Department of Primary Industries
and Regional Development

Dairy Cow (Holstein)

Results Report

Climate Vulnerability Assessment

NSW GOVERNMENT

Authors

The NSW Department of Primary Industries and Regional Development Climate Vulnerability Assessment and Dairy teams.

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Data availability

The geospatial data which was used to prepare this report (including parts of the model not presented in detail) is available on SEED, the NSW Government's environmental data portal: www.seed.nsw.gov.au.

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Acknowledgement of Country

The NSW Department of Primary Industries and Regional Development acknowledges that it stands on Country which always was and always will be Aboriginal land. We acknowledge the Traditional Custodians of the land and waters and show our respect for Elders past, present and emerging. We are committed to providing places where Aboriginal people are included socially, culturally and economically through thoughtful and collaborative approaches to our work.

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Contact us

For more information, please get in touch with
vulnerability.assessment@dpird.nsw.gov.au

Introduction

Storm and Flood Industry Recovery Package

The Storm and Flood Industry Recovery Package (SFIRP) Program 2a, the Natural Disaster Vulnerability and Risk Assessment project, aims to support the preparedness of the NSW dairy industry for future climate change by improving understanding of the industry's climate vulnerability as well as exploring any opportunities under climate change and assessing the value and effectiveness of adaptation options for overall resilience and continued productivity.

Climate Vulnerability Assessment

The aim of the Dairy Climate Vulnerability Assessment was to deliver a consistent and state-wide understanding of the climate change impacts on dairy in NSW, providing strategic information for policymakers and industry. This information will help the dairy industry understand the risks ahead, prepare and adapt to any identified climate vulnerabilities, and take advantage of future opportunities in the dairy industry in NSW.

Purpose of this report

This report contains results for the dairy cow model within the Climate Vulnerability Assessment. The report introduces the industry in NSW and provides an overview of the model, key features, assumptions, and exclusions. The main modelling results and findings provide insights into future climate vulnerabilities and potential opportunities. The report also recommends adaptation options, where appropriate.

Climate within NSW

The climate in NSW varies across the state, influenced by topography, weather patterns, and proximity to the Great Dividing Range and the Tasman Sea. The state's diverse climates include arid and semi-arid inland regions, humid subtropical coastal areas, temperate coastal regions, and alpine areas.

The changing climate is impacting primary industries.

Australia has one of the world's most variable climates, and its primary producers have always managed climate variability. Now, they are planning for and adapting to climate change arising from anthropogenic greenhouse gas emissions. These changes in long-term climate patterns at global and regional scales are adding a new dimension to the challenge of producing food and fibre in Australia. Changes in climate include increasing temperatures and alterations to rainfall patterns, alongside increasing challenges from extreme events.

The $23.1 billion primary industries sector supports economic growth and development, contributes to food security at the state and national scale and plays a vital role in biosecurity management. The limited availability of practical and targeted information on the impact of climate change on commodity productivity or the changing prevalence of biosecurity risks has hindered adaptation to climate change in this sector.

Projected climate change impacts

A review of research literature on the impacts of projected climate change on primary industries in Australia revealed disparities in research efforts across the primary industry sectors and in our understanding of what is likely to occur.

Climate change is expected to impact both pastures and dairy cows across various dairying regions in Australia. The main factors driving these changes will be shifts in rainfall patterns and rising temperatures. Some regions may be impacted less by climate change. For instance, projected temperature increases of 1.2–2°C in NSW by 2040 under the high emissions scenario are likely to affect the productivity of both dairy cows and pastures[1].

Changing rainfall patterns, warmer temperatures, and decreased water availability are likely to have negative effects on the pastures and forages[2]. This could lead to poor-performing pastures and ultimately result in changes to the feed base used on these farms.

Research suggests that by 2050 the number of moderate to severe heat stress days in the Riverina Murray dairy region could increase by 31 to 42 days compared to past levels[3]. This increase in heat stress days is likely to adversely impact milk production in cows. Further investigation into future trends in heat stress across all dairy regions in Australia is necessary to provide a foundation for the industry to adapt and maintain production under future climate conditions.

However, it is challenging to draw a consistent and comprehensive understanding of the effects of climate change from these studies because of the differences in methodology, assumptions, and projection data used[4].

Assessing the impacts of climate change

To address these issues, the Climate Vulnerability Assessment examined the potential impacts of climate change on dairy cows and their most common pastures. This enabled us to identify key areas of risk and, thus, most in need of adaptation strategies, as well as those areas where climate change might bring new opportunities or relief from existing challenges.

1 Hennessy, K, Clarke, J, Erwin, T, Wilson, L and Heady, C (2016). Climate change impacts on Australia's dairy regions. CSIRO Oceans and Atmosphere, Melbourne, Australia, 64p

2 Eckard, R. J., & Cullen, B. R. (2011). Impacts of future climate scenarios on nitrous oxide emissions from pasture based dairy systems in south eastern Australia. *Animal Feed Science and Technology*, 166, 736-748.

3 Nidumolu, U., Crimp, S., Gobbett, D., Laing, A., Howden, M., & Little, S. (2014). Spatio-temporal modelling of heat stress and climate change implications for the Murray dairy region, Australia. *International Journal of Biometeorology*, 58, 1095-1108

4 Darbyshire, R. O., Johnson, S. B., Anwar, M. R., Ataollahi, F., Burch, D., Champion, C., Coleman, M. A., Lawson, J., McDonald, S. E., & Miller, M. (2022). Climate change and Australia's primary industries: factors hampering an effective and coordinated response. *International Journal of Biometeorology*, 1-12.

Dairy production in NSW

Dairy is a significant agricultural industry in NSW, and the Holstein breed plays a significant role within it. NSW is the second largest dairy-producing state in Australia, and the industry is a major source of employment in regional areas[5]. Over the 2024/25 financial year, the NSW industry produced over 1 billion litres of milk, contributing 12.8% of Australia's milk production[5].

The industry is widespread across different climates in NSW (Figure 1), from a subtropical climate in Lismore to semi-arid conditions in the Riverina Murray. Most dairy farms in NSW are located on the mid-north coast or the far south coast. As of 2025, there are 443 total licensed dairy farms in NSW with an average milking herd size of 343 cows[5].

