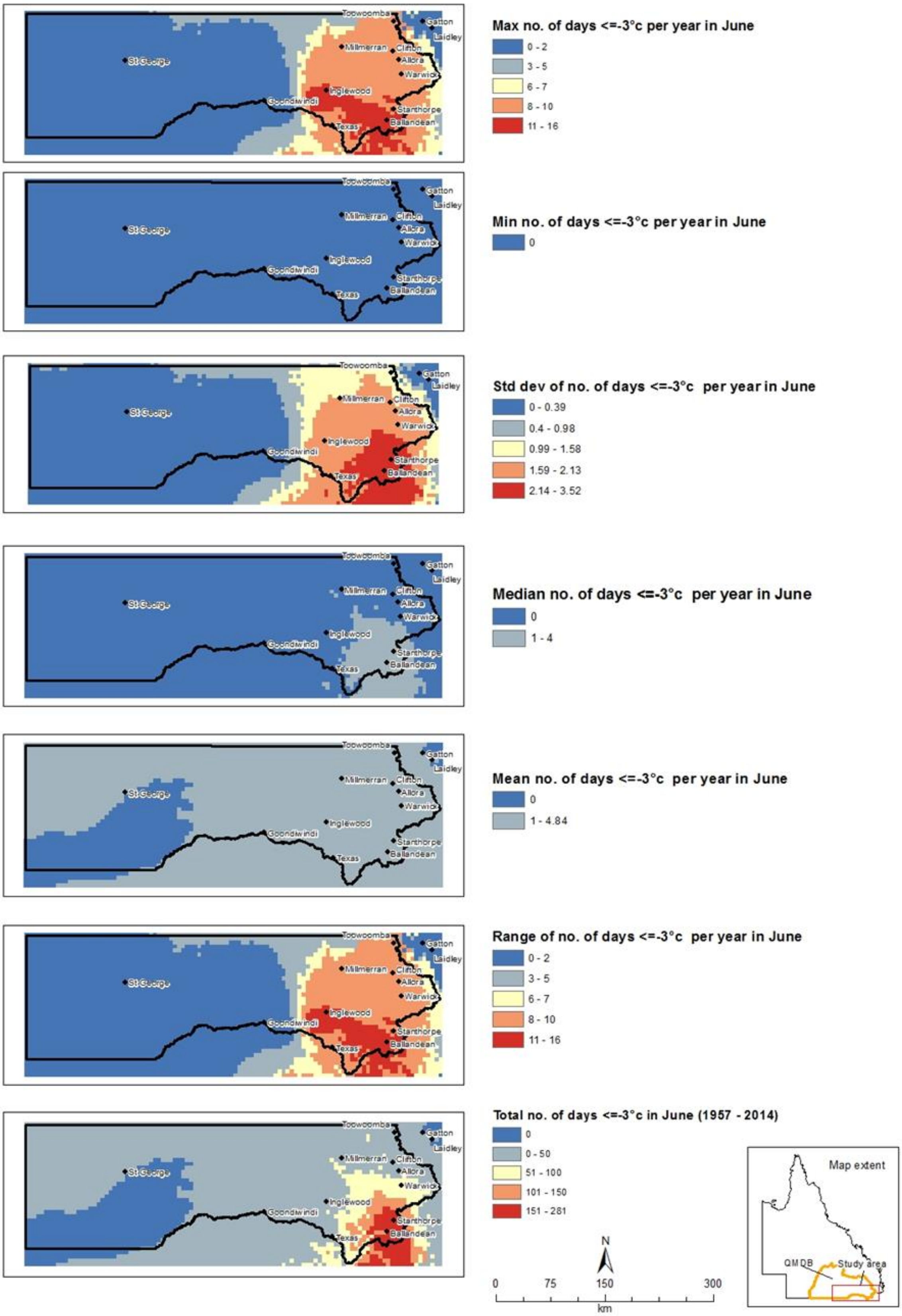

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Figure 13 - number of occurrences of minimum temperatures (for the month of July for all the years from 1957 to 2014) =< -3°C.

July

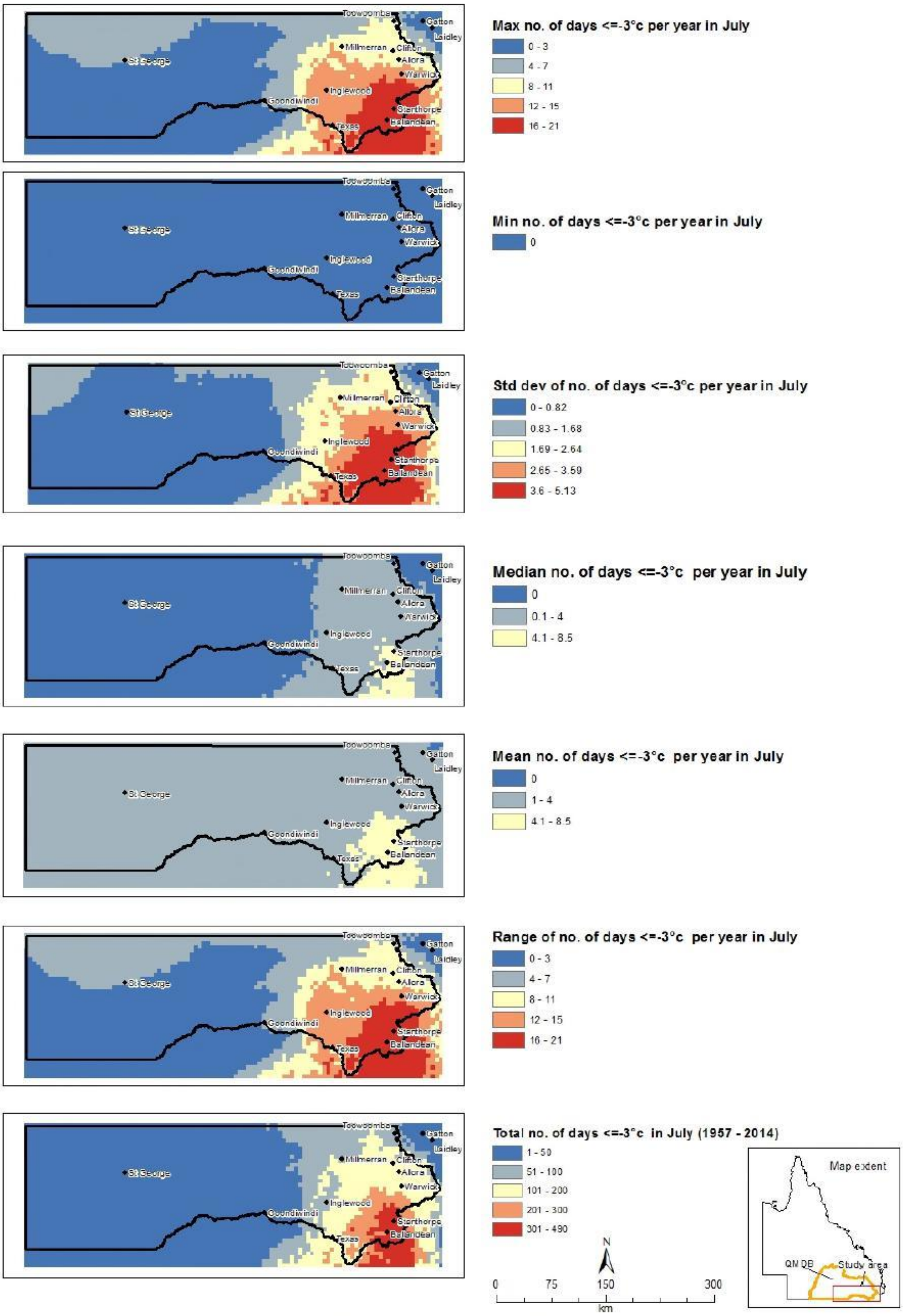

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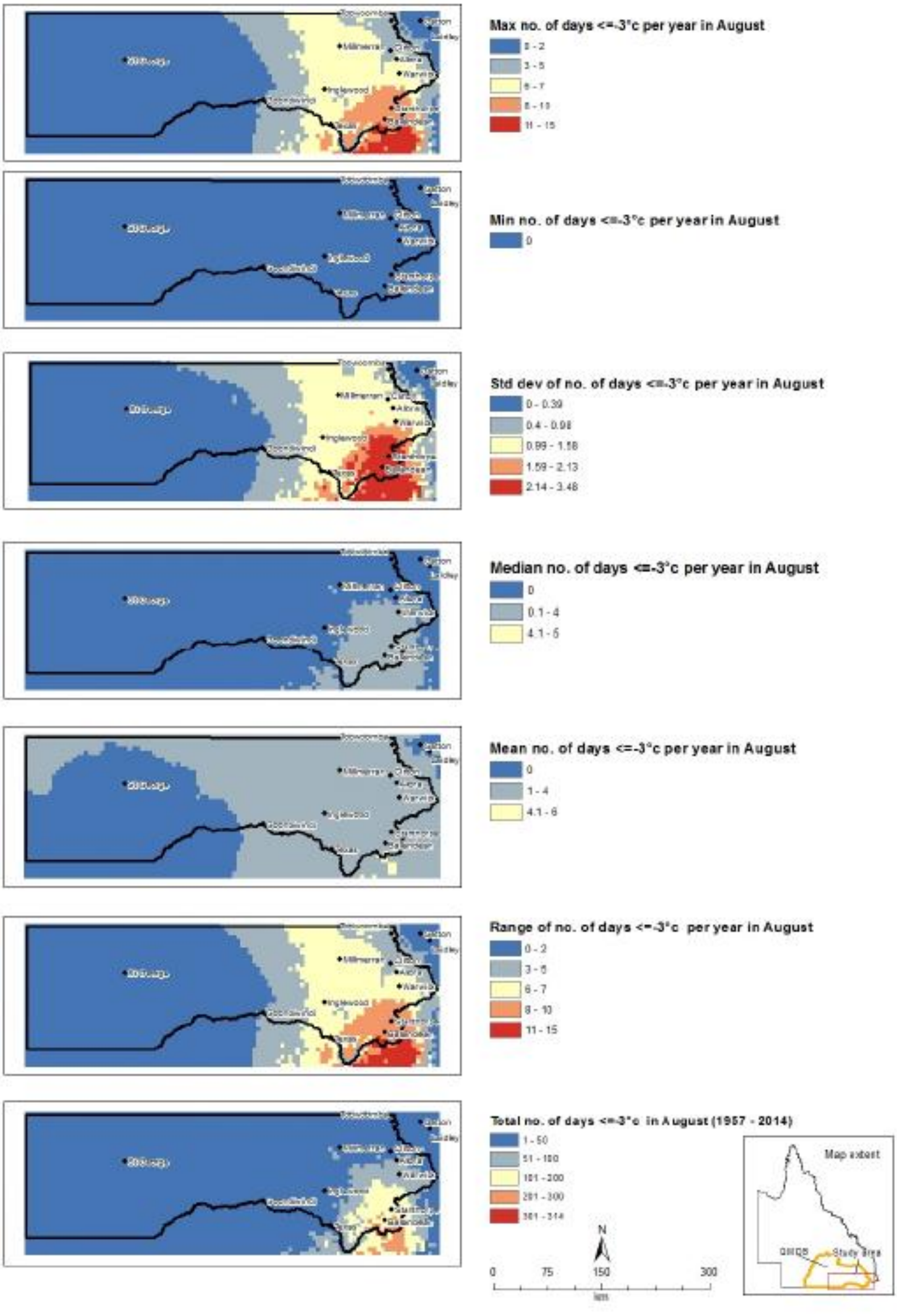
Figure 14 - number of occurrences of minimum temperatures (for the month of August for all the years from 1957 to 2014) =< -3°C.

August



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2.3 Number of days above a Temperature Threshold (monthly assessment) — Sweet Corn.

Sweet Corn is a temperate vegetable crop, grown in Queensland during the summer in the south (e.g. Lockyer Valley) and the winter in the north (e.g. Bowen).

Silking is a critical development phase in sweet corn, during which temperatures above the critical threshold (more than 3 days with a maximum temperature above 35°C) will affect pollination and subsequent cob quality. Only high quality sweet corn cobs are acceptable on the market. Figure 15 to Figure 22 map the number of occurrences of maximum temperatures (on a monthly basis for all the years from 1957 to 2014) greater than or equal to 35 C, in the study area.

Above 35°C, sweet corn pollen becomes desiccated, pollination is impacted, and cob quality is significantly reduced. As the number of days with maximums equal to or above 35 C increases, the negative impacts on sweet corn marketable yield and quality become more pronounced.

The maps below (of the number of days with maximum temperatures over 35°C) demonstrate the effects of high temperatures on the potential performance of sweet corn at St George compared with the Lockyer Valley production area (see also Economic Analysis section).

The map series below depicts temperatures greater than or equal to 35°C in the same format as was used in the previous broccoli temperature examples. These maps show the best case, worst case, average and variation in number of days greater than or equal to 35 C by month based on daily temperature data from 1957 to 2014. Figure 15 shows that temperatures greater than or equal to 35 C are relatively infrequent in September but can occur, particularly around St. George and further west. The occurrence of hot days (over 35 C) increases in October (Figure 16) particularly for western parts of the region. By November (Figure 17) large parts of the region experience some days over 35 C. Areas west of Inglewood experience, on average, 3 - 7.5 days of 35 C or more in November and areas from St. George to the west have up to 12 hot days.

By December (Figure 18) nearly all of the study area experiences more than 3 days of 35 C or higher. Only the Eastern Downs and Granite Belt has less. In the hottest year recorded areas from Goondiwindi to the west recorded temperatures of at least 35 C every day of the month. January (Figure 19) has the highest number of days above 35 C across the study area. Again, only the Eastern Downs and Granite Belt receive a few hot days. There is a lower risk of experiencing days over 35 C in February (Figure 20) but areas west of Inglewood are still likely to experience at least 3 days of at least 35 C.

By March (Figure 21) the likelihood of getting extremely hot days reduces further. Areas west of Goondiwindi may still experience 3 or more days of 35 C or higher. In April (Figure 22) the median number of days greater than or equal to 35 C is 0 for the whole region.

Due to the likelihood of extremely hot days, adopting a split production season that avoids the hottest temperature periods from mid-November to mid-February would be the preferred method for growing sweet corn and other crops susceptible to high temperatures in this region.

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Figure 15 - number of days where maximum temperatures (for the month of September for all the years from 1957 to 2014) reach 35°C

September

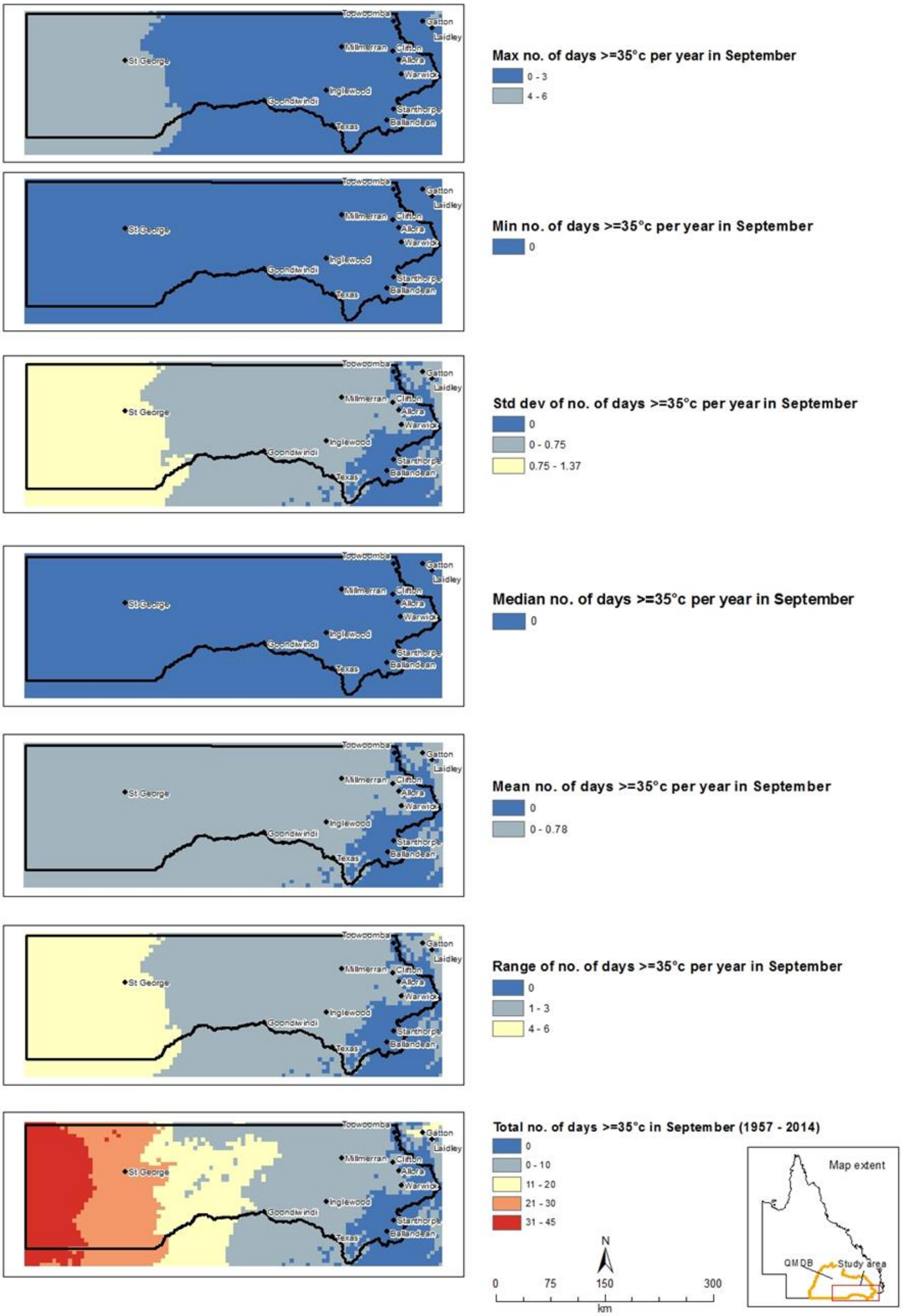

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Figure 16 - number of days where maximum temperatures (for the month of October for all the years from 1957 to 2014) reach 35°C.