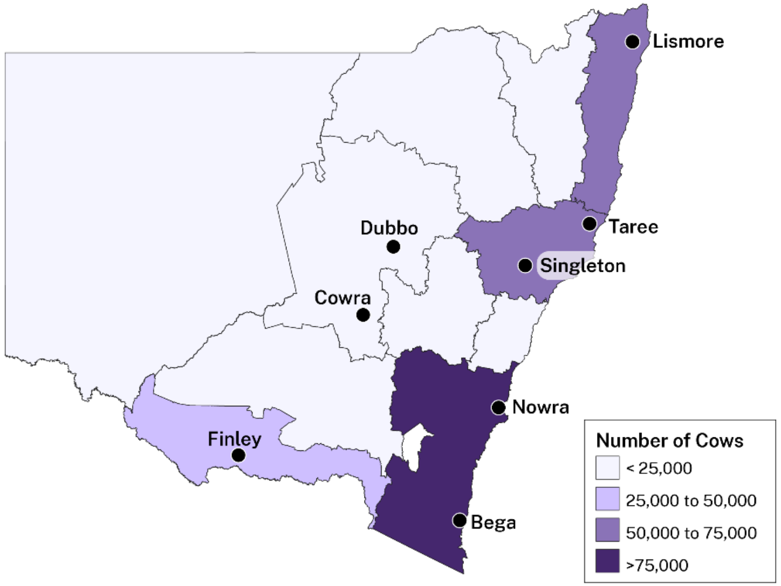


Figure 1: Number of dairy cows across NSW Local Land Services regions.

[5] NSW DPIRD, 2025. NSW Dairy Industry Overview

Climate Vulnerability Assessment framework

This section provides an overview of the framework used for this project and, hence, includes biosecurity risks. The Climate Vulnerability Assessment was designed to provide an overview of the impact of future climate change on all stages of production for the commodities and biosecurity risks assessed. To achieve this, a modelling approach was adopted that would produce assessments for the commodities and biosecurity risks in a consistent and therefore comparable way.

Figure 2: Outline of expert engagement in the assessment framework developed by the Climate Vulnerability Assessment. Internal and external experts are involved throughout the process, helping to develop and refine the model of their primary industry commodity or biosecurity risk.

The assessment framework, outlined in Figure 2, provides a rigorous, flexible and transparent process for assessing vulnerability to climate change. It begins with a literature review, used to inform a draft model of the commodity or biosecurity risk. External experts review the model at three points during the model development as a small focus group. The participation of experts throughout the process was critical for integrating expert knowledge into the models developed by the Climate Vulnerability Assessment.

Six staff from the NSW Department of Primary Industries Dairy Team took part in this work, and a further 10 experts participated in the focus groups which supported the review and refinement of the models. External experts were drawn from industry bodies, producers and academia.

MCA modelling approach

The steps in the framework developed for the Climate Vulnerability Assessment are designed to identify and compare the climate variables important in the production of each commodity and the survival of each biosecurity risk assessed. The chosen modelling approach, using multi-criteria analysis (MCA) models, allows knowledge obtained about these climate variables from scientific literature, expert focus group knowledge and other sources to be combined in a way that is consistent across all commodities and biosecurity risks.

A simple MCA model with customisable assumptions and exclusions (detailed below) was developed for each commodity and biosecurity risk. A hierarchical structure underpins the MCA modelling approach, and the models were developed using a combination of empirical data and expert judgment. The commodity or biosecurity risk sits at the top of the hierarchy, then divided into the key production stages, each containing the climate variables that influence the production stages.

Each production stage is weighted relative to the others to reflect the importance of its contribution to the overall success in the growth of the commodity or the survival of the biosecurity risk. The weightings are derived using the analytical hierarchy process[6] and reflect the consensus reached by the focus group experts.

[6] Saaty, T.L. (1980) The Analytic Hierarchy Process, McGraw-Hill, New York

The MCA model is not designed as a yield estimating model but as a *climate suitability* model. *Climate suitability* is defined as the extent to which climatic conditions satisfy the requirements of plant or animal growth in the absence of other limiting factors[7]. The MCA model provides an assessment of climate suitability (ranging from unsuitable to highly suitable) for each climate variable, for each production stage, and for the overall model. Climate suitability is modelled for both historical (recent past) conditions and for projected (near future) climate to understand how the climate suitability may be affected by climate change.

Experts reviewed the historical and future assessments and provided insights and interpretations, highlighting findings of importance for future planning. The following sections of this report provide an overview of the model structure for dairy cows and key results showing important changes to future climate suitability as identified by the assessment.

For further details on the Climate Vulnerability Assessment Project framework, MCA models, and climate data (historical observations and future projections), please refer to the Climate Vulnerability Assessment Methodology Report.

The project limitations and exclusions are summarised to the right, and the dairy cow model-specific assumptions are summarised on the next page.

Project scope and exclusions

The scope was limited to the assessment of vulnerability to future climate change. The assessment captures the response of dairy cows to changes in future average climatic conditions. The project was designed to support policy and regional investment decisions, not provide farm-scale advice. The following were not considered:

- topography
- socio-economic factors
- other non-climatic biophysical parameters.

These exclusions should be considered alongside the project's findings when examining the ongoing or future viability at a given location.

Certain climate data were excluded due to future climate projection data limitations. Models excluded wind due to its variability on short timescales and the use of relative humidity on timescales shorter than a month. Extreme weather events such as intense rainfall, heatwaves, storms, drought, floods, and bushfires were also excluded due to their unpredictable nature and the complexities of their interaction with the climate. Future work incorporating more sophisticated future climate projections as they become available is likely to provide an improved capacity for describing the impacts of extreme weather events and climate variability.

[7] Zhao, J., Yang, X., Liu, Z., Lv, S., Wang, J. and Dai, S. (2016) Variations in the potential climatic suitability distribution patterns and grain yields for spring maize in Northeast China under climate change. *Climatic Change*, 137:29-42.

Overview of the dairy cow model

For more information, see the Climate Vulnerability Assessment Methodology Report.

Climate variables

The climate variables used in the dairy cow MCA model include minimum temperature (Tmin, °C) and the derived temperature-humidity index (THI).

Categorising climate variables

The hierarchical structure of the MCA model (Figure 3) categorises climate variables to assess their impact on dairy cows. Each category (for example, a temperature between 15 and 30°C) is assigned a rating, R, between 0 and 1 that indicates how well it suits dairy cows, from unfavourable (R=0) to optimal (R=1). This is repeated for each production phase.

Modules used in the dairy cow MCA model

The dairy cow MCA model uses the following standardised modules to produce ratings from the climate variables:

- Proportional module: examines the duration (in days) spent in each climate category during a given production phase.