October

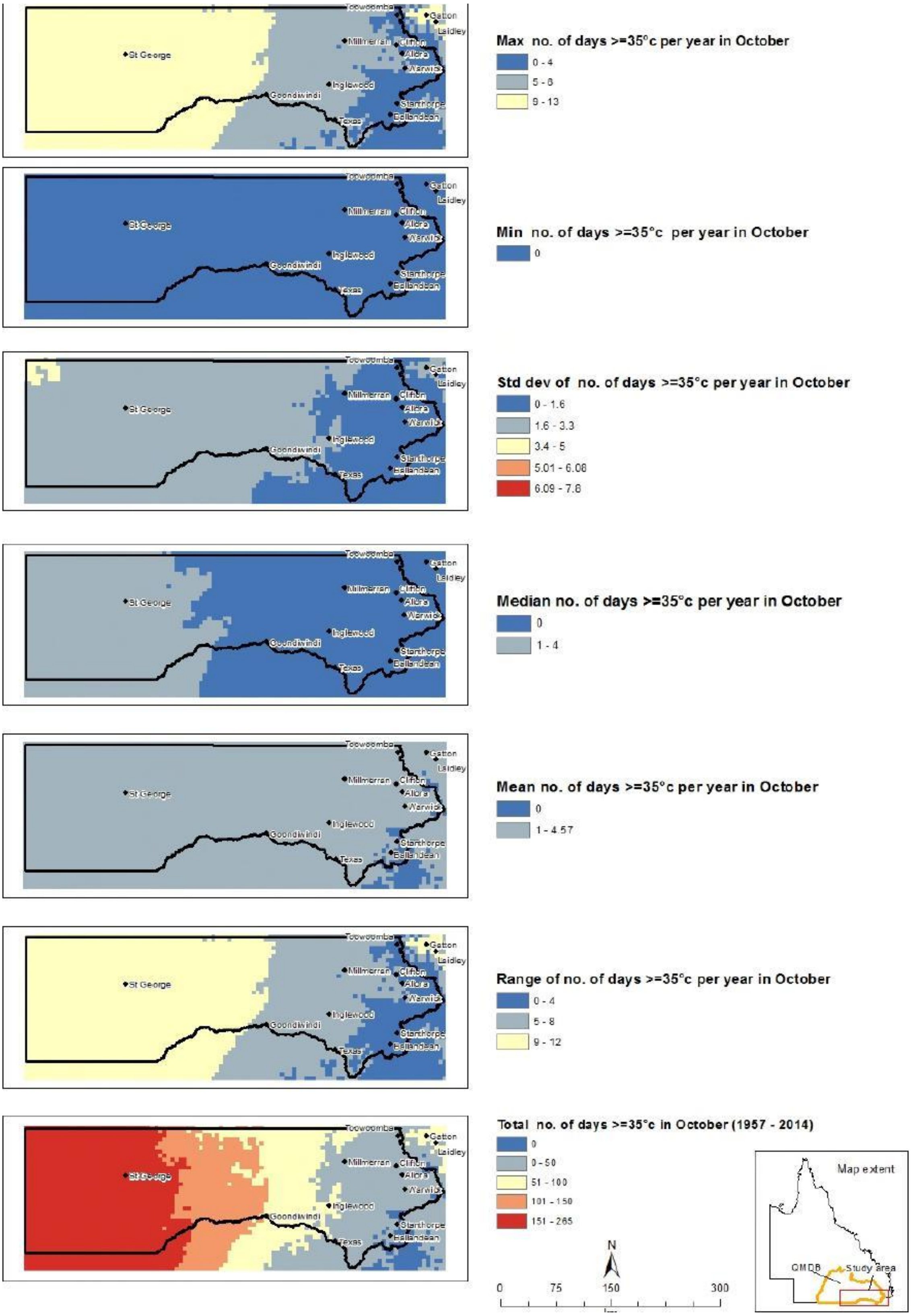

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Figure 17 - number of days where maximum temperatures (for the month of November for all the years from 1957 to 2014) reach 35°C.

November

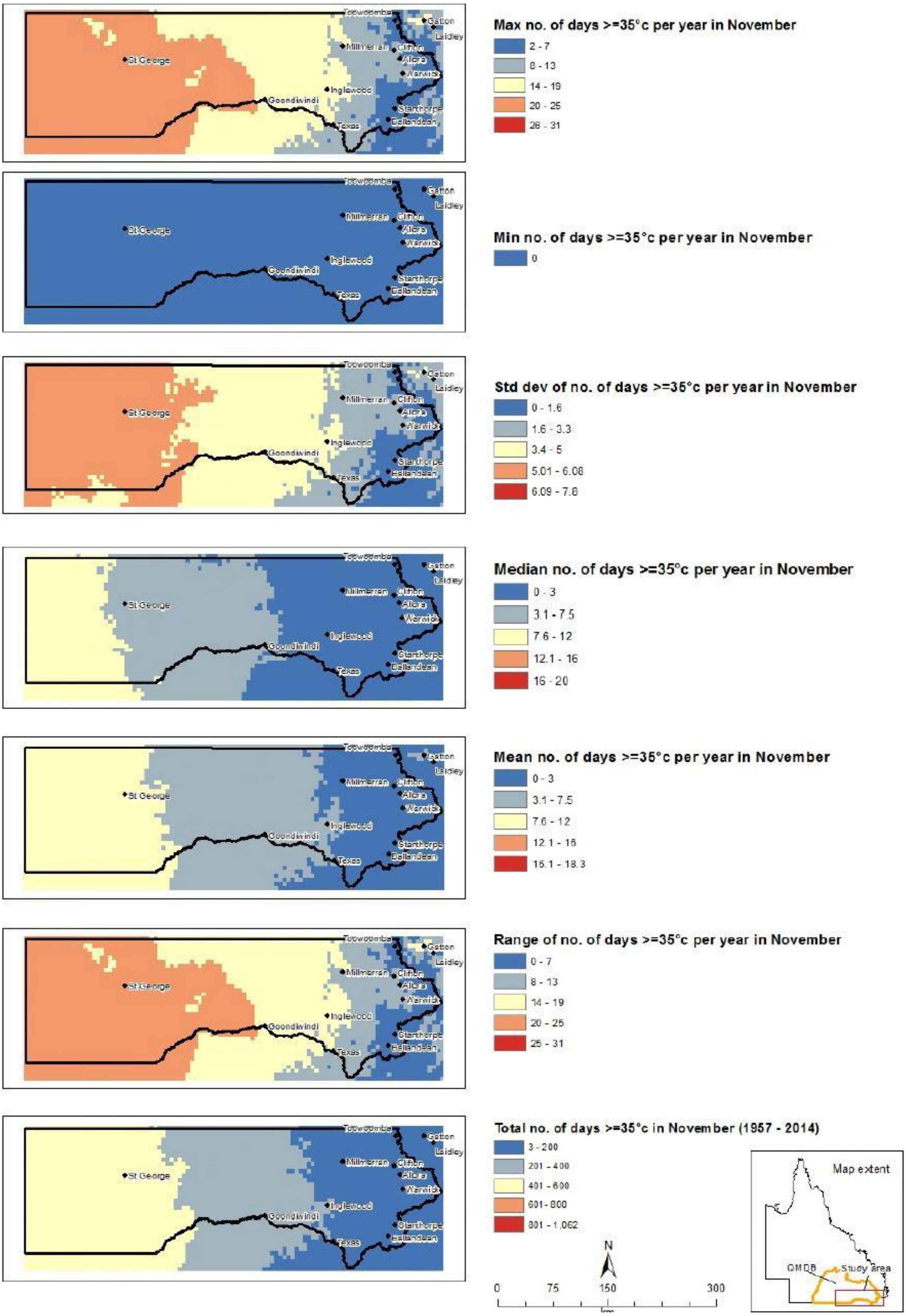

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Figure 18 - number of days where maximum temperatures (for the month of December for all the years from 1957 to 2014) reach 35°C.

December

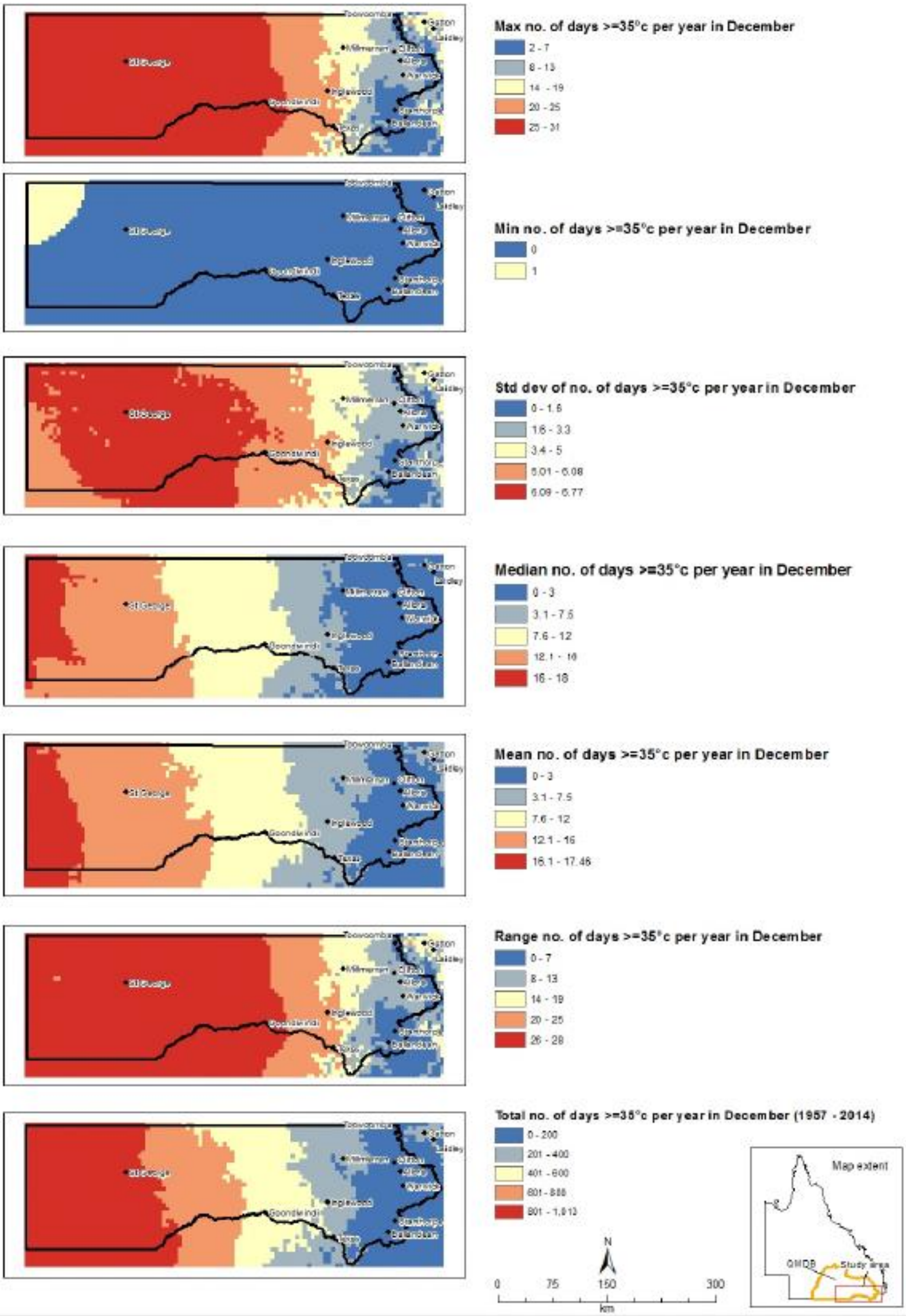

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Figure 19 - number of days where maximum temperatures (for the month of January for all the years from 1957 to 2014) reach 35°C.

January

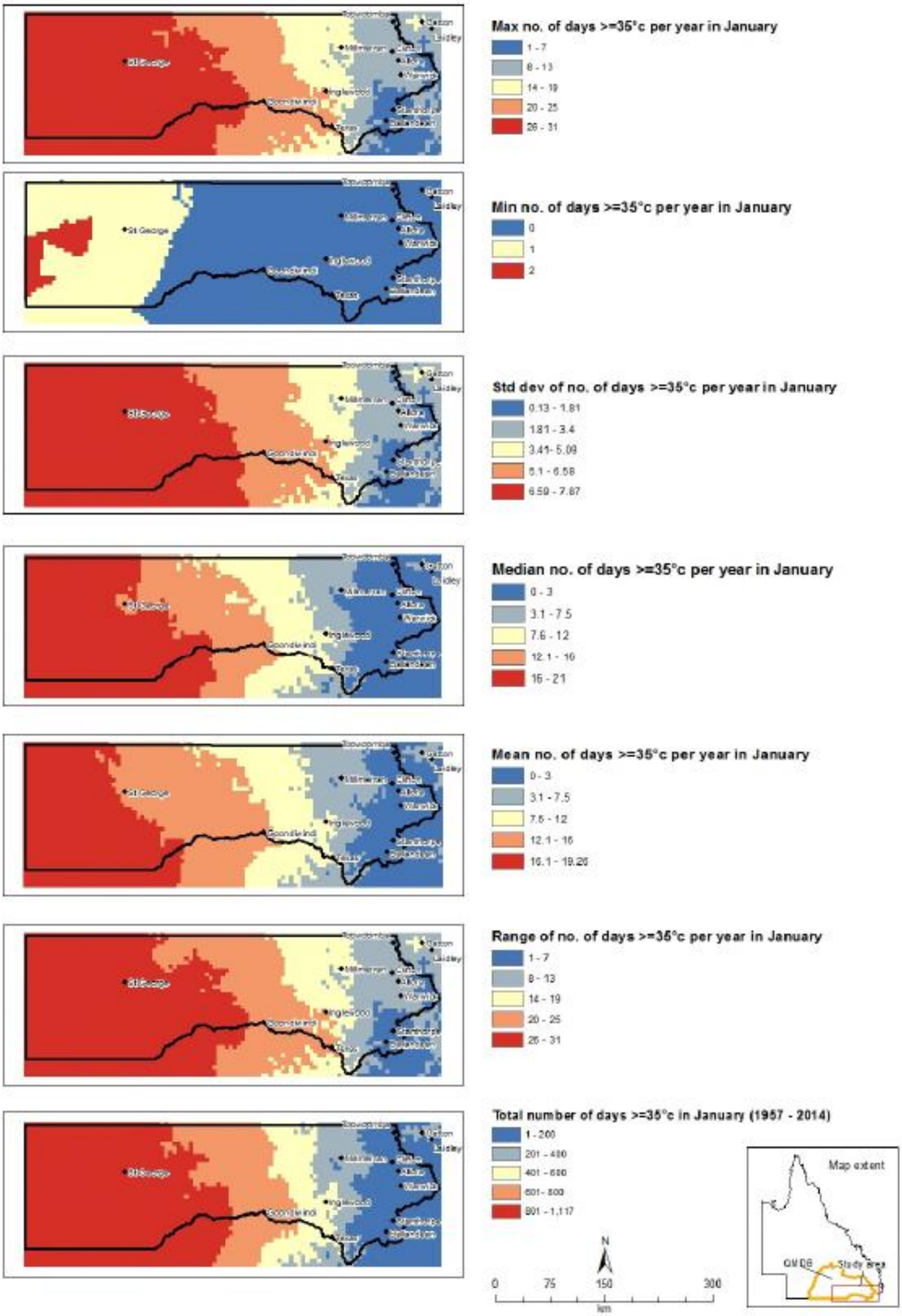

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Figure 20 - number of days where maximum temperatures (for the month of February for all the years from 1957 to 2014) reach 35°C

February

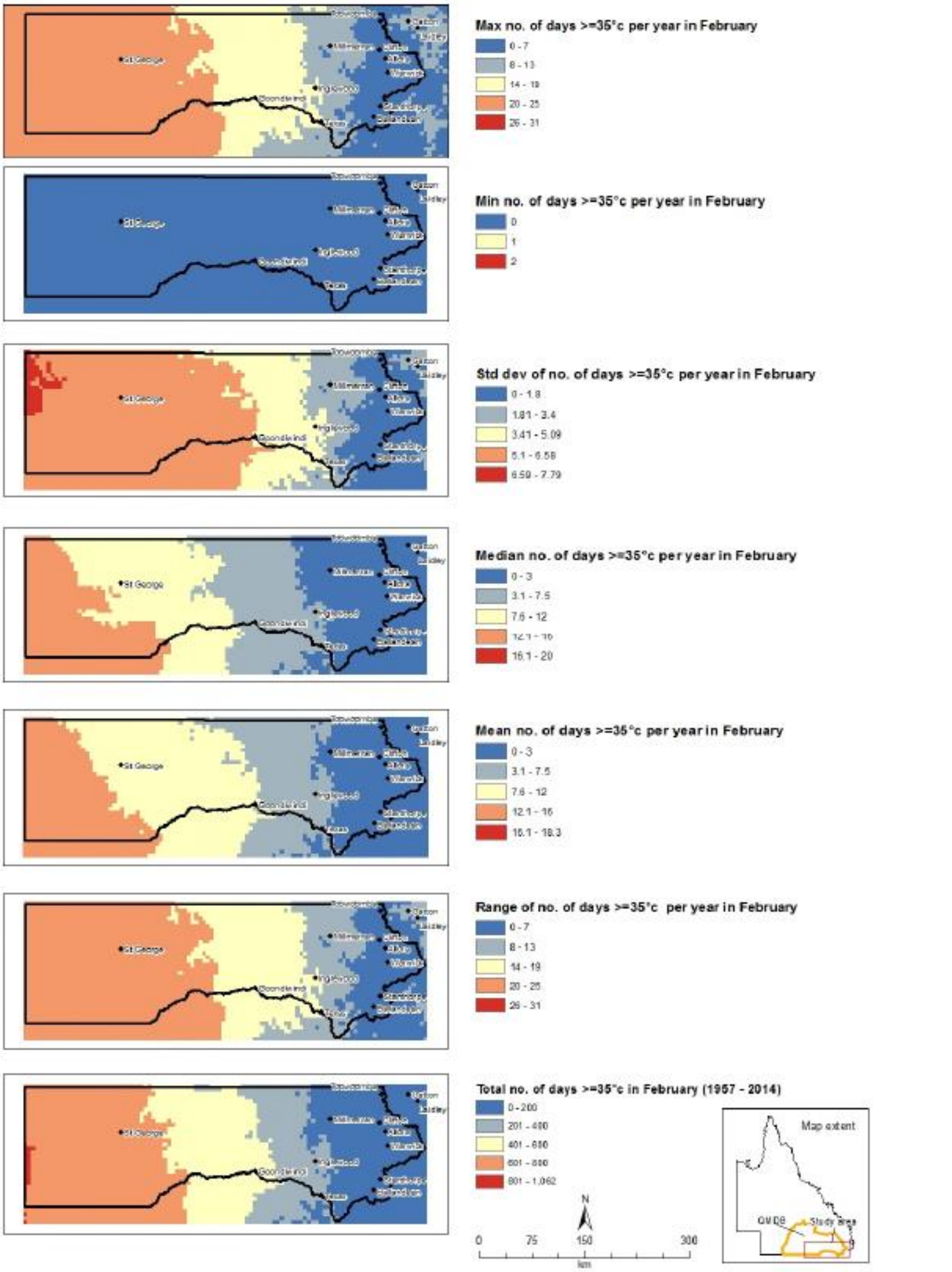

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Figure 21- number of days where maximum temperatures (for the month of March for all the years from 1957 to 2014) reach 35°C