The ratings for each climate variable, together with the weighting assigned to each branch in the hierarchical structure and the climate data itself, produce the climate suitability index for dairy cow.

Dairy cow model assumptions

In addition to the global assumptions and exclusions, the dairy cow model also contains the following:

- Holstein breed, producing approximately 7500L of milk per year.
- Pasture-based system (minimal shading).
- Cows in all production stages have unlimited access to drinking water and feed (pasture and supplementary).
- Good management practices are in place.
- Farm infrastructure (such as refrigeration, power and sheds) is not limited.
- A year-round calving system is operating.

What is THI?

The temperature humidity index (THI) measures the perceived temperature based on air temperature and relative humidity. It is a way to measure how hot it feels when humidity is factored in with the actual air temperature.

The THI values indicate the level of heat stress the livestock are experiencing. The higher the THI value, the more heat stress the animal is feeling and the greater the production losses. In this report mentions of heat stress relate to THI.

THI was calculated using relative humidity measured at the daily maximum temperature together with the daily maximum temperature. This approach was selected to reflect the acute heat stress conditions experienced by cows during the hottest part of the day.

For the THI calculation used in this assessment please see the Climate Vulnerability Assessment Methodology Report.

Dairy cow production stages

Calf growth, heifer growth, lactation and non-lactating (dry period) were the production stages chosen as key drivers of performance in dairy cows that could be impacted by changing climate conditions. The dairy cow MCA model was analysed monthly to take into consideration year-round calving dates. Descriptions of these stages are detailed in Table 1.

Table 1: Descriptions of the dairy cow production stages used in the MCA model

<table>
<tr><th colspan="2">Production Stage</th><th>Description</th></tr>
<tr><td colspan="2">Calf Growth</td><td>Young calves up to 1 month of age.</td></tr>
<tr><td colspan="2">Heifer Growth</td><td>Older calves from 1 to 15 months of age or until joining.</td></tr>
<tr><td rowspan="2">Lactation</td><td>Early Lactation, Feed Intake and Joining</td><td>Early lactation is considered the first 100 days of the lactation period. This stage also takes into consideration the feed intake and joining phases due to having similar THI thresholds.</td></tr>
<tr><td>Mid to Late Lactation</td><td>Mid to late lactation occurs in the last 200 days of lactation, during which milk production declines.</td></tr>
<tr><td colspan="2">Non-Lactating (Dry Period)</td><td>The dry period can occur at any stage of the year. The dairy cow non-lactating period lasts for approximately 65 days, compared with 300 days of lactation.</td></tr>
</table>

Final dairy cow model

The dairy cow MCA model structure is shown on the following page (Figure 3). The model is divided into the key dairy production stages, followed by the climate variables for each stage.

The weightings for production stages and climate variables were determined using the analytical hierarchy process during the focus group meeting. These ratings reflect the impact of climate factors on each of these production stages. Conditions at lactation account for most of the MCA model (w = 0.61), followed by the Non-Lactating Dry Period (w = 0.16), Heifer Growth (w = 0.14) and Calf Growth (w = 0.09). These ratings reflect the impact of climate factors on each of these production stages.

For calf growth, cold stress received the most weight (w = 0.75) because calves are more vulnerable to cold stress, which impacts their growth and/or potential mortality.

Heifer growth had heat stress (weighting: 0.8) receive a greater weighting than cold stress (w = 0.2). This is because heifers (1-15 months) are more susceptible to heat as they begin to ruminate and produce heat.

For lactation, early lactation (w = 0.8) was given a higher rating than late lactation (w = 0.2). This is because early lactation is also when joining occurs, and these are both important stages of production when cows are susceptible to heat.

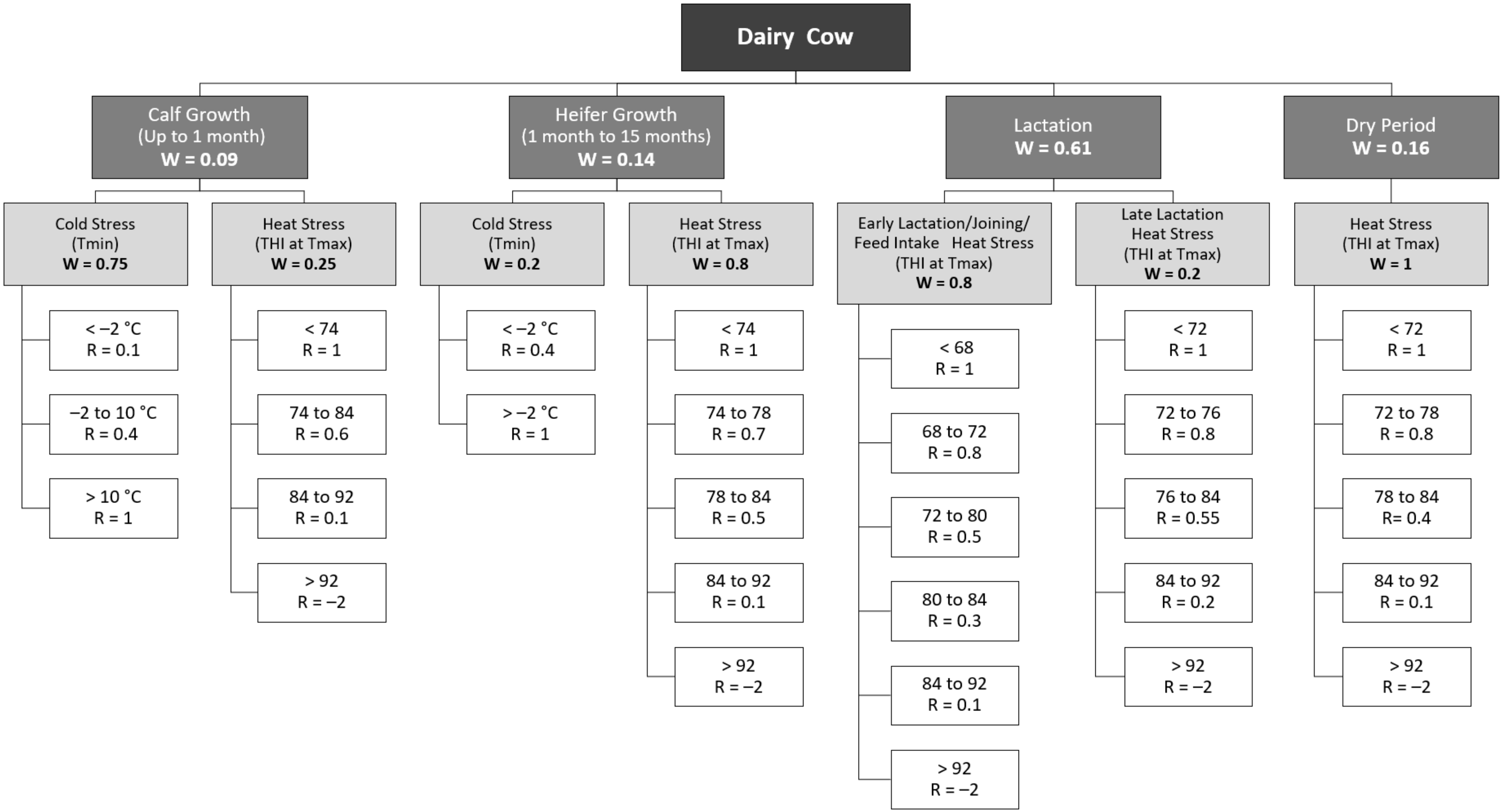


Figure 3: MCA model hierarchical structure and model components for dairy cows. The top level of the hierarchy is dairy cow. The second level contains the production stages identified as climate-sensitive by the literature review and expert judgment. The third level contains the climate variables which impact each month and production stage.

Interpreting the results

The results are presented as panels of 7 maps, comparing historical climate suitability with climate suitability under the two future emissions scenarios (RCP4.5, an intermediate emissions scenario and RCP8.5, a high emissions scenario). For the future emissions scenarios, maps of change and confidence in change in climate suitability are also presented. Polygons and key sites are displayed on each map to indicate the areas where dairy is currently produced.

The historical climate suitability map shows the mean suitability for 30 years (1981 to 2010). For future projections, the mean suitability for 30 years (2036 to 2065) was calculated for 8 global climate models[8] (GCMs), and the median of these models was used to produce ensemble future projection climate suitability maps.

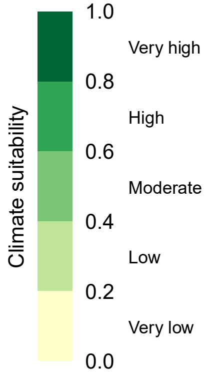


Figure 4: Colour scheme for the climate suitability maps

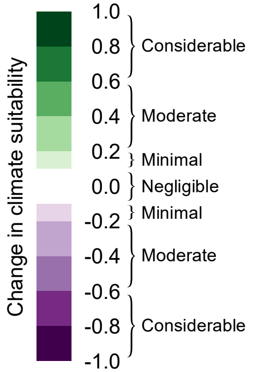


Figure 5: Colour scheme for the change in climate suitability maps

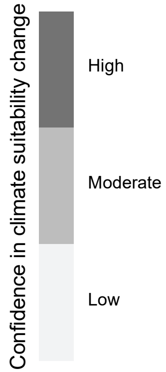


Figure 6: Colour scheme for the confidence in the change in climate suitability maps

Climate suitability maps

The 'climate suitability' maps show the climate suitability on a scale of 0 to 1. Pale yellow is very low suitability, and dark green is very high suitability.

Change in climate suitability maps

The 'change in climate suitability' maps use a green-white-purple colour scheme with 11 categories: positive change in green, where the future becomes more suitable; negative change is in purple. Negligible change is represented by white and occurs for values between −0.1 and 0.1, where the future suitability will be very similar to the historical.

Confidence in the change in climate suitability maps

The 'confidence in change in climate suitability' maps represent the level of agreement across the ensemble of 8 global climate models on the direction and magnitude of change in climate suitability. The lightest shade of grey represents low confidence, and the darkest shade of grey represents high confidence.

[8] Data were sourced from Climate Change in Australia: Application Ready Data

Interpreting the number of highly suitable months

The number of highly suitable months per year is defined as the average number of months with high or very high climate suitability. The results are presented as panels of maps, comparing the historical number with future numbers under the two emissions scenarios.

Maps of change in the number of highly suitable months and confidence in the change are also presented. Polygons and key sites are displayed on each map to indicate where dairy is produced in NSW.

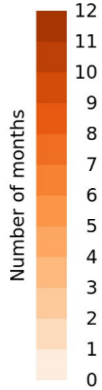


Figure 7: Colour scheme for the number of highly suitable months maps

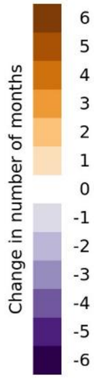


Figure 8: Colour scheme for the change in the number of highly suitable months maps

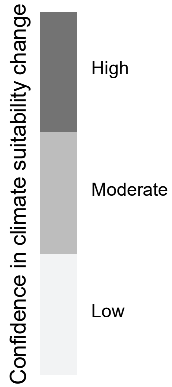


Figure 9: Colour scheme for confidence in the change in the number of highly suitable months maps

Number of highly suitable months maps

The 'number of highly suitable months' maps show the mean number of highly suitable months on a scale of 0 to 12. Pale Orange corresponds to a low number of months, and dark orange corresponds to a high number of months. The values represent the mean overall years (historical or future projections periods) and can take any value between 0 and 12 (they need not be whole numbers).

Change in the number of highly suitable months maps.

The 'change in the number of highly suitable months' maps use a purple-white-orange colour scheme with 11 categories. Shades of Orange indicate an increase in the number of highly suitable months; shades of purple indicate where the number is likely to decrease. Negligible change is represented by white and occurs for values between -0.5 and 0.5; in these areas, the future number of highly suitable months will be very similar to the historical number.

Confidence in change in the number of highly suitable months maps

The 'confidence in the change in the number of highly suitable months' maps represent the level of agreement between the ensemble of 8 global climate models on the direction and magnitude of change in the number of highly suitable months. These maps use a grey colour scheme with three categories: the lightest grey represents low confidence, and the darkest grey represents high confidence.

Interpreting calendars

Calendars were made for individual sites of interest. These plots provide a visual comparison of the change in climate suitability over the year, comparing the mean historical climate suitability with the median future climate suitability for each emissions scenario (RCP4.5 and RCP8.5). Calendars are included for the level of dairy cows and each production stage.