March

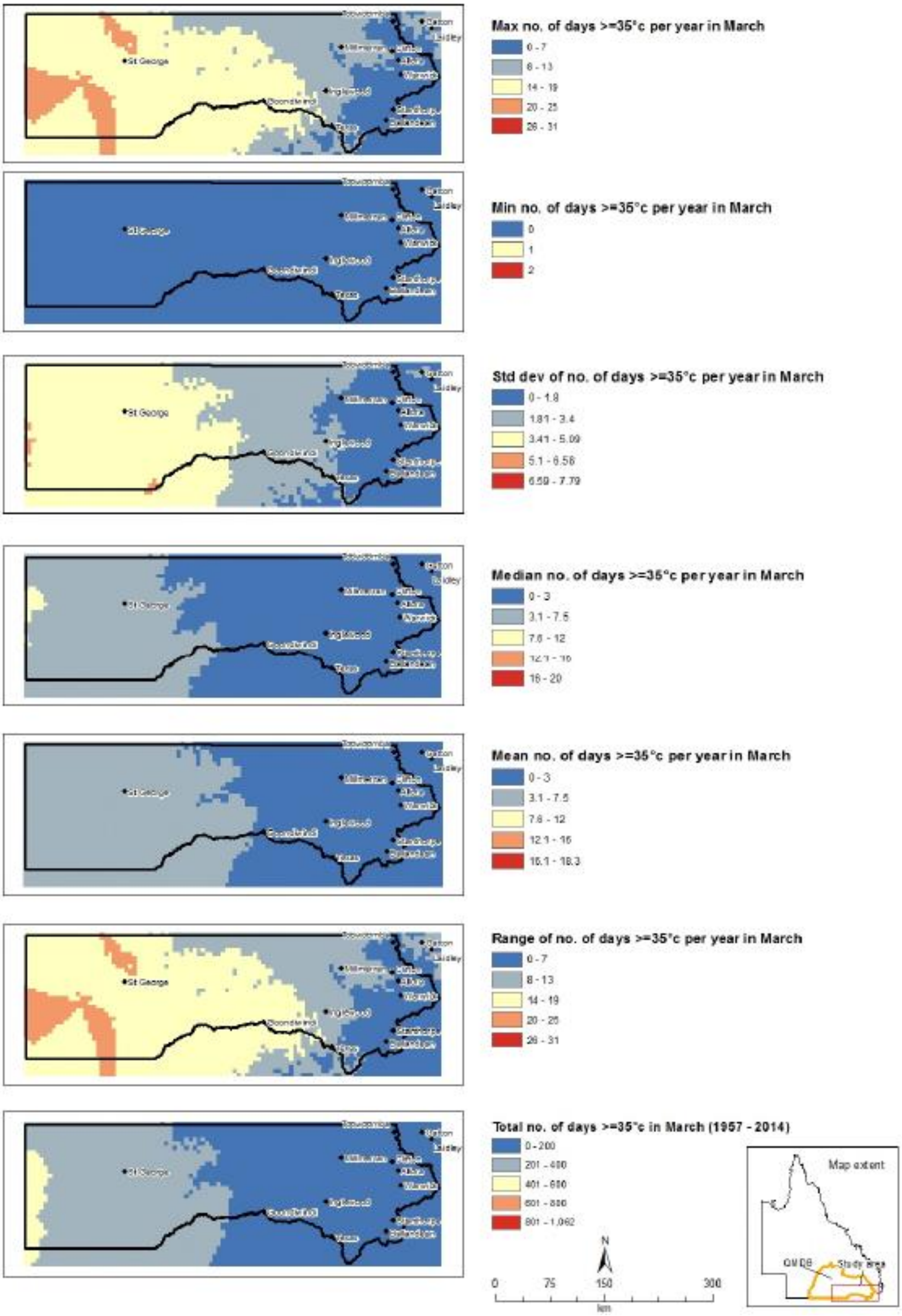

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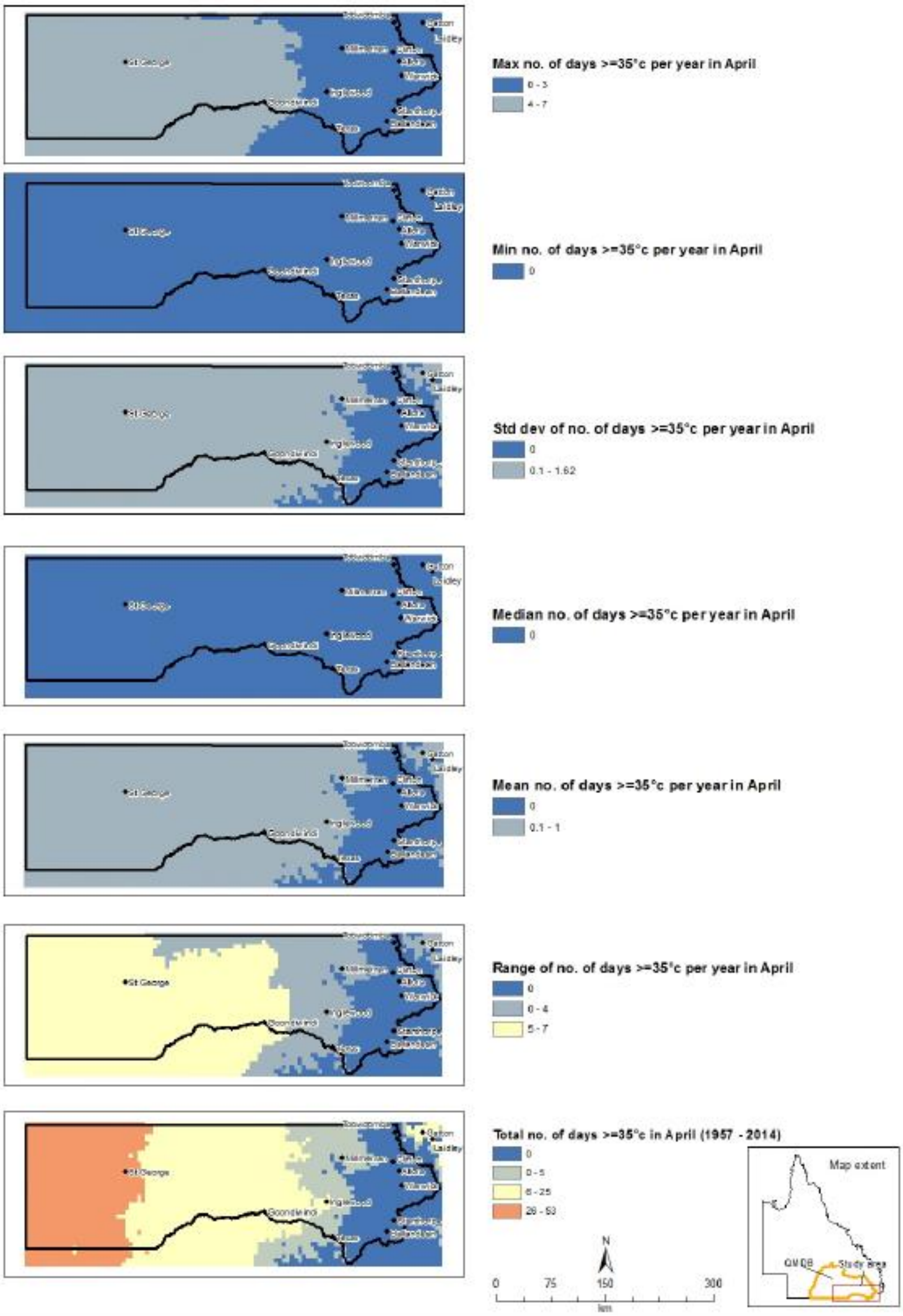
Figure 22 - number of days where maximum temperatures (for the month of April for all the years from 1957 to 2014) reach 35°C

April



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2.4 Potential production periods and locations for example crops (sweet corn, broccoli & lettuce)

In order to better compare the impacts of minimum and maximum temperatures on production windows and locations across the region, maps were developed for sweetcorn, broccoli and lettuce based on mean monthly minimum and mean monthly maximum temperatures within the study area.

Figure 23 shows potential production periods for sweetcorn based on mean monthly minimum temperatures of >9.5°c and mean monthly maximum temperatures of less than 30.5°c. Minimum temperatures are too low across all of the region from May to August for optimal sweetcorn production whereas maximum temperatures exclude Western parts of the region from November to March.

Figure 24 shows potential production windows for Broccoli based on a mean monthly minimum of >4.5°c and a mean monthly maximum of <30°c. High and low temperatures, particularly during floral initiation, impact floret formation and head quality. All but the most easterly parts of the region and the Granite Belt need to consider impacts of high temperatures from November to March. April, May and September, October provide minimal limitations in terms of high and low temperatures. Minimum temperatures need to be considered from June to August.

Figure 25 shows potential production windows for lettuce based on mean monthly minimum temperatures of 6°c and mean monthly maximum of 28°c. Lettuce quality is impacted by both high and low temperatures. High temperatures at the time of head rolling and filling can cause seed stalk development and fluffy, loose heads. High temperatures limit production across most of the region apart from the Granite Belt from November to March. Minimum temperatures need to be considered for most of the region from June to August and May to September for the Granite Belt.

Whilst mean monthly temperatures give a good overview of historical temperature variation across the region it is important to consider that current season temperatures may be much higher or lower than *t*he long term average. The large geographical scale of the data also does not capture local micro-climates due to the size of the grid squares and interpolation from a small number of weather stations.

Temperature while a major plant growth driver is only one of many factors that influence crop growth and product quality. Soil type, variety, irrigation and nutrition regime, grower expertise and many other factors also influence crop quality and production outcomes.

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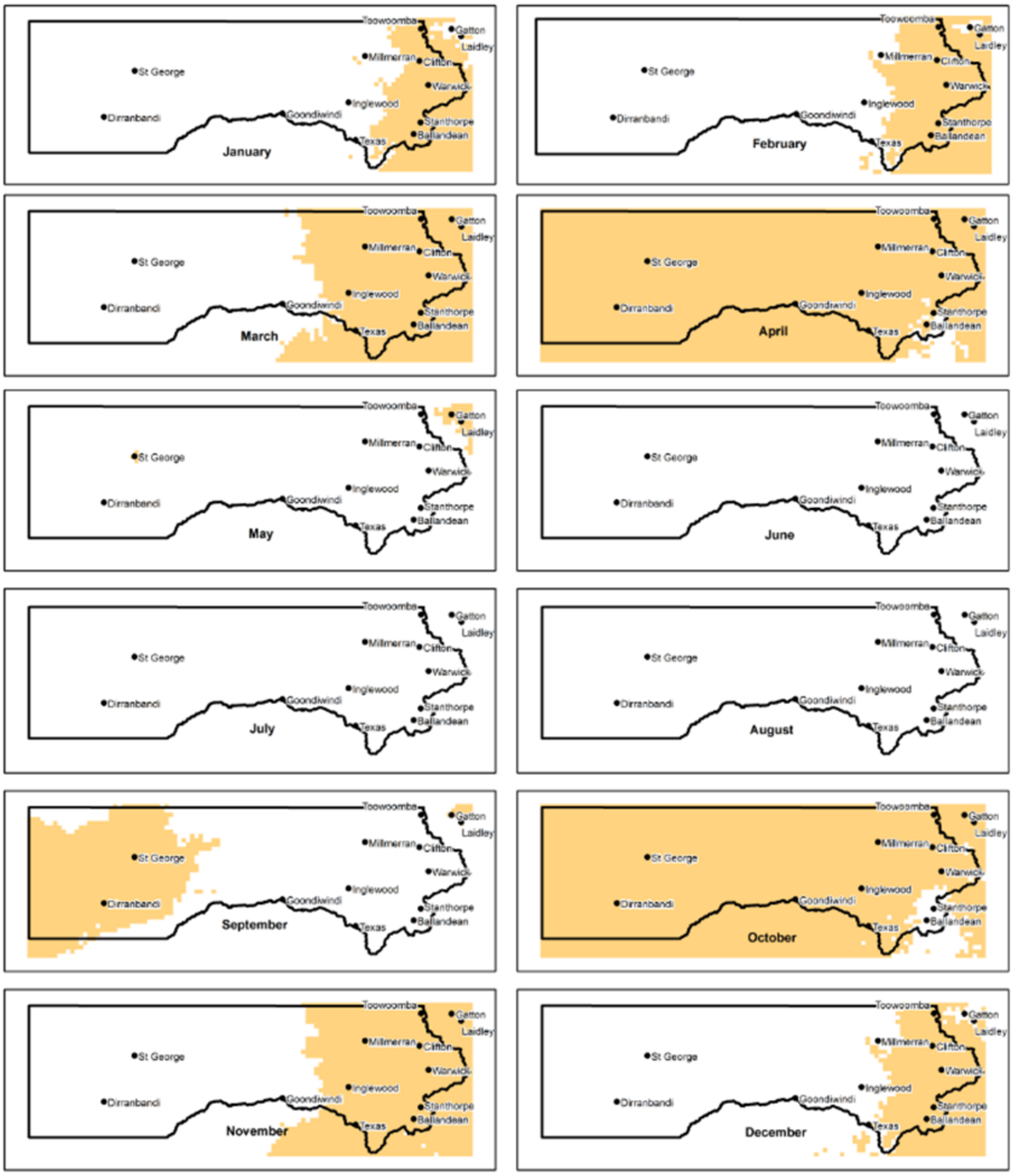
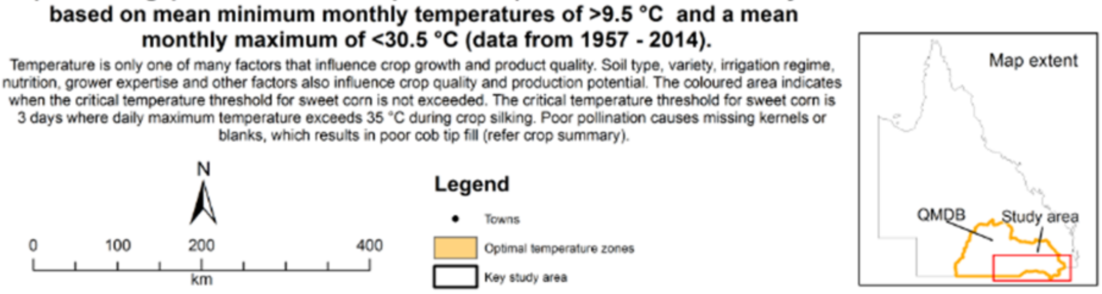
Sweet corn In the QMDB study area - example mapping

Figure 23 - potential sweetcorn production periods based on mean monthly minimum and maximum temperatures



Map indicating potential sweet corn production periods in the QMDB study area based on mean minimum monthly temperatures of >9.5 °C and a mean monthly maximum of <30.5 °C (data from 1957 - 2014).

Temperature is only one of many factors that influence crop growth and product quality. Soil type, variety, irrigation regime, nutrition, grower expertise and other factors also influence crop quality and production potential. The coloured area indicates when the critical temperature threshold for sweet corn is not exceeded. The critical temperature threshold for sweet corn is 3 days where daily maximum temperature exceeds 35 °C during crop silking. Poor pollination causes missing kernels or blanks, which results in poor cob tip fill (refer crop summary).



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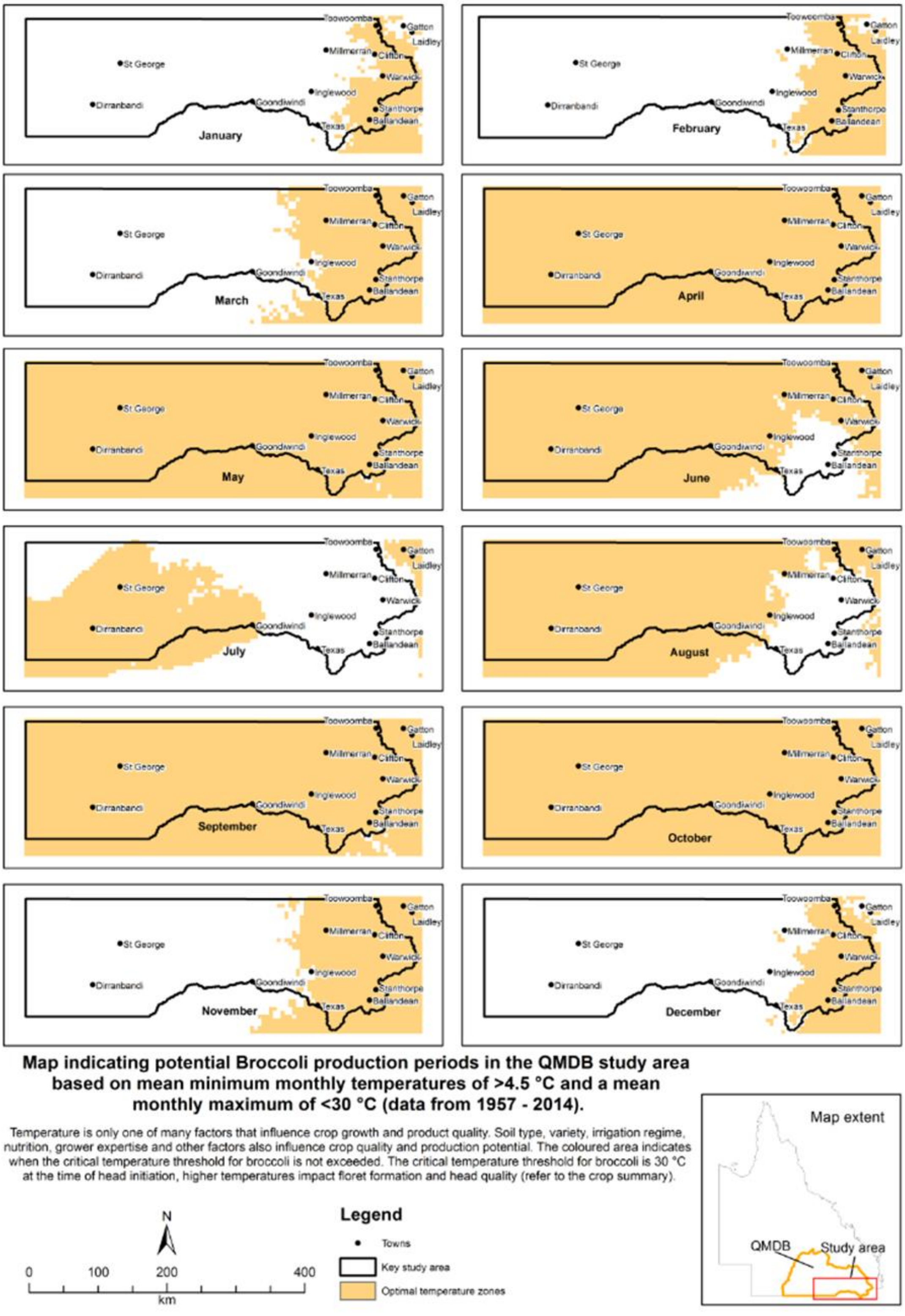
Broccoli in the QMDB study area - example mapping

Figure 24- potential broccoli production periods based on mean monthly minimum and maximum temperatures



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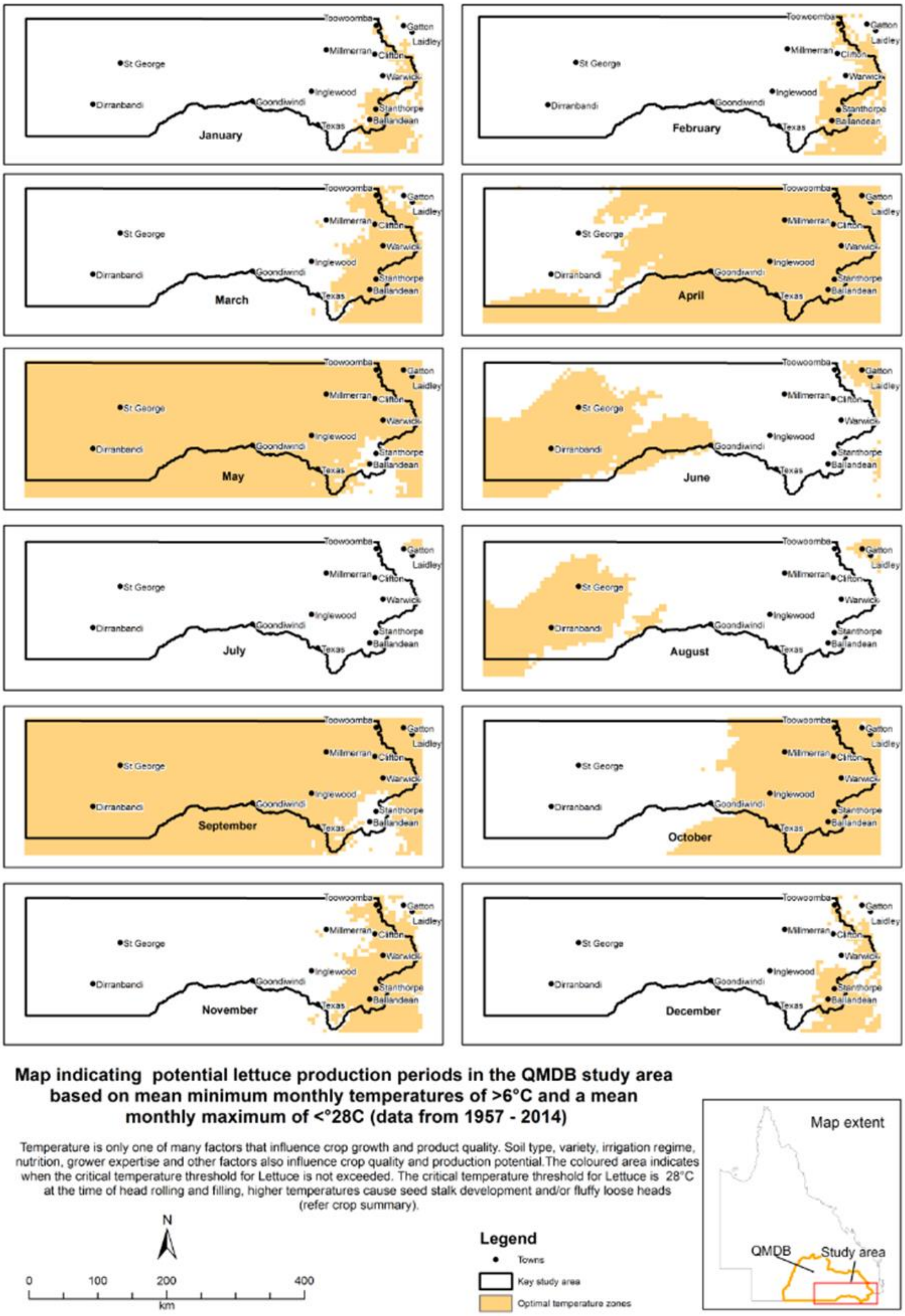
Lettuce in the QMDB study area - example mapping

Figure 25 - potential lettuce production periods based on mean monthly minimum and maximum temperatures



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2.5 Chill Hours in the Balonne-Border Rivers Area of the QMDB (Silo Data)

Initial discussions with local industry in the study area regarding climate investigations and temperature mapping carried out as part of Activity #1 Milestone 1 report, revealed discrepancies between the temperature observations reported by growers in the St George region and the data available from the Australian Bureau of Meteorology (BoM). The official BoM weather data site was moved from the St George post office to the airport in 1997. The project team became aware there was no data comparison or correlation available as a result of this change ,this prompted a full analysis of all available climate data by Dr Neil White to ensure the climate data used in this report was the best available - refer to section 3 (Weather data used for chill hour and temperature mapping).

This recent analysis has allowed us to cross check, validate and update the local temperature data, which is now utilised in the chill hours and temperature mapping in this final report.

Chilling is a physiological requirement for many perennial horticultural crops. A "Chilling Requirement" must be fulfilled for winter dormancy to be broken, and growth to be resumed in the spring. (Luedeling, E. and Brown, P.H., 2011).

"If the buds do not receive sufficient chilling temperatures during winter to completely release dormancy, trees will develop one or more of the physiological symptoms associated with insufficient chilling: - delayed and extended bloom, delayed foliation, reduced fruit set and reduced fruit quality" - Victoria Government - Chill units of stone fruit

Figure 26 to Figure 41 map the percentage of years (from 1957 to 2014) where the number of chill hours exceeds a defined threshold for the study area.

These maps demonstrate the ability of the environment in the Granite Belt to provide sufficient chilling accumulation for apples, whereas this chilling is not achieved anywhere else in the study area (and nowhere in Queensland other than the Granite Belt).

Similarly, chilling accumulation (or a lack thereof) will determine the performance of other horticultural species in the study area, which have a specific chilling requirement.

For example:

Pecan nuts require 200-400 chill hours (depending on cultivar). Therefore chill accumulation is unlikely to be a limiting factor in Pecan production in the study area.

Kiwifruit require 600-900 chill hours (depending on cultivar). Therefore chill accumulation will be a limiting factor in Kiwifruit production in some locations in the study area.

Luedeling, E. and Brown, P.H. (2011). A global analysis of the comparability of winter chill models for fruit and nut trees. Int. J. Biometeorol. (2011) 55:411-421.

The following chill accumulation mapping was developed and provided by Dr Neil White, Principal Scientist, H&FS, DAF.

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Figure 26 - the percentage of years (from 1957 to 2014) where the number of chill hours exceed 1000.

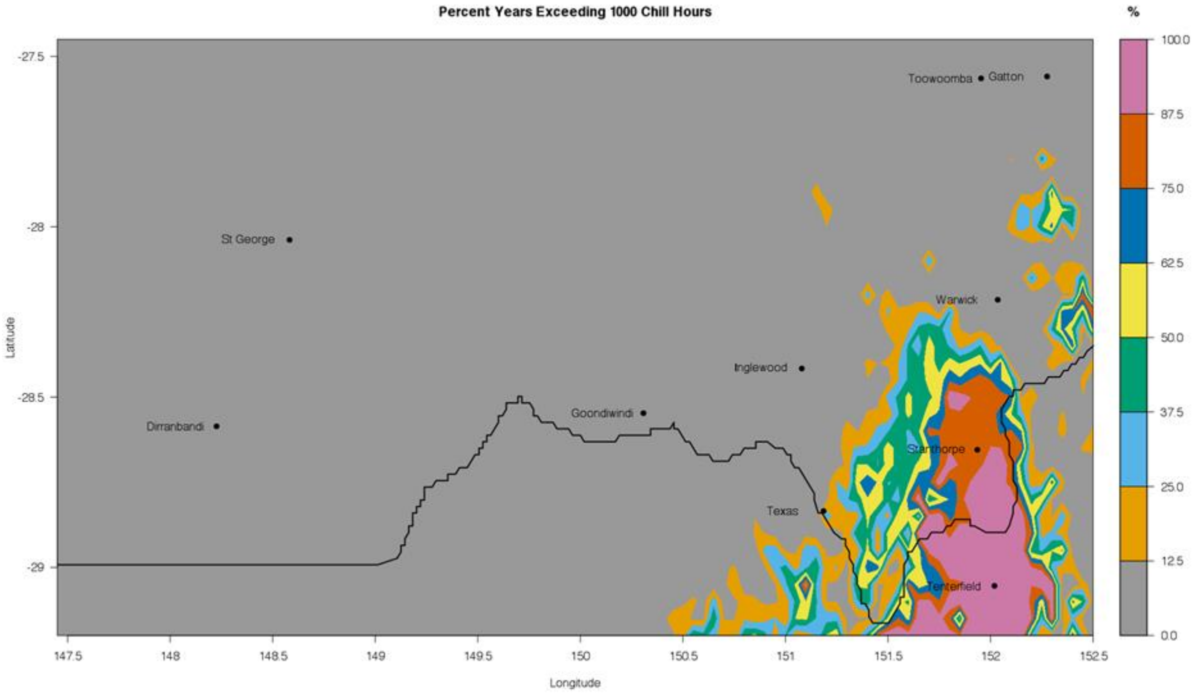

Figure 27 - the percentage of years (from 1957 to 2014) where the number of chill hours exceed 950.

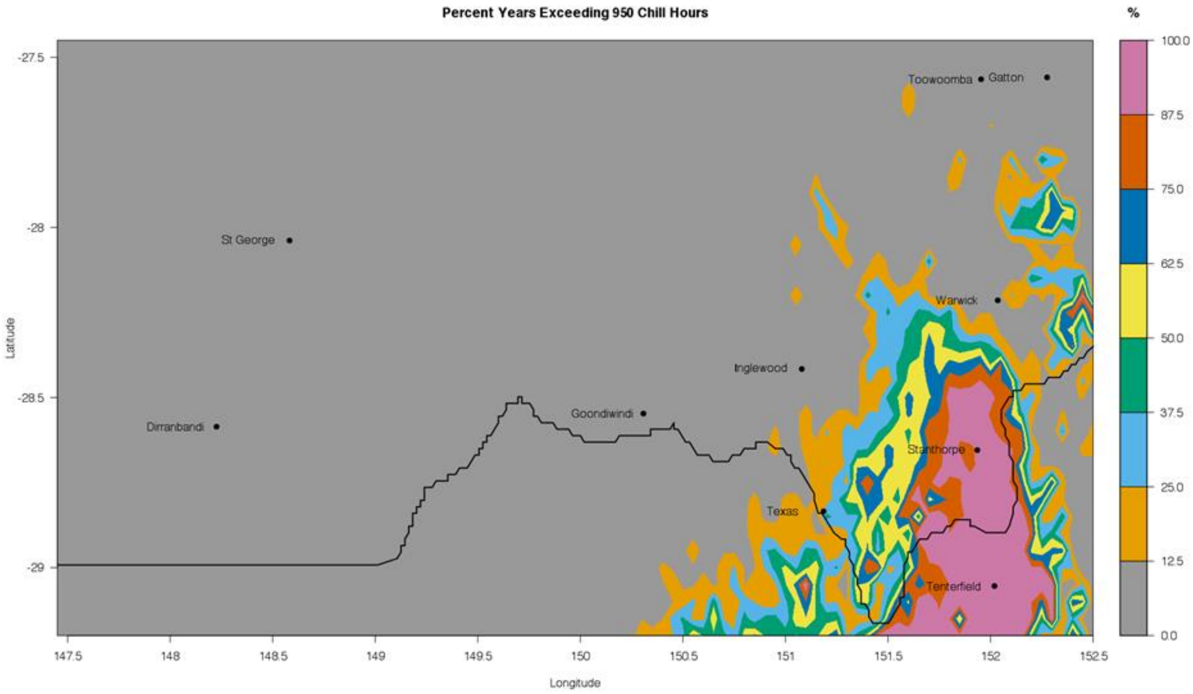

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Figure 28 - the percentage of years (from 1957 to 2014) where the number of chill hours exceed 900.

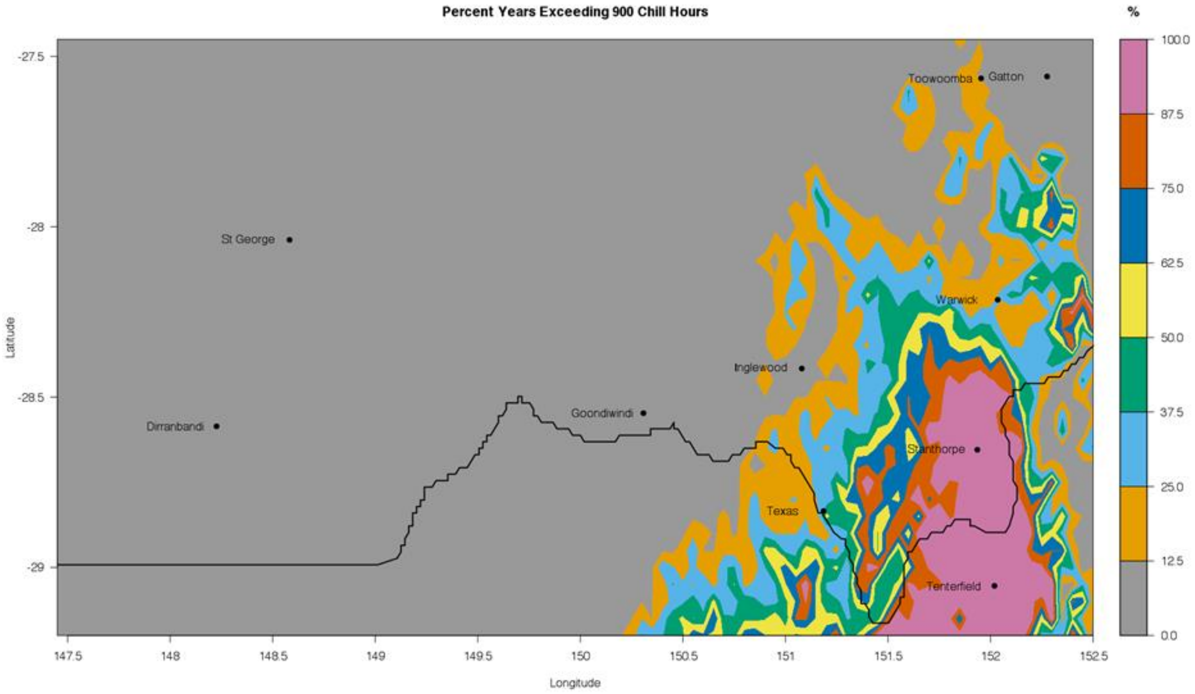

Figure 29 - the percentage of years (from 1957 to 2014) where the number of chill hours exceed 850.

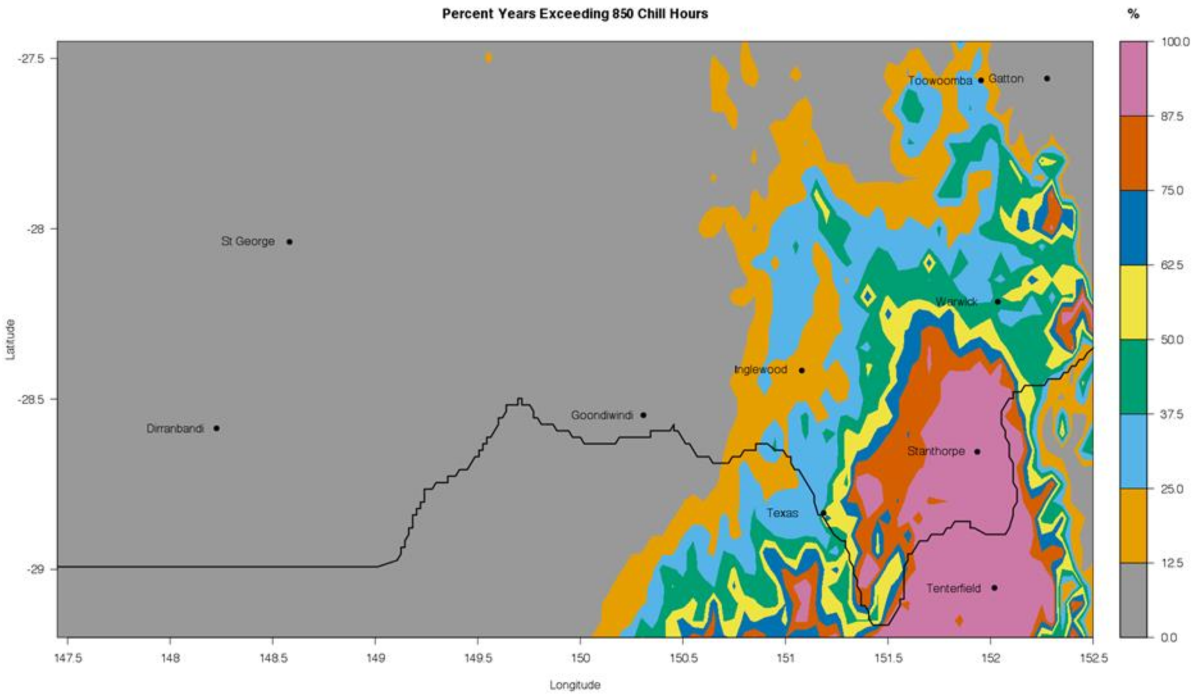

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Figure 30 - the percentage of years (from 1957 to 2014) where the number of chill hours exceed 800.

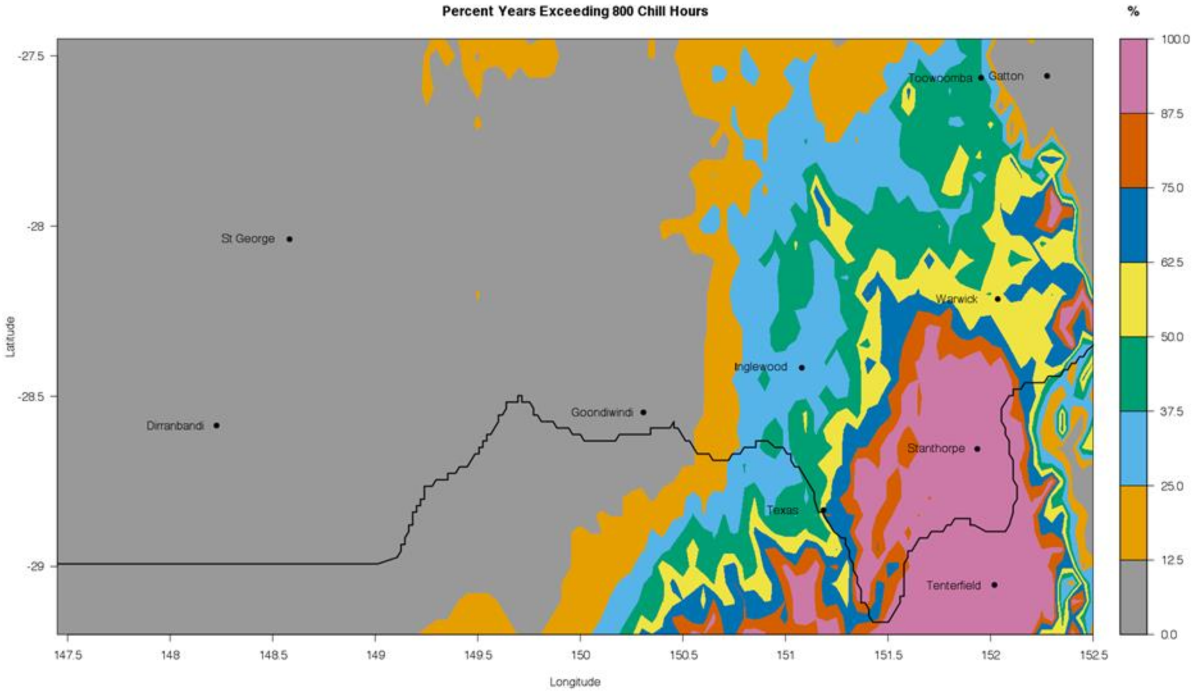

Figure 31 - the percentage of years (from 1957 to 2014) where the number of chill hours exceed 750

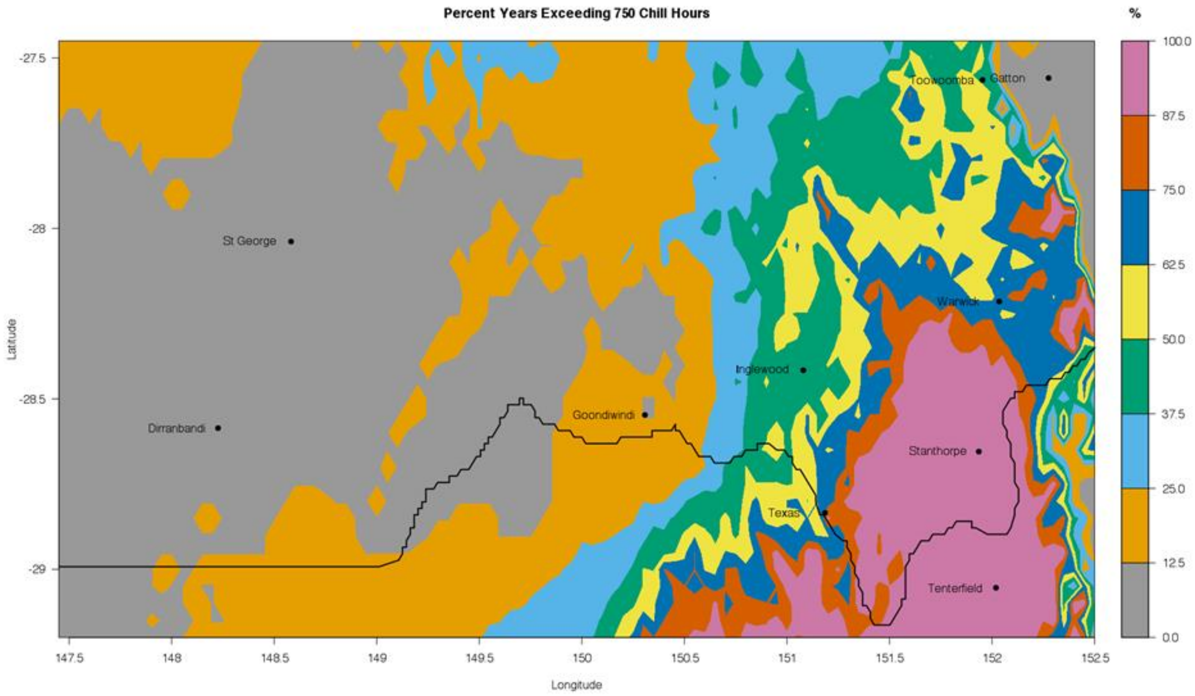

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Figure 32 - the percentage of years (from 1957 to 2014) where the number of chill hours exceed 700.