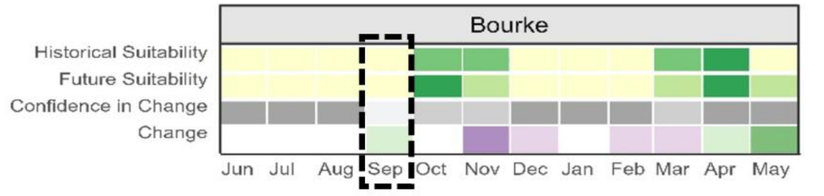
Calendars use the same colour categorisation as the climate suitability panels (Figure 4, Figure 5 and Figure 6), except that the 'change in climate suitability' maps use 7 colours instead of 11, condensing them into the following categories: negligible, minimal, moderate and considerable.

There are two important points to note when interpreting calendars. One occurs when the historical and future climate suitability categories are the same, but the 'change in suitability' is non-negligible (green or purple; see Example 1). The other occurs when the change from historical to future climate suitability is negligible (white), but the climate suitability is in different categories (see Example 2).

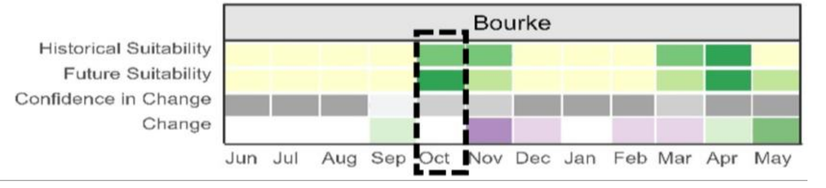
The situation shown in **Example 1** has arisen from a historical September climate suitability of 0.000 and a future (RCP8.5) climate suitability of 0.125. Both fall into the 'very low' suitability category, shown as pale yellow, but the change in the value of +0.125 falls into the 'minimal' change category, shown as pale green.

The situation shown in **Example 2** has arisen from a historical October climate suitability of 0.577 and a future (RCP8.5) climate suitability of 0.666. The category changes from 'moderate' to 'high' (pale green to green), but the change in the value of +0.089 falls into the 'negligible' change category (white).

Example 1. The calendar in this example for Bourke shows a 'minimal' change in climate suitability for September, but the historical and future climate suitability categories are the same ('very low'). The amount of change has not been enough to change the suitability classification for this site. This also occurs in December, February, and April.



Example 2: The calendar in this example for Bourke shows a 'negligible change' in suitability for October, but when comparing the historical and future suitability rows, there has been an increase in suitability from 'moderate' to 'high'. The suitability category assigned to this site has changed, but the magnitude of change is small.



Projected changes in climate suitability for dairy cows

Climate change is likely to offer both opportunities and challenges for dairy cow production in NSW by 2050.

This section provides the key results for the dairy cow model. The section begins with an overview of the main impacts, vulnerabilities, and opportunities, followed by the maps from the assessment that show notable changes. The relevant interpretation and findings are provided in text on the bottom left corner of each map panel. The findings have been summarised with key Figures and additional maps provided in the Appendix.

Analysis of the model outputs has been undertaken spatially across NSW, presented as maps, and over time (on a monthly basis), presented as calendars. Each map includes the outline (in blue) of key dairy regions in NSW. These regions are shown in Figure 10, and will be referred to as the North Coast, Hunter, Inland, Riverina Murray, and South Coast in the results section of this report. The following pages will detail these findings and present Figures that illustrate where these changes occur, which dairy regions in New South Wales are likely to be impacted and which production stages of dairy are likely to be affected by the projected future climate.

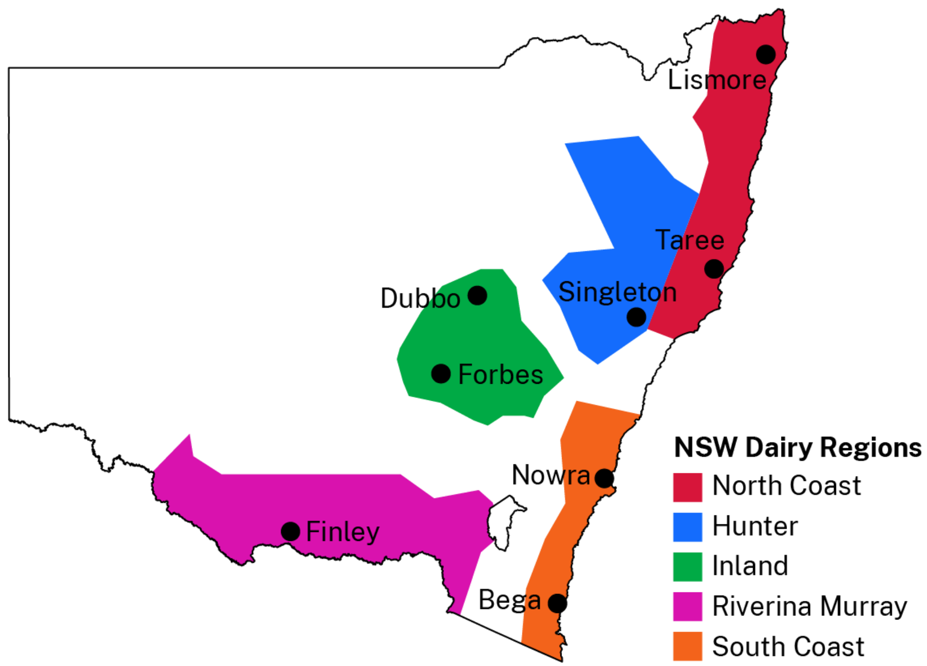


Figure 10. The key dairy production regions in NSW. Locations marked by black dots show towns near dairy farms.

Overall annual climate impacts

Annual climate suitability trends: impacts on the NSW dairy regions

NSW dairy farming regions experience a range of climate conditions throughout the year, impacting dairy cows. The following pages detail the expected changes in climate suitability and provide figures illustrating where these changes are likely to occur. The findings identify the regions that may be impacted, the months in which these changes may take place and the impacted production stages.