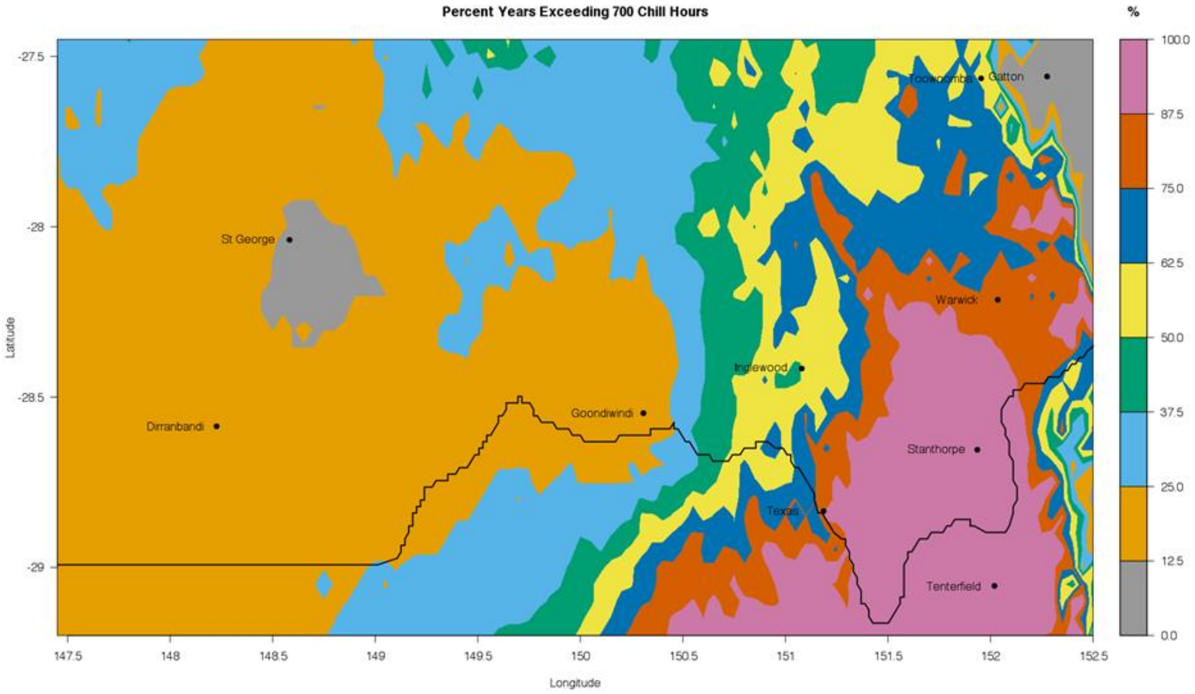

Figure 33 - the percentage of years (from 1957 to 2014) where the number of chill hours exceed 650.

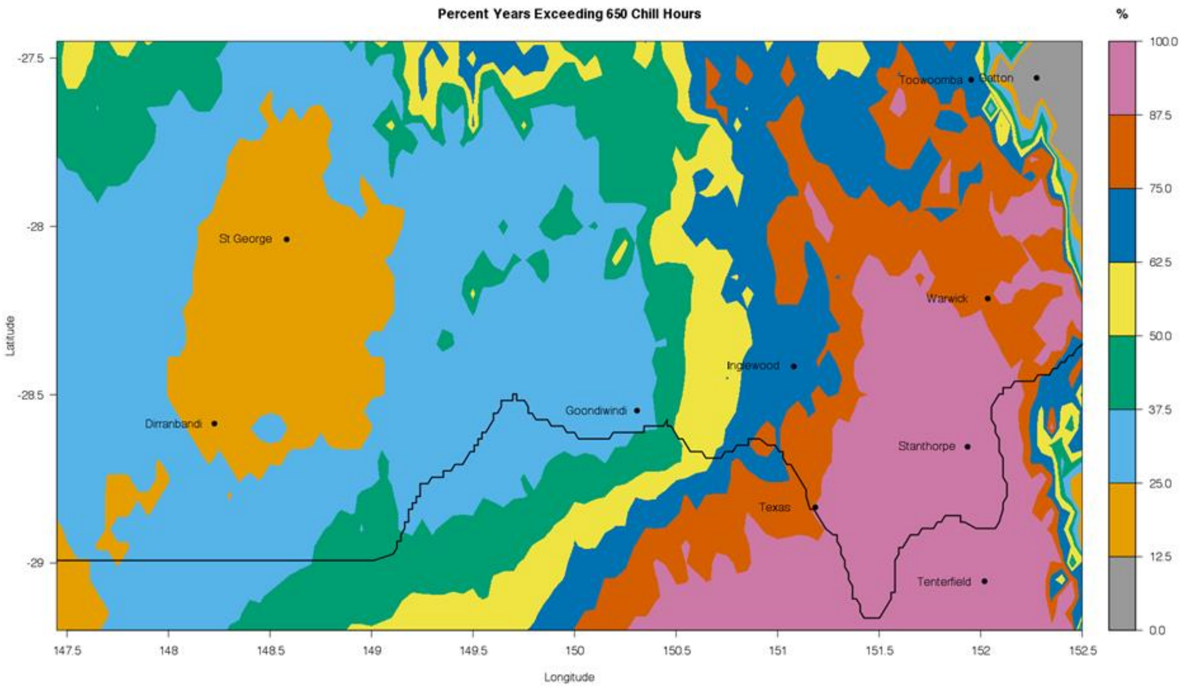

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Figure 34 - the percentage of years (from 1957 to 2014) where the number of chill hours exceed 600

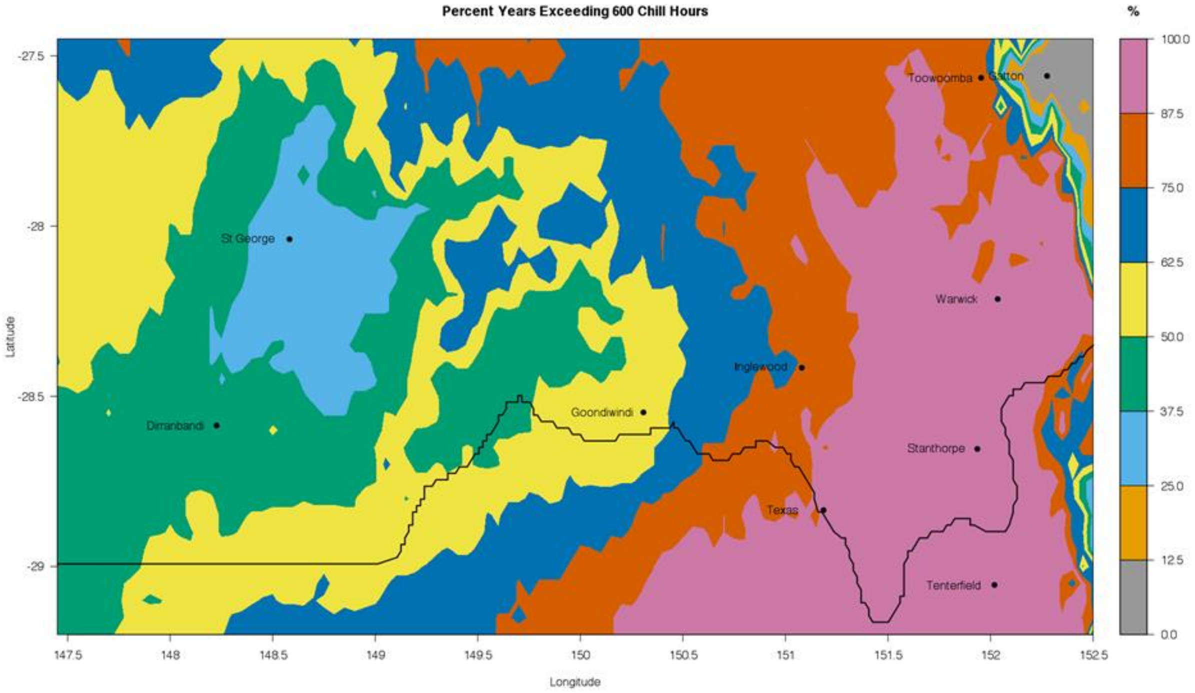

Figure 35 - the percentage of years (from 1957 to 2014) where the number of chill hours exceed 550.

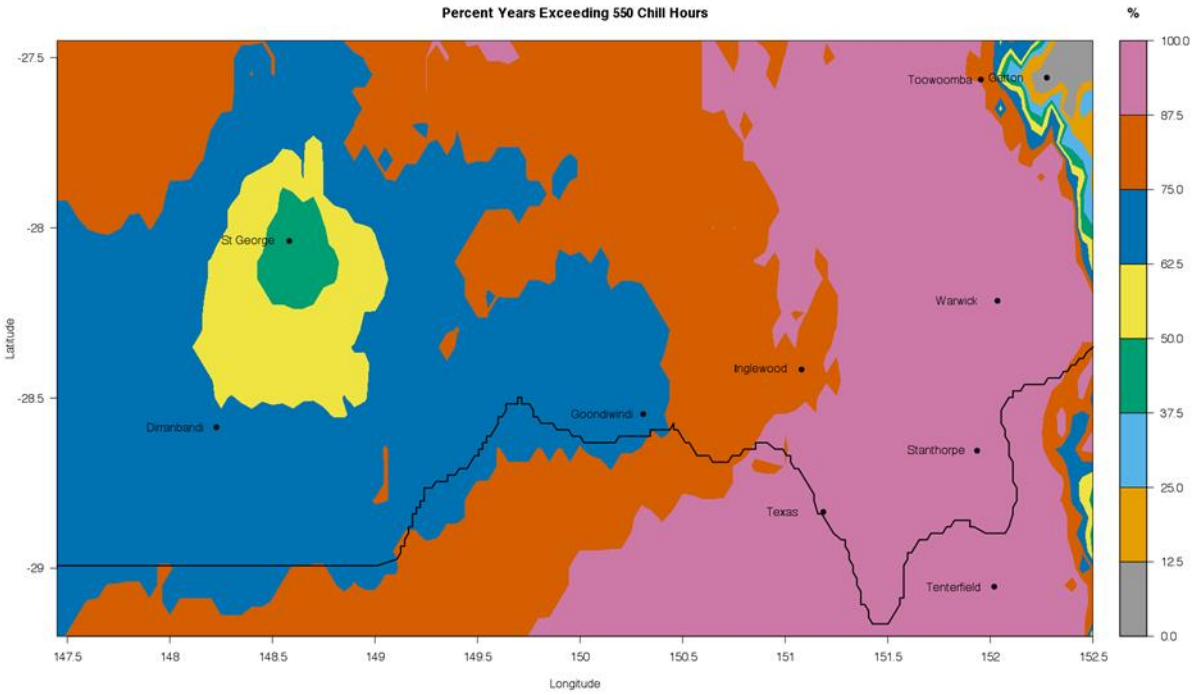

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Figure 36 - the percentage of years (from 1957 to 2014) where the number of chill hours exceed 500

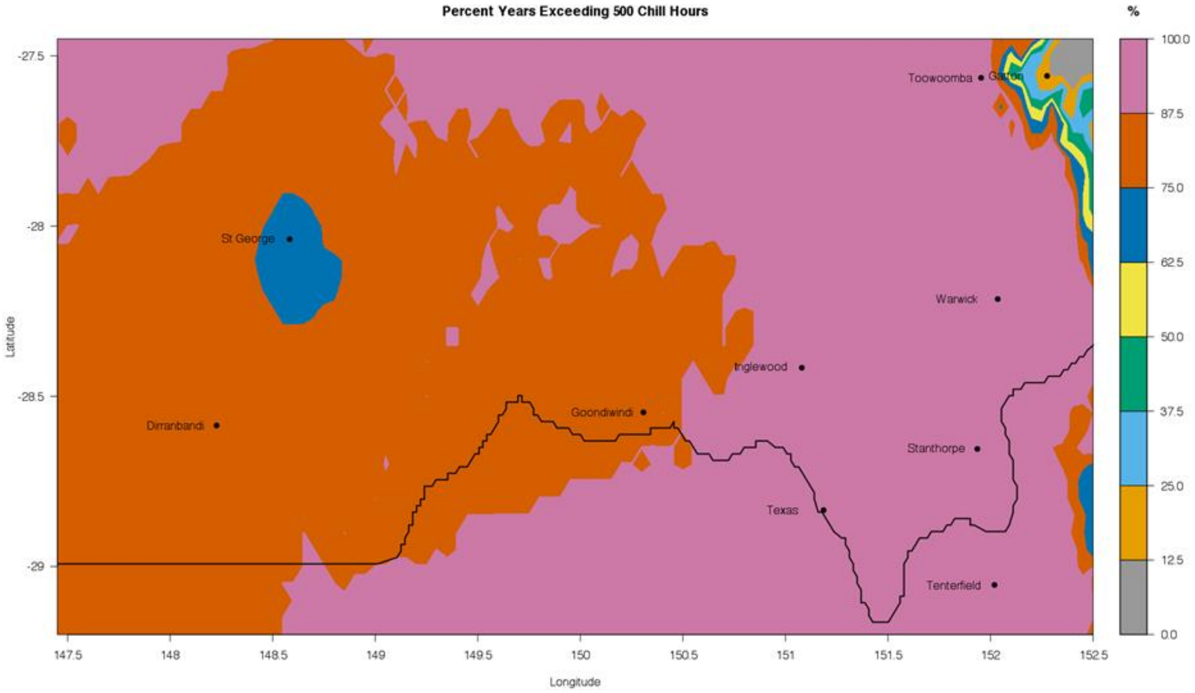

Figure 37 - the percentage of years (from 1957 to 2014) where the number of chill hours exceed 450.

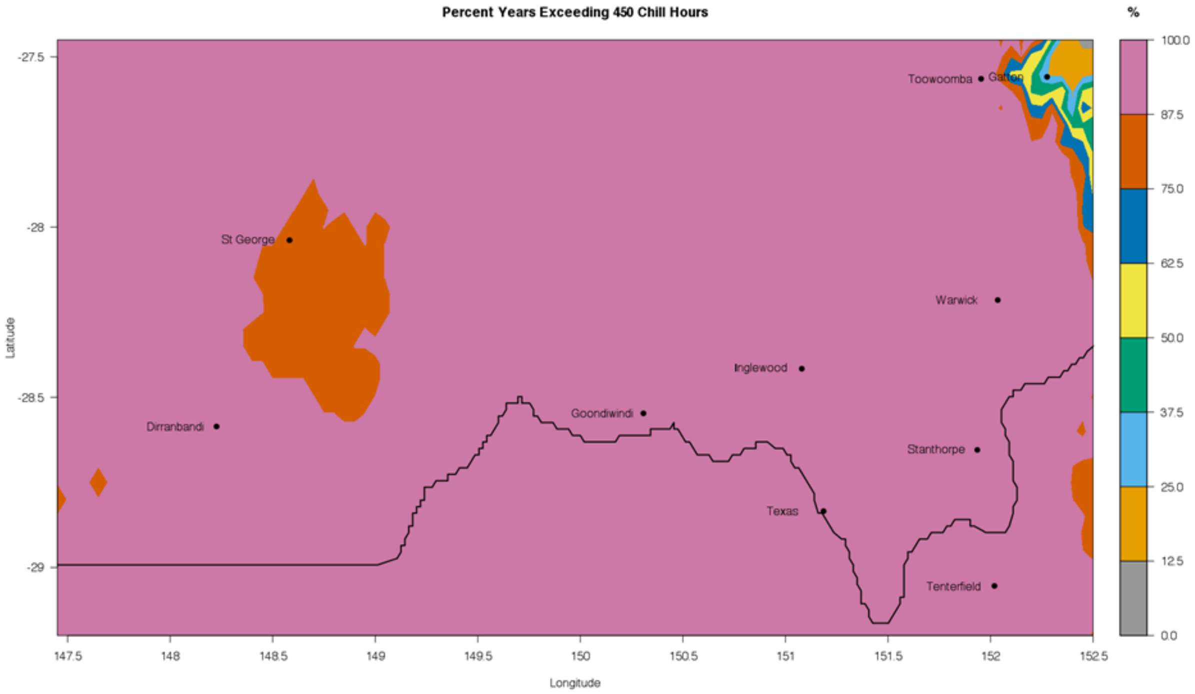

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Figure 38 - the percentage of years (from 1957 to 2014) where the number of chill hours exceed 400.