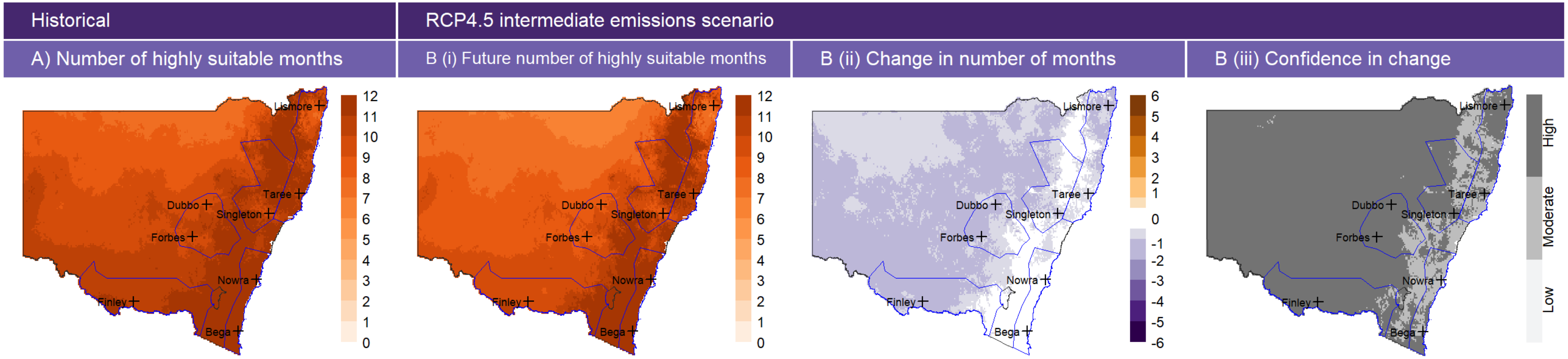
The number of highly suitable months each year, in which the climate suitability is classified as 'high' or 'very high', is used as a measure[9] of overall climate suitability for dairy cows, and varies across different regions of the state (Figure 11).

By 2050, the number of highly suitable months for dairy cows is likely to decrease by 0.5 to 2 months per year across most of the state under both emissions scenarios (*moderate to high confidence*). A projected decrease in the number of highly suitable months of 1 to 2 months in the Inland, Riverina Murray and North Coast dairy regions is more pronounced under the high emissions scenario. This is likely to create an extended 'challenging' period for dairy cows in these regions. Heat stress is the main driver of the decrease, and it is likely that dairy operators will need to introduce heat management strategies earlier and for longer. If actions are not taken to reduce the impacts of the increased THI on cows, this can negatively impact the whole production system from calf growth through to the dry period.

Some NSW dairy regions, however, are likely to experience negligible change in highly suitable months (less than 0.5 months): this includes most of the South Coast dairy region, the north-east of the Hunter dairy region and the far eastern end of the Riverina Murray dairy region (*moderate confidence*). These regions, and other areas along the Great Dividing Range, are likely to maintain their historically high numbers of highly suitable months (11-12 months per year). This means that the future climate in these regions is likely to maintain their current suitability for dairy production.

[9] The value is the mean over the relevant historical or future time period (30 years), and so values are not always whole numbers of months.

Dairy cow: number of highly suitable months



Findings: The number of highly suitable months in a year varies across the state. Under both scenarios, there are likely to be decreases in the number of highly suitable months across all dairy regions except in the South Coast. Up to a 3-month decrease is expected under the high emissions scenario in a few areas of the state.

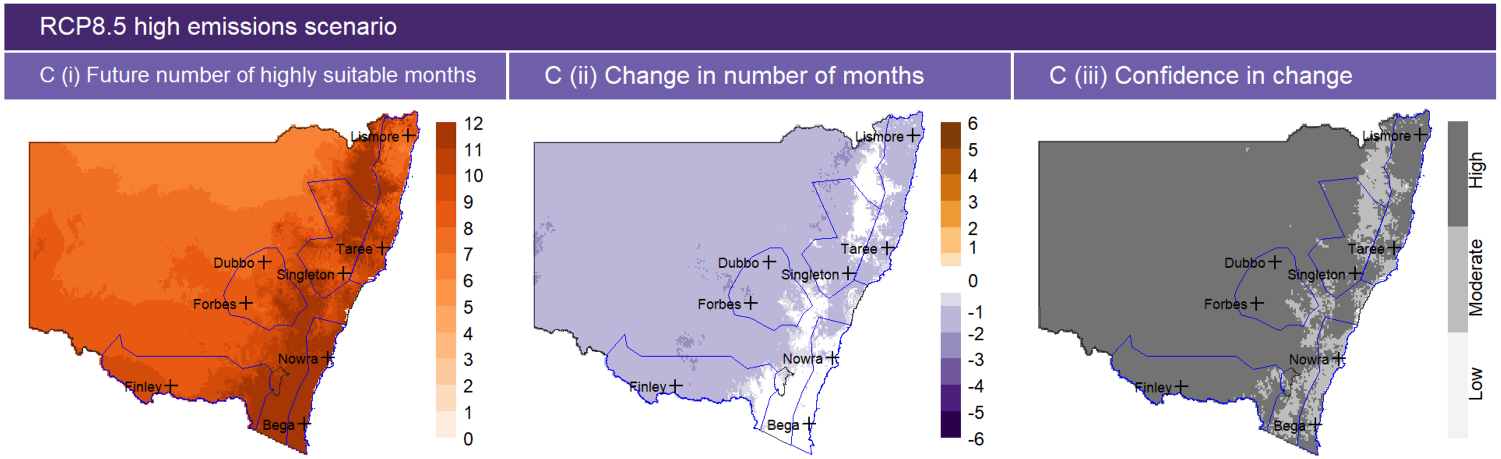


Figure 11: Number of highly suitable months per year for overall dairy cow. This measures the months in which climate suitability is greater than or equal to 0.6. The panel is comprised of 7 maps: A) shows the historical number of highly suitable months; B) and C) show the future number of highly suitable months for the intermediate and high emissions scenarios, respectively; (i) shows future number of highly suitable months, (ii) shows the expected change in number of months as negligible (white), increasing (orange) or decreasing (purple) change, and (iii) shows the level of confidence in this change (low, moderate or high). Polygons and key sites are displayed on each map to indicate the areas where dairy production is predominantly carried out in NSW.

Changes in monthly climate suitability

Spatial trends: How climate change will impact NSW dairy regions

The preceding pages have analysed trends in climate suitability for dairy cows for the year overall. This section examines climate suitability for dairy cows for specific months of the year.

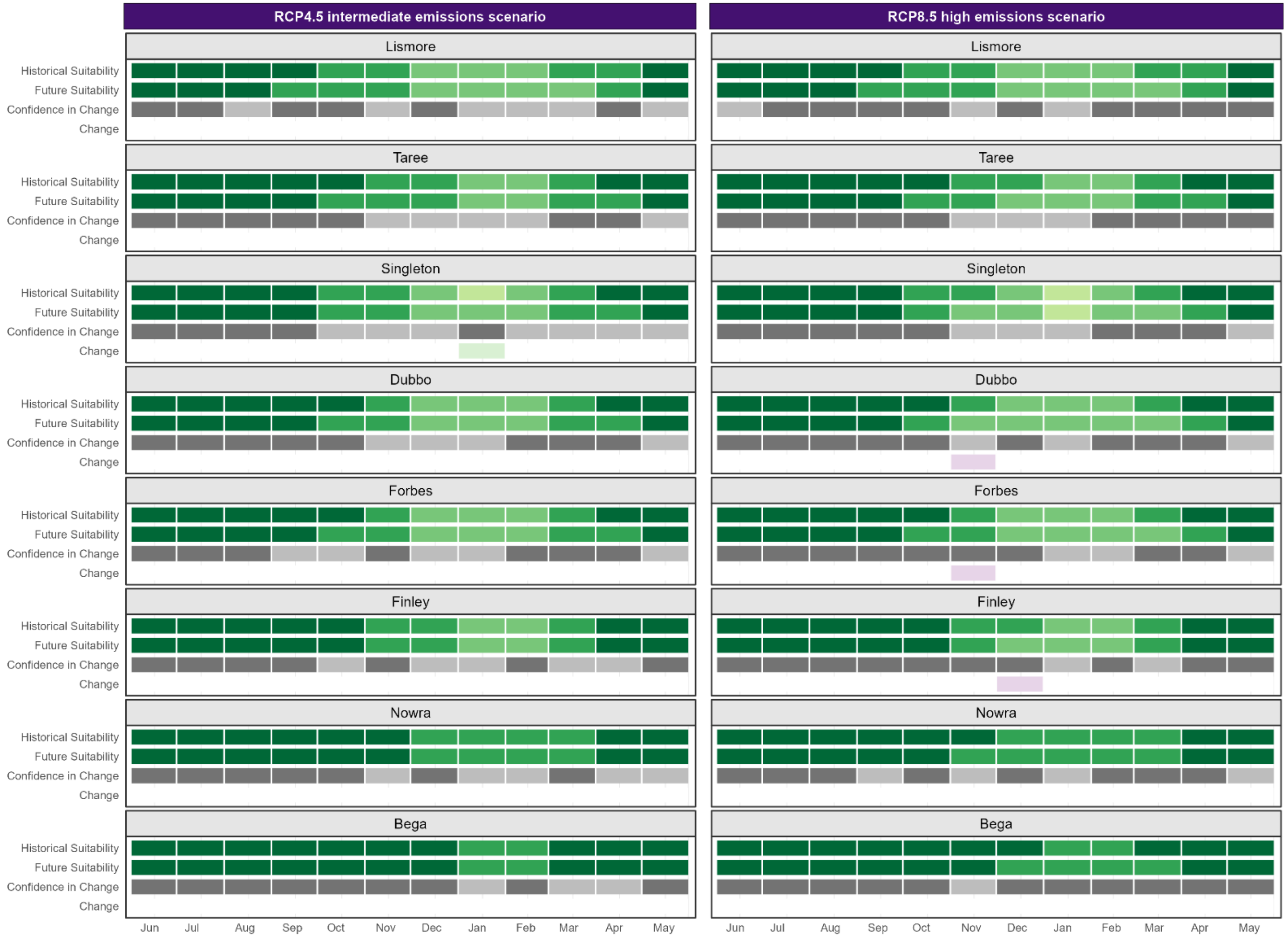
- **Intermediate emissions scenario:** climate suitability for all months is likely to remain at its historical levels across all NSW dairy regions, with negligible change (*moderate to high confidence*), except for a minimal increase around Singleton in the Hunter dairy region during January (*high confidence*), see Appendix Figure A5. For other months, see Appendix Figures Figure **A6** to Figure **A16**.
- **High emissions scenario:** climate suitability for most months is likely to remain at its historical levels across all NSW dairy regions, with negligible change (*moderate to high confidence*), with the following exceptions:
    - **November:** climate suitability in the western part of the Inland dairy region (from Dubbo to Forbes) is likely to experience a minimal decrease during November (*moderate confidence*) (see Appendix Figure A15).
    - **December:** climate suitability in the central parts of the Riverina Murray dairy region (east and west of Finley) is likely to experience a minimal decrease during December (*high confidence*). The northernmost area of the Hunter dairy region is also likely to experience a minimal decrease in this month (*high confidence*) (see Appendix Figure A16).
    - **January:** isolated areas of the Riverina Murray, Inland and Hunter dairy regions are likely to experience a minimal decrease in climate suitability during January (*high confidence*) (see Appendix Figure A5).
    - **February:** there is likely to be a minimal decrease in climate suitability in the Inland dairy region, around Dubbo and in the westernmost part of the Hunter dairy region, in February (*high confidence*) (see Appendix Figure A6).

Monthly trends at dairy sites: how climate change will alter climate suitability throughout the year

Figure 12, the overall calendar, shows the expected temporal change in monthly climate suitability throughout the year around sites of importance to dairy cows. An analysis of future climate suitability around these sites provides insights into potential future monthly trends by 2050.

- Under the high emissions scenario, climate suitability for dairy cows is expected to decrease during some of the summer months for Dubbo, Forbes and Finley areas (*moderate to high confidence*).
- The climate suitability during late autumn, winter and early spring is likely to remain similar to the historical suitability under both emissions scenarios (*moderate to high confidence*)

Dairy cow: climate suitability calendar



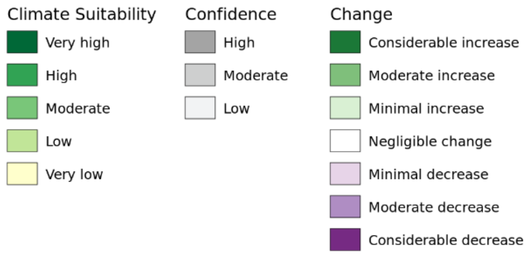


Figure 12: Climate suitability calendar for dairy cow, showing the monthly climate suitability value for the historical climate suitability (top row in each box) and future emissions scenarios (RCP4.5 and RCP8.5), for each key site. The climate suitability categories represent the median value within a 10km radius of each site.

Findings: Climate suitability varies throughout the year across different sites, with high to very high climate suitability typically occurring from March/April through to September/October. The summer months tend to have decreased suitability, and climate suitability levels differ between sites.