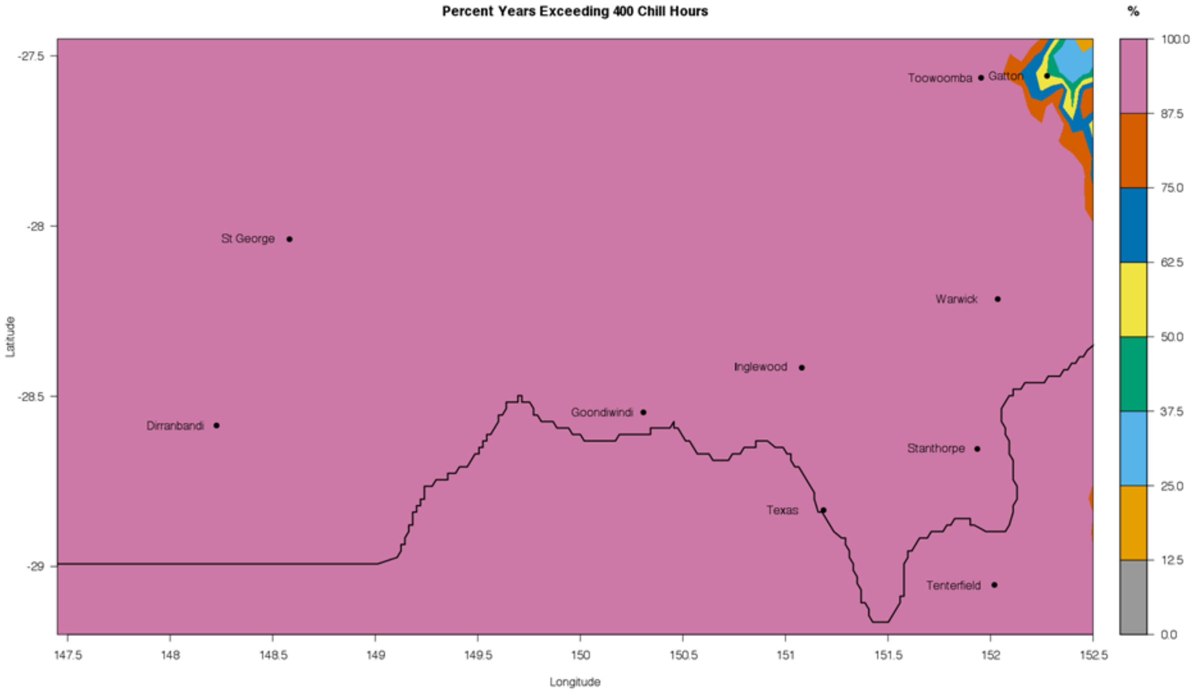

Figure 39 - the percentage of years (from 1957 to 2014) where the number of chill hours exceed 350.

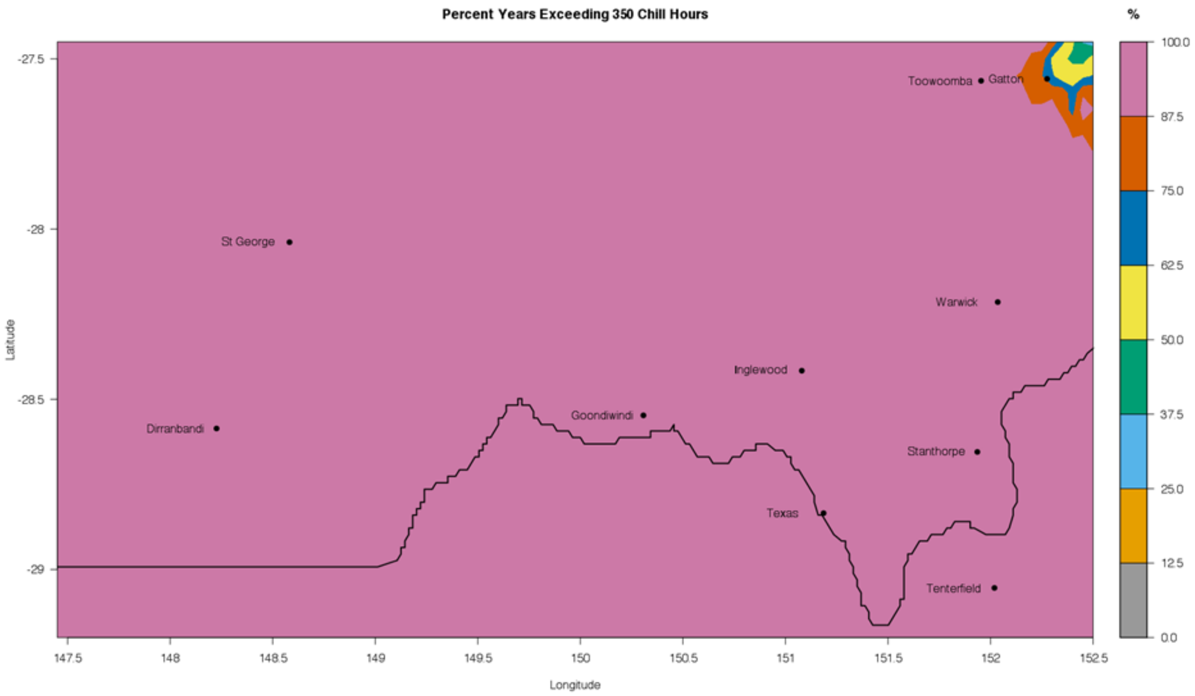

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Figure 40 - the percentage of years (from 1957 to 2014) where the number of chill hours exceed 300.

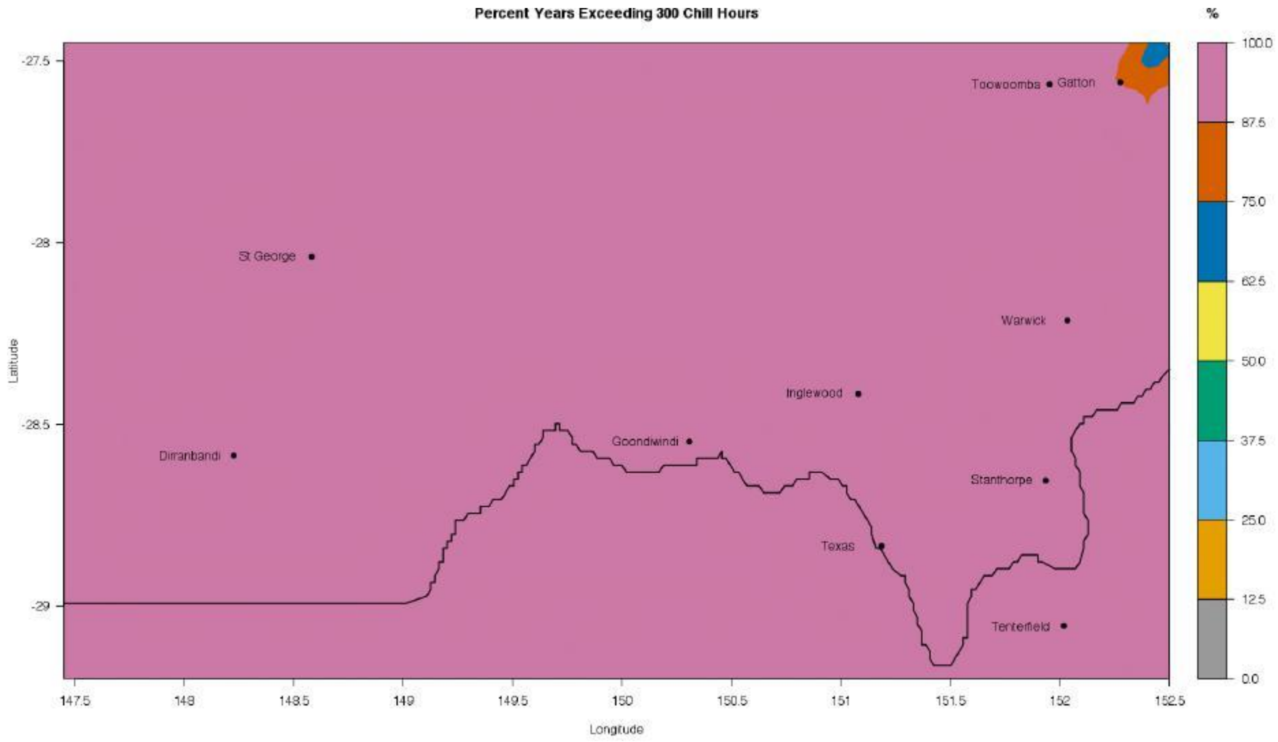
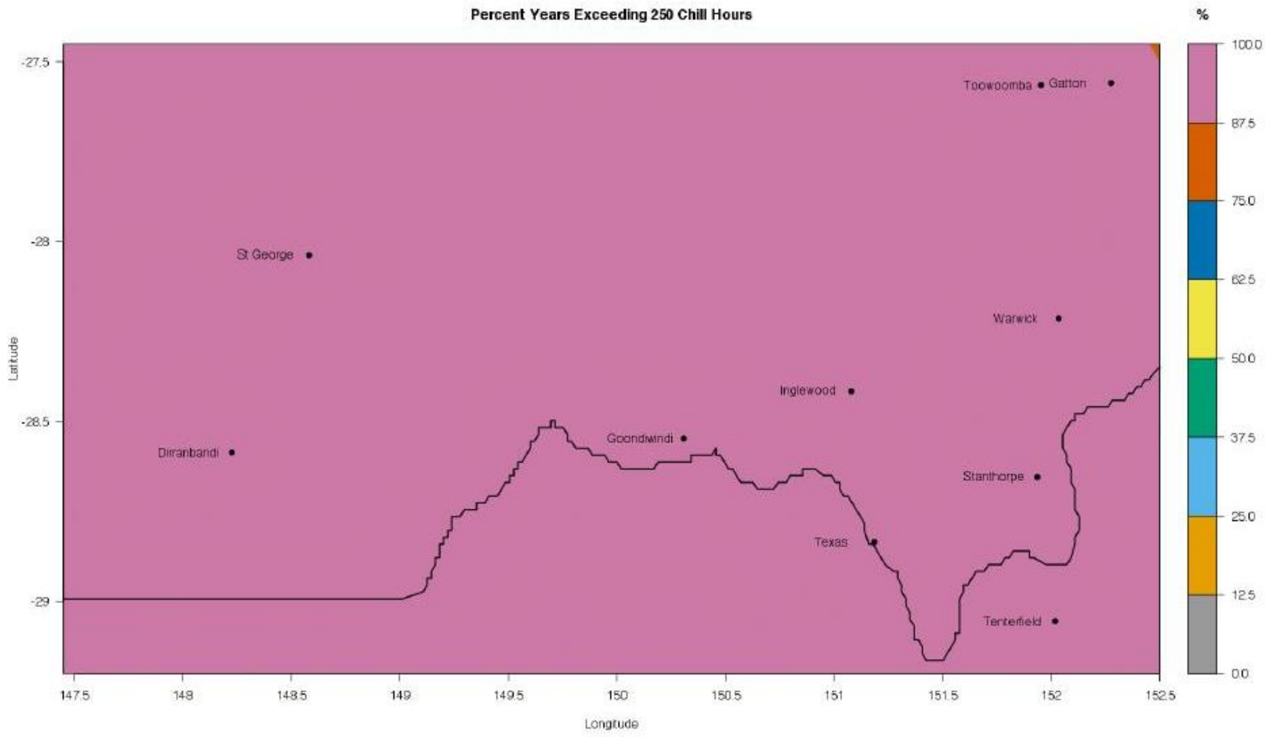


Figure 41 - the percentage of years (from 1957 to 2014) where the number of chill hours exceed 250



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2.6 Dynamic interactive Chill Hours and Heat Hours - Look Up Tool for Queensland

The Chill Hours and High temperature - Look Up Tool - was programmed and created by Dr Neil White (DAF Queensland) as part of Activity 1 - Horticultural Crop Selection based on biophysical suitability in the QMDB study area - Balonne and Border Rivers irrigation area project.

Created for Queensland this unique, dynamic, interactive chill hours and heat hours tool enables growers and industry to obtain current site specific temperature data from the SILO data base (web link below). SILO (Scientific Information for Land Owners) is a daily time series of meteorological data at point locations, consisting of station records that have been supplemented by interpolated estimates where observed data are missing SILO data is available from: silo-patched-point-datasets-for-queensland

The Chill Hours and High temperature - Look Up Tool can be used to access all existing temperature data from your nearest official Bureau of Meteorology weather station site. The dynamic (live) nature of this tool means that all current temperature data (on the day you use the tool) will be used in the tool calculation.

On accessing the web link below simply follow the onscreen instructions

The Chill Hours and High temperature - Look Up Tool can be accessed via the web link; hort-science shiny apps

You can also just type the above address into a web browser to access the Chill Hours and High temperature - Look Up Tool

2.7 Currently irrigated areas in the QMDB Study Area

Reliable irrigation water is an essential component of any horticultural enterprise.

The following maps identify the known locations of irrigated agriculture and plantations in the years 1999, 2006 and 2012/13 — 2013. This information was sourced from the Queensland Land Use Mapping Program (QLUMP) data set.

Figure 42 and Figure 43 use data from the Queensland Land Use Mapping Program (QLUMP) to show which areas of the QMDB Study Area are used and have been used in the past for irrigated cropping (broad acre and horticulture). Figure 42 shows areas in purple that were classified as 'production from irrigated agriculture and plantations' in 2012 / 2013. Areas in pink are additional areas that were irrigated in 2006 but not 2013 and blue areas show further additional areas that were irrigated in 1999 but not in the other years. Figure 43 uses the same data but breaks it down by which year or years it was shown to be irrigated. This provides a spatial representation of where in the region water for irrigation has previously been available.

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Figure 42 —Areas shown as 'Production from irrigated agriculture and plantations in 1999, 2006 and 2012/2013 in the Queensland Land use Mapping Program (QLUMP) dataset

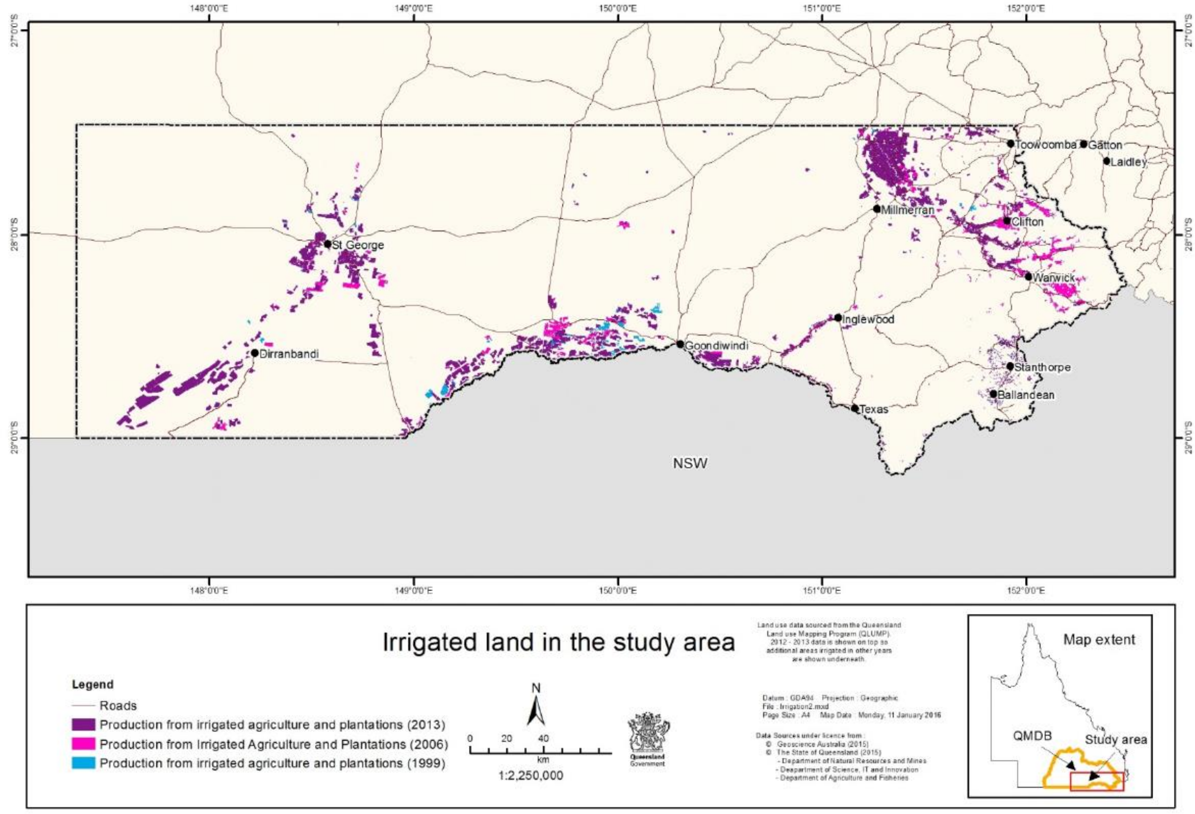
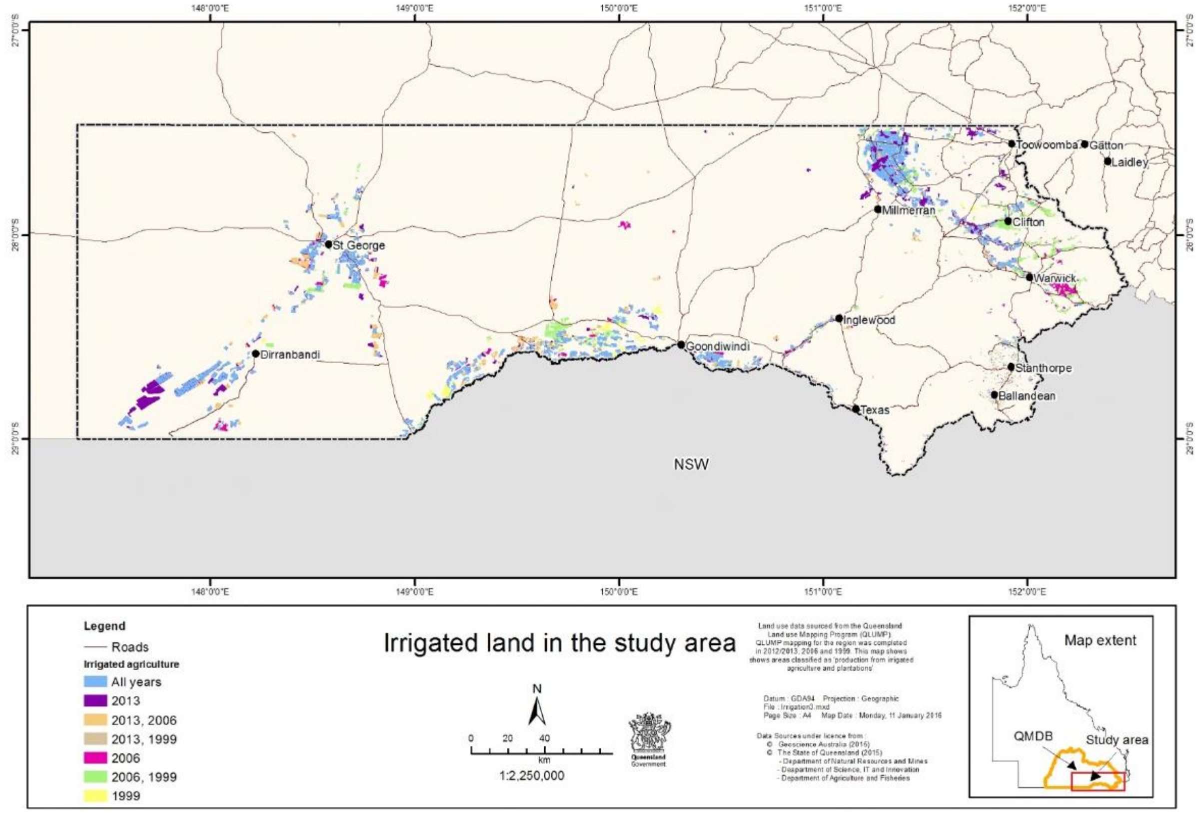


Figure 43 - Areas shown as 'Production from irrigated agriculture and plantations in 1999, 2006 and 2012/2013 in the Queensland Land use Mapping Program (QLUMP) dataset



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2.8 Soils best suited to horticulture in the Qld Murray Darling Basin study area.