In the north coast sites, Lismore and Taree, climate suitability is expected to remain moderate to very high throughout the year. Similarly, the south coast sites such as Nowra and Bega are likely to maintain high to very high suitability. As a result, the dairy industry in these regions is likely to experience similar climate conditions in the future as it has in the past.

Conversely, in November or December, climate suitability is expected to decrease in inland and Riverina Murray areas, as represented by Dubbo, Forbes, and Finley. This decrease in suitability may cause further challenges for some dairy businesses, as the reduction is due to increased heat stress during this period. These businesses are likely to need to implement heat management strategies to reduce adverse impacts on production.

Climate impacts on dairy cow production stages

Calf growth

Calf growth, particularly if impeded, can directly impact future milk production, with climatic factors such as heat stress or cold stress being catalysts for this. In this model, calving is assumed to be year-round; therefore, calves (less than one month) will be present throughout the year. Changes to monthly climate suitability during calf growth are likely to lead to an increase in climate suitability.

The number of highly suitable months for each year for calf growth (Figure A1) is likely to increase by 0.5 to 2 months across NSW. A part of the north coast region around Lismore is likely to retain historical numbers of highly suitable months under both emissions scenarios (*high confidence*).

Figure 13, the calf growth climate suitability calendar, shows the expected change in monthly climate suitability throughout the year at the dairy sites. These changes in climate suitability are:

- **Increased climate suitability in some areas** is expected under both emissions scenarios. Under the intermediate emissions scenario, there is likely to be a minimal to moderate suitability increase around Singleton from November to January (*high* confidence) and around Finley during January (*high confidence*), as warmer temperatures will reduce the effects of cold stress on calf growth. Under the high emissions scenario, climate suitability is expected to increase at the following locations during these months: Taree (September), Singleton (September and January), Finley (January), Nowra (May to September) and Bega (October) (*high confidence*).
- **Decreased climate suitability** under the high emissions scenario is likely to occur in inland NSW. These impacts can be seen in Figure 14, which shows calf heat stress climate suitability for December. Most of the decreases in climate suitability are occurring in regions that are not currently used for dairy production (as shown in map C (ii)). These minimal reductions in climate suitability during calf growth in summer are a result of more heat stress (*moderate to high confidence*). These changes are expected to impact parts of the Riverina Murray, Inland and Hunter regions in some months from November through to March (*high confidence*) (data not shown).
- **Historical climate suitability is likely to be maintained** throughout winter, early spring and late autumn across most dairy regions under both emissions scenarios (*moderate to high confidence*). While future projections do not indicate a further decline in climate suitability during some of these months, it is essential to implement strategies to manage the historical heat stress already present during this period.

Calf growth: climate suitability calendar

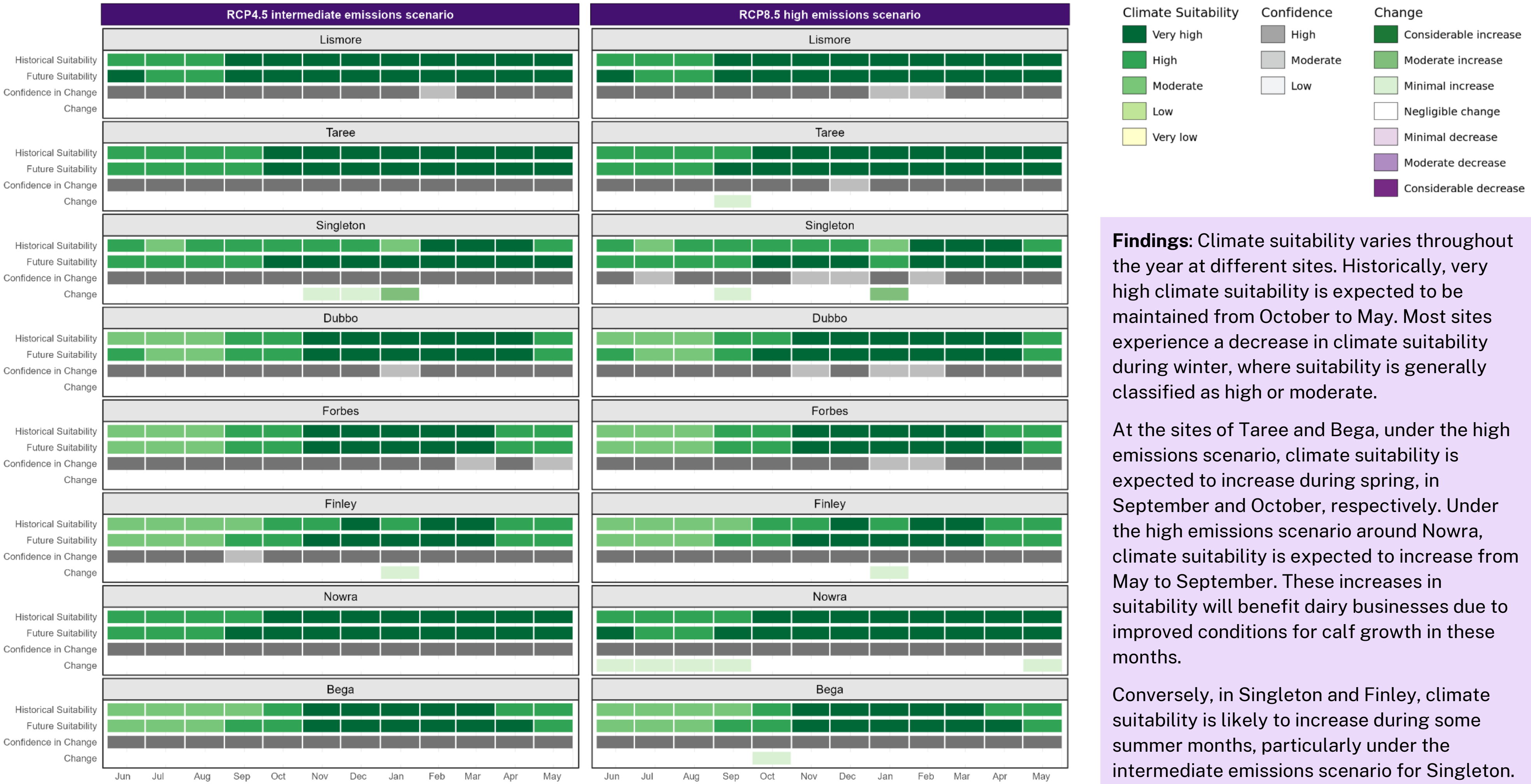