The areas mapped consist primarily of uniform sandy soils of varying depth. In alluvial areas, the profiles may be many metres deep, while in the Granite Belt, they are typically "shallower" In most areas the sands are fine to medium-grained, but in the granitic areas they are coarse grained. The low soil strength and good drainage characteristics of the sandy soils makes them ideal for horticultural development (given appropriate water supply, climate and other factors are satisfied). The mapped area also includes some texture contrast soils with deep sandy surface horizons, particularly in the Granite Belt. In the Traprock area South West of Stanthorpe there are small areas of limestone related soils that are red in colour and loam to clay texture. Some of these areas are too small to be illustrated on the map.

This soil map data is based on existing Department of Natural Resources and Mines soils and land system mapping. The scale of the mapping means that there may well be small pockets of suitable horticultural soils that are not captured in this mapping. Local knowledge of soil types on your property and in your area may indicate additional suitable soils not depicted in this map.

A suitable reliable water supply is also an essential element to consider when investigating potential horticultural cropping sites and is not considered in this horticultural soil graphic. Refer to the separate water maps for information on water availability.

The authors acknowledge and thank Mr Andrew Biggs of The Department of Natural Resources and Mines (Tor St Toowoomba) for his contribution and assistance in accessing this soil mapping data and his time discussing and contributing to this soils mapping information. The map graphic was developed by project team member Heather Taylor.

The following maps (Figure 44 and Figure 45) show soils considered most suited to horticultural production and known horticultural cropping locations within the study area. Figure 46 below allows easy comparison of known horticultural production areas, suitable soils and historical water availability.

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Figure 44 —Sandy soil types best suited to horticulture in the QMDB study area.

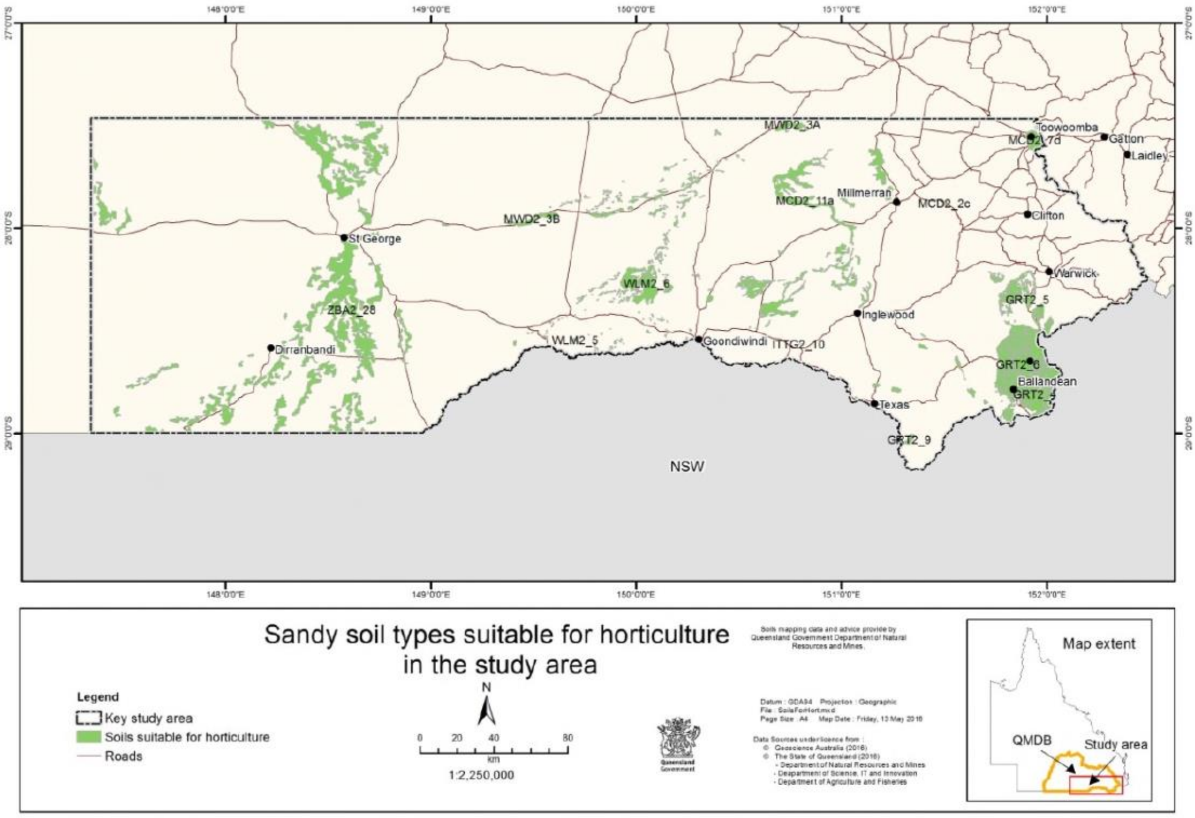

Figure 45 - Current known horticultural production locations in the QMDB study area

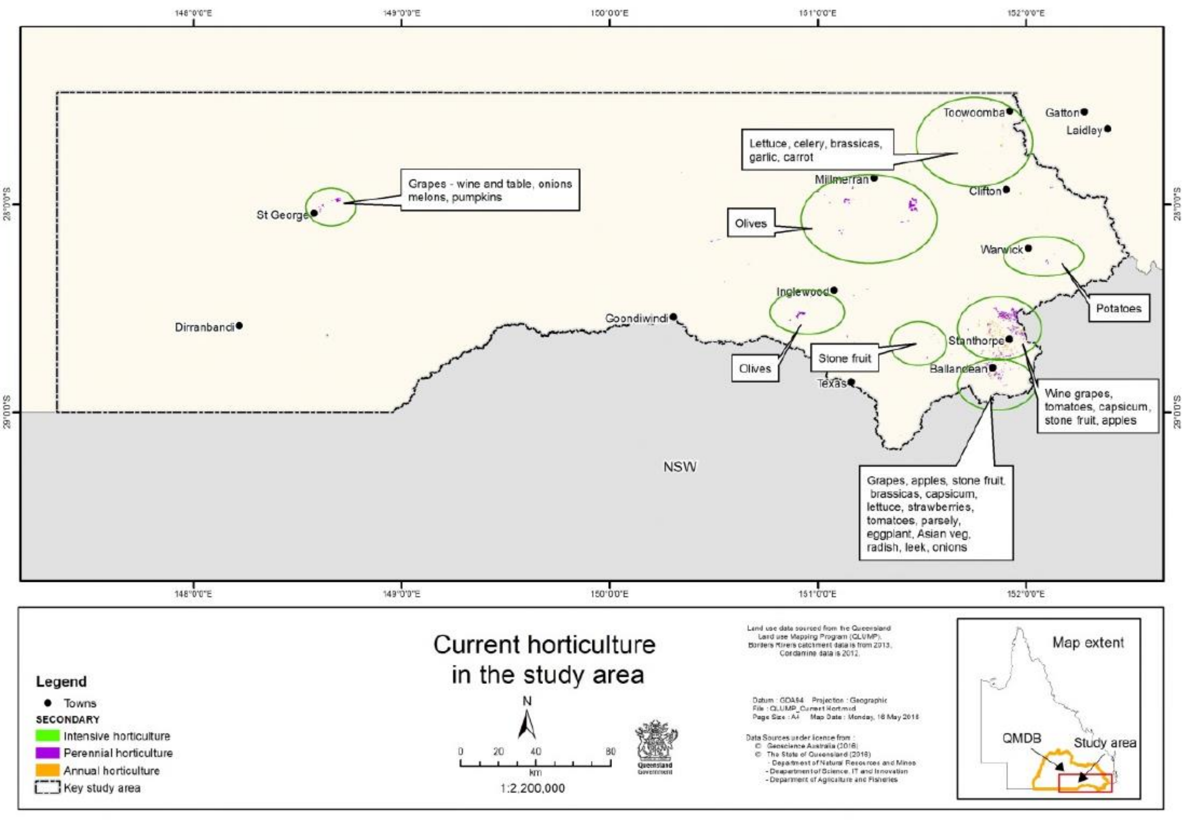

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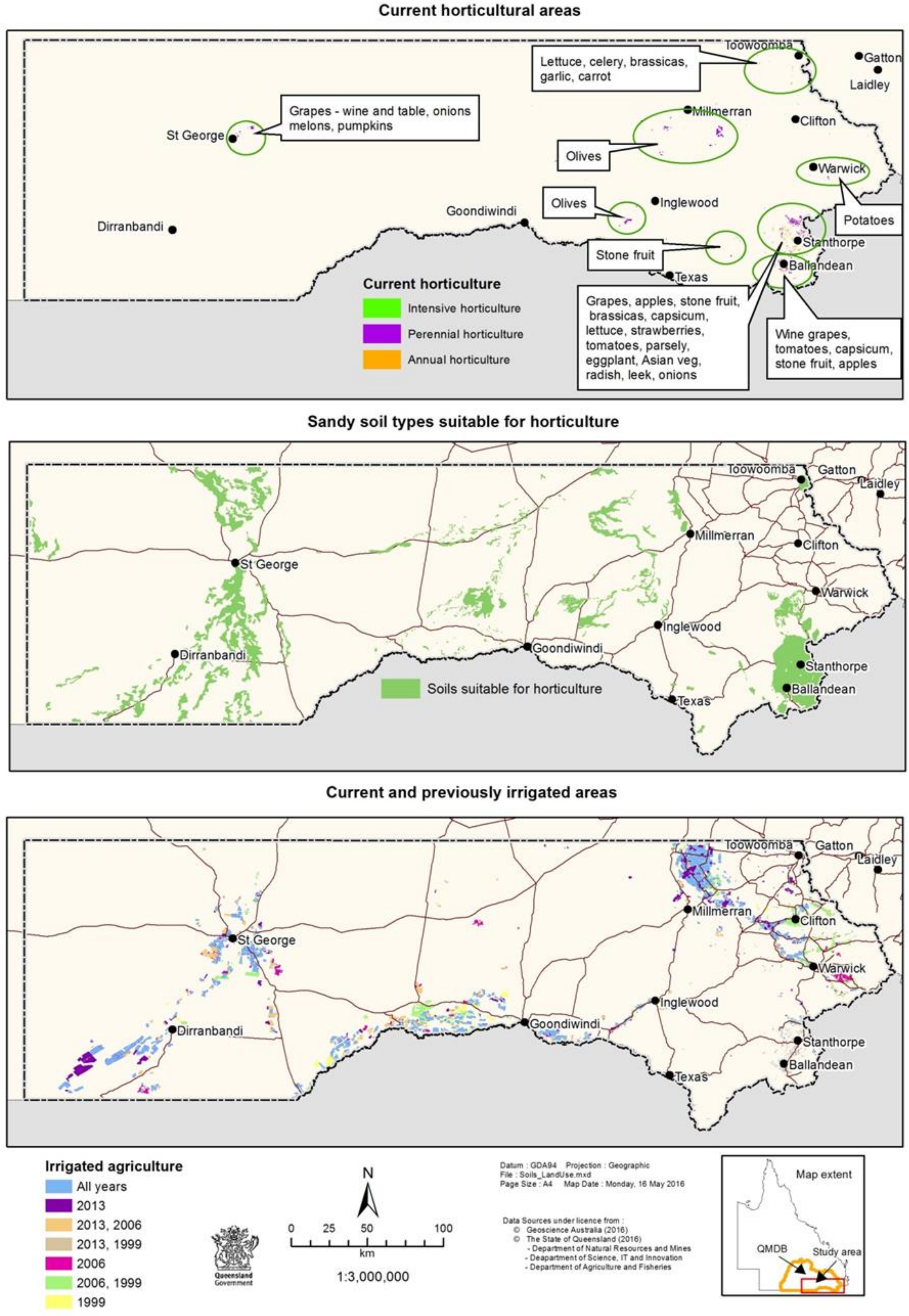
Figure 46—Combined graphic showing known current horticultural production locations, most suitable soils and irrigation water location and availability.



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2.9 Seasonal Production Windows for Suitable Annual Crops

Planting (green) Harvest (yellow)

Crop	Planting	Harvest	Comments
Asparagus	May – Jul	Aug – Dec	Perennial vegetable crop - crowns planted when dormant (May to July - first harvest occurs in 2 years and continues for 10-15yrs).
Asian Vegetables	Mar – Jun	mid May – Aug	Large number of species - mainly brassicas.
Beetroot	mid Mar – mid Jun	Jul – Sep	Heat sensitive crop - Summer and winter temperatures will determine planting and harvest dates.
Broccoli, Broccolini &	Mar – May	Jun – Aug	Heat sensitive crops - Summer and winter temperatures will determine planting and harvest dates.
Brussels Sprouts	Apr – mid May	Jun – mid Aug	Only suitable for midwinter production in those locations where maximum temperatures do not limit product quality.
Cabbage	mid Feb – May	mid May – Aug	Heat sensitive crop - Summer and winter temperatures will determine planting and harvest dates.
Capsicum & Chilli	Jan – Mar; mid Aug – mid Sep	Apr – Jun; mid Nov – mid Dec	Cold and frost sensitive crops - Split season possible due to high temperatures in spring and early summer affecting pollination & fruit set. Also significant losses from sunburn.
Carrot	mid Mar – Jun	mid May – Sep	Summer and winter temperatures will determine planting and harvest dates.
Celery	Mar – May	Jun – Aug	Heat sensitive crop - Summer and winter temperatures will determine planting and harvest dates.
Chinese Cabbage	Mar – May	Jun – Aug	Heat sensitive crop - Summer and winter temperatures will determine planting and harvest dates.
Cucurbits	Jan – Feb; Sep – Dec	Jan – Apr; Dec	Cold and frost sensitive crops -- summer heat may restrict plantings to spring and late summer - potential for split season.
Eggplant	Jan – mid Apr; mid Aug – mid Sep	Apr – Jun; mid Nov – mid Dec	Cold sensitive crop - Split Season due to high temperatures in spring and early summer adversely affecting fruit set.
Garlic	Apr	Oct – Nov	Winter temperatures will determine planting and harvest dates.
Green Bean	Jan – mid Apr; mid Aug – mid Sep	Apr – Jun; mid Nov – mid Dec	Cold and frost sensitive crop - Split Season possible due to high temperatures in spring and early summer adversely affecting pollination and pod set.
Leek	May – Jun	Oct – Nov	Heat sensitive crop - Heat of summer and autumn will determine planting dates.
Lettuce	Mar – mid Jun	Jun – Aug	Heat sensitive crop - High summer temperatures will restrict early plantings in the west, and cold winter temperatures will affect quality in some years.

The candidate crop information presented in this QMDB study area report (Activity 1) is based on the analysis of the published biophysical needs of the crops (e.g. temperature, frost sensitivity, chill requirement, water quality, etc.) and current climate records for the QMDB study area. The candidate crops are deemed suited to the study area where the biophysical needs are met either year round or for portion of the year and will allow crop production.

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Seasonal Production Windows for Suitable Annual Crops (cont.)

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Comments
Melons (Rock and Water)													Cold and frost sensitive crops -- summer heat may restrict plantings to spring and late summer - potential for split season.
Mushroom													Not affected by environment as grown in controlled environments.
Okra													Split season due to high temperatures in spring and early summer adversely affecting pollination and fruit set.
Onion													Winter temperatures will determine planting and harvest dates.
Parsley													Mid-summer heat may restrict plantings to spring and autumn - potential for split season.
Parsnip & Turnip													Summer and spring temperatures will determine planting and harvest dates.
Pea													Frosts and summer heat will determine planting and harvest dates.
Potato													Frosts and summer heat will determine planting and harvest dates.
Radish													Frosts and summer heat will determine planting and harvest dates.
Shallot & Spring Onion													Frosts and summer heat will determine planting and harvest dates.
Rhubarb													Perennial cold climate crop - crowns planted when dormant (May to July).
Silverbeet													High summer temperatures will restrict plantings in the west, and cold winter temperatures will affect plant growth andf leaf quality.
Snowpea &Sugar Snap													Frosts and summer heat will determine planting and harvest dates.
Edible Soybean													Earlier and later plantings may be possible at locations where temperatures are suitable.
Spinach													High summer temperatures will restrict plantings in the west, and cold winter temperatures will affect plant growth andf leaf quality.
Sweet Corn													Cold and frost sensitive crop - Split season due to high temperatures in spring and early summer adversely affecting pollination and cob quality.
Sweet Potato													High summer temperatures will restrict plantings in the west, and cold winter temperatures will affect plant growth and root quality.
Tomato													Cold and frost sensitive crop - Split season due to high temperatures in spring and early summer affecting pollination and fruit set.

The candidate crop information presented in this QMDB study area report Activity 1) is based on the analysis of the published biophysical needs of the crops (e.g. temperature, frost sensitivity, chill requirement, water quality, etc.) and current climate records for the QMDB study area. The candidate crops are deemed suited to the study area where the biophysical needs are met either year round or for portion of the year and will allow crop production.

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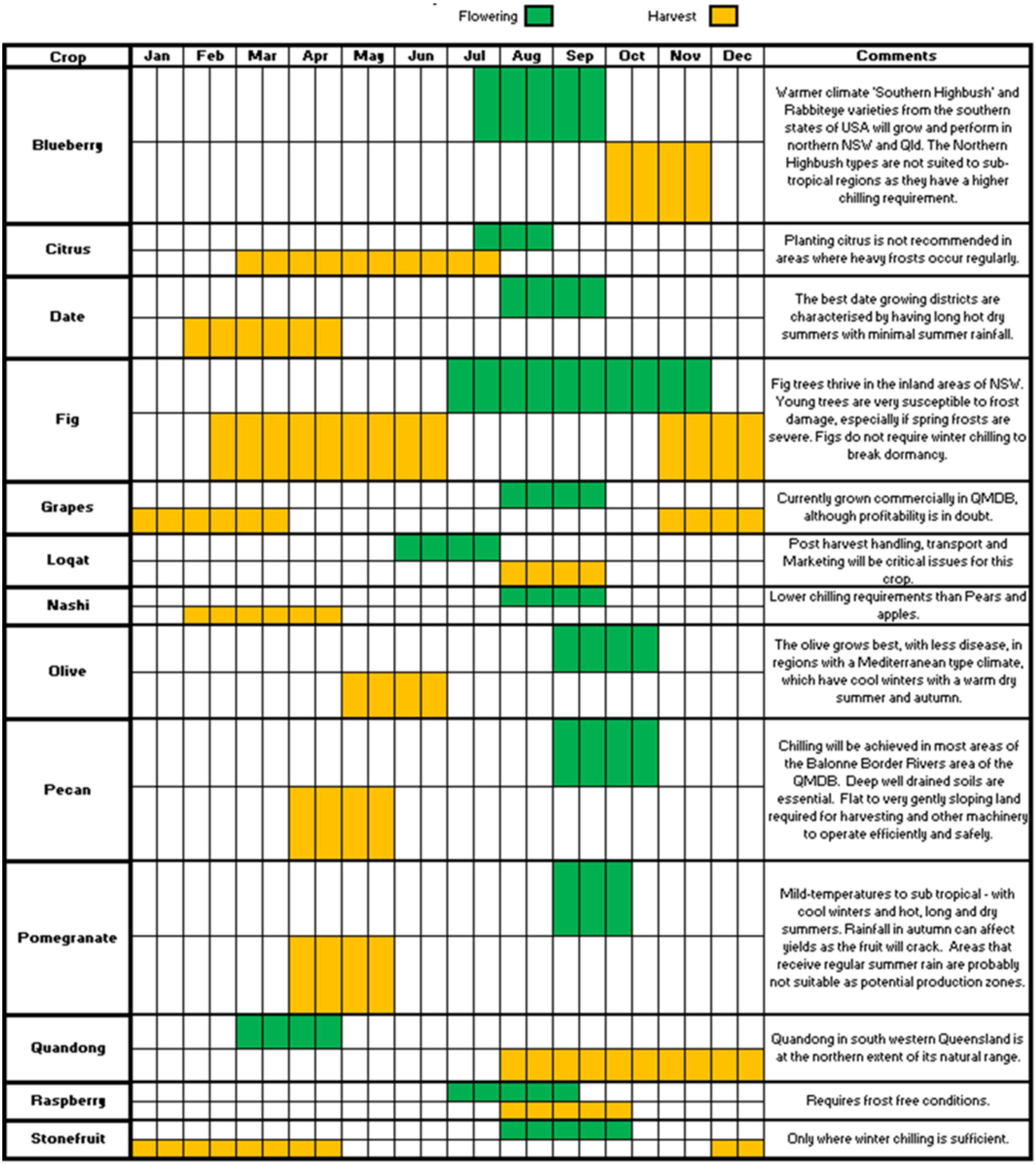
2.10 Seasonal Production Windows for Suitable Perennial Crops



The candidate crop information presented in this QMDB study area report (Activity 1) is based on the analysis of the published biophysical needs of the crops (e.g. temperature, frost sensitivity, chill requirement, water quality, etc.) and current climate records for the QMDB study area. The candidate crops are deemed suited to the study area where the biophysical needs are met either year round or for portion of the year and will allow crop production.

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2.11 Present and Future Temperatures for QMDB Region

No report dealing with the potential suitability of horticultural crops to the Australian climate would be complete or credible unless it contained the latest best quality scientific information relating to Australia's future climate projections. Observations and climate modelling paint a consistent picture of ongoing, long-term climate change interacting with underlying natural variability. These changes affect many Australians, particularly changes associated with increases in the frequency or intensity of heat events, fire weather and drought. Australia will need to plan for and adapt to some level of climate change.

The latest full Australian government funded State of the Climate 2016 was released in late October 2016 and is available at: bom- state-of-the-climate

The information below is specifically tailored for the QMDB study area and outlines projections for minimum and maximum temperatures derived from scientifically credible climatic models.

Overview of Climate Projections

Future climate projections were derived using simulations of the earth's climate system (Global Climate Model or GCM) under different scenarios of future greenhouse gas and aerosol emissions. The scenarios are referred to as representative concentration pathways (RCP) and represent a plausible set of future emissions. A GCM uses this information through the complex set of equations that determine how the climate responds to changes in the atmosphere.

Representative Concentration Pathways

RCPs are referred to by the amount of radiative forcing that will be experienced in 2100.

Radiative forcing is the extra heat that the lower atmosphere will retain as the result of additional greenhouse gases. In 1979 this amounted to 1.7 W.m-2. By 2014, this has risen to 2.9 W.m-2. In 1979 the CO2 concentration was 335 ppm. The current level as of February 2016 is 398 ppm.

The most ambitious RCP, RCP2.6, implies that by 2100 the radiative forcing will have returned to levels found in the early 2000s.

RCP8.5 This is a business-as-usual scenario, with a CO2 concentration continuing to rapidly rise, reaching 940 ppm by 2100.

RCP6.0 In this future achieves lower emissions through the use of some mitigation strategies and technologies. Although CO2 concentration rises less rapidly, it reaches 660 ppm by 2100 and total radiative forcing stabilises shortly after 2100.

RCP4.5 Interestingly, CO2 concentrations are slightly above those of RCP6.0 until after mid-century. However, they peak earlier and the CO2 concentration only reaches 540 ppm by 2100.

RCP2.6 This is the very ambitious mitigation scenario requiring early participation from all emitters and 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.

From the descriptions provided above RCP4.5 and RCP8.5 have been selected as representative of the range of plausible futures.

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Selection of Global Climate Models

Global climate models suitable for applications such as this have been identified and made available from the Changing Climate in Australia web site. The reasons for their inclusion in this subset of models can be found in (CSIRO and Bureau of Meteorology, 2015). Anomalies (changes from a baseline period) were derived from gridded data sets obtained from the CIMPS multi-model ensemble (http://nrm- erddap.nci.org.au/erddap/index.html) (see Taylor et al., 2011) and applied as monthly climate change factors to the daily data for the gridded data set. The GCM data are at a much coarser resolution than the daily set and this was downscaled using bilinear interpolation using the package raster (Hijamns, 2015) within the R programming Language (R Core Team, 2015). This statistical downscaling does not take into account elevation, distance from the coast etc. that might affect a location.

Web reference: climate change in Australia

Future Temperature Projections

Seasonal mean maximum and minimum temperatures were calculated for RCP 4.5 and RCP 8.5 for 2030 and 2050. The data are presented as the mean of the eight GCMs (Figures 47, 48, 49 & 50) and for the model(s) that represented the lowest and highest zonal average temperature (Appendix). The latter give an indication of the best and worst cases.

Table 1- Model details.

Model	**Institute**	**Ocean**	**Atmosphere Resolution (°)**
ACCESS1.0	CSIRO-BOM, Australia	1.0x1.0	1.9x1.2, [210x130]
CanESM2	CCCMA, Canada	1.4x0.9	2.8x2.8, [310x310]
CESM1- CAMS	NSF-DOE-NCAR, USA	1.1x0.6	1.2x0, [130x100]
CNRM-CM5	CNRM-CERFACS, France	1.0x0.8	1.4x1.4, [155x155]
GFDL- ESM2M	NOAA, GFDL, USA	1.0x1.0	2.5x2.0, [275x220]
HadGEM2- CC	MOHC, UK	1.0x1.0	1.9x1.2,.[210x130]
MIROCS	JAMSTEC, Japan	1.6x1.4	1.4x1.4,.[155x155]
NorESM1-M	NCC, Norway	1.1x0.6	2.5x1.9,.[275x210]

[1] climate change in australia

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Figure 47 - Mean seasonal minimum temperatures for present and 2030 under RCP 4.5 and RCP 8.5

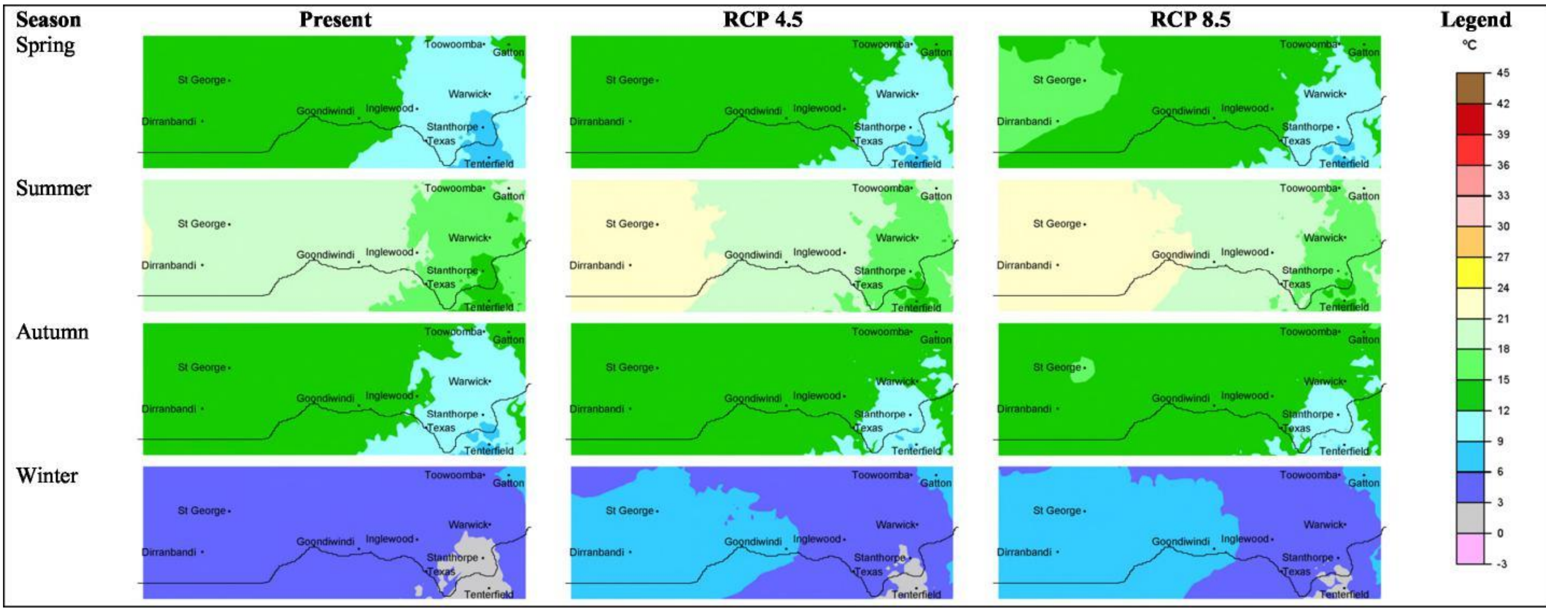

Figure 1 - Mean seasonal maximum temperatures for present and 2030 under RCP 4.5 and RCP 8.5

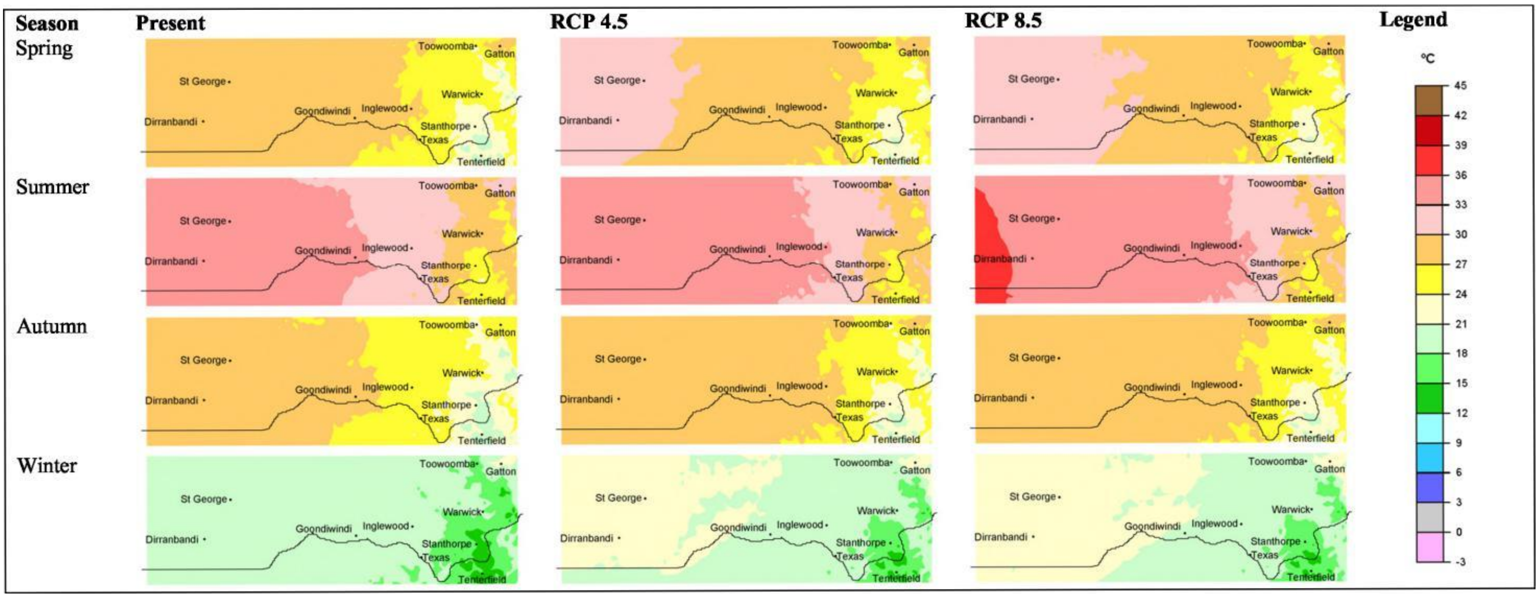

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Figure 49 - Mean seasonal minimum temperatures for present and 2050 under RCP 4.5 and RCP 8.5

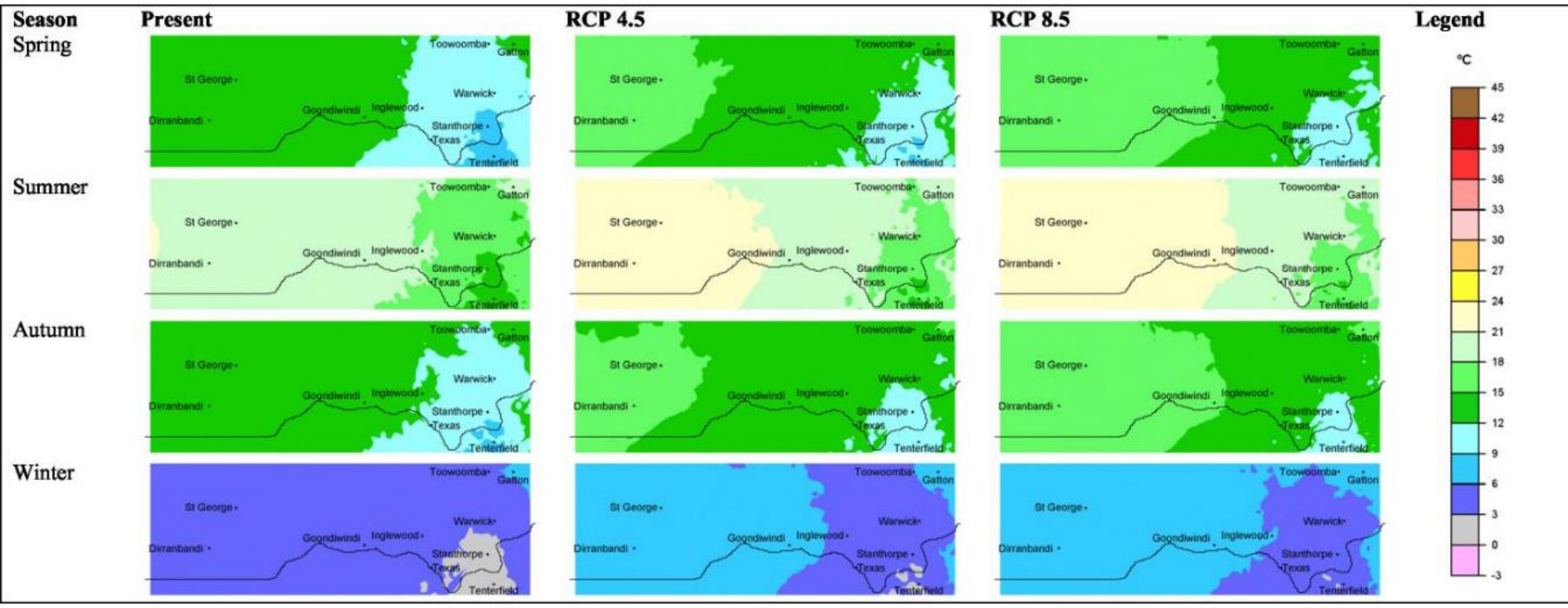
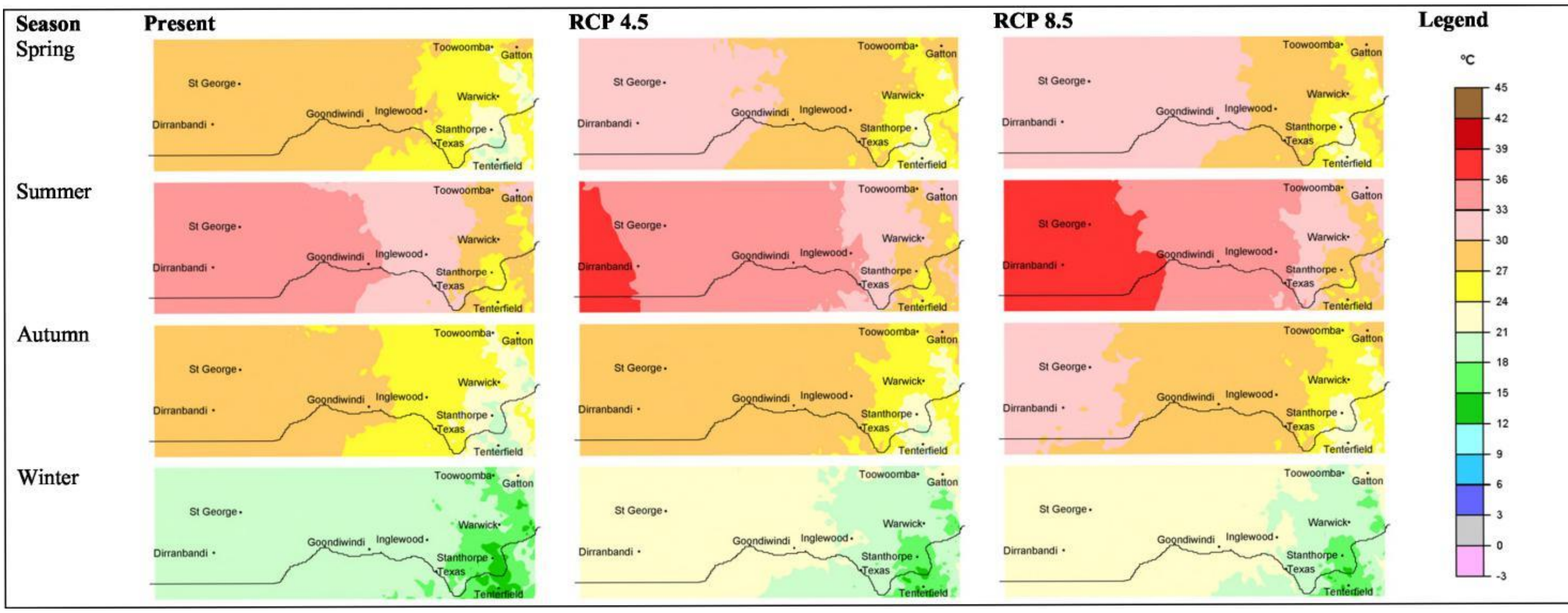


Figure 50 - Mean seasonal maximum temperatures for present and 2050 under RCP 4.5 and RCP 8.5



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3. References

Butler JH, Montzka SA (2016) the NOAA annual greenhouse gas index (AGGI). pp Page.

CSIRO (2016) Cape Grim Greenhouse Gas data. pp Page, CSIRO.

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

Hijamns RJ (2015) raster: Geographic Data Analysis and Modelling. R package version 2.4-18. pp Page, https://cran.r-project.org/package=raster.

R Core Team (2015) R: A Language and Environment for Statistical Computing. pp Page, Vienna, Austria, R Foundation for Statistical Computing.

Taylor KE, Stouffer RJ, Meehl GA (2011) An Overview of CMIPS and the Experiment Design. Bulletin of the American Meteorological Society, 93, 485-498.

Land use data was provided by the Department of Science, IT and Innovation's (DSITI) Queensland Land Use Mapping Program (QLUMP), part of the Australian Collaborative Land Use Mapping Program (ACLUMP). Temperature data was provided from DSITI's Scientific Information for Land Owners (SILO) database and analysed by DAF staff. Soils data was provided by the Department of Natural Resources and Mines from the Soils and Land Information database (SALI). Raw data used to create these maps is available from the Queensland Open Data portal: https://data.qld.gov.au/ and QSpatial: http://qldspatial.information.qld.gov.au/

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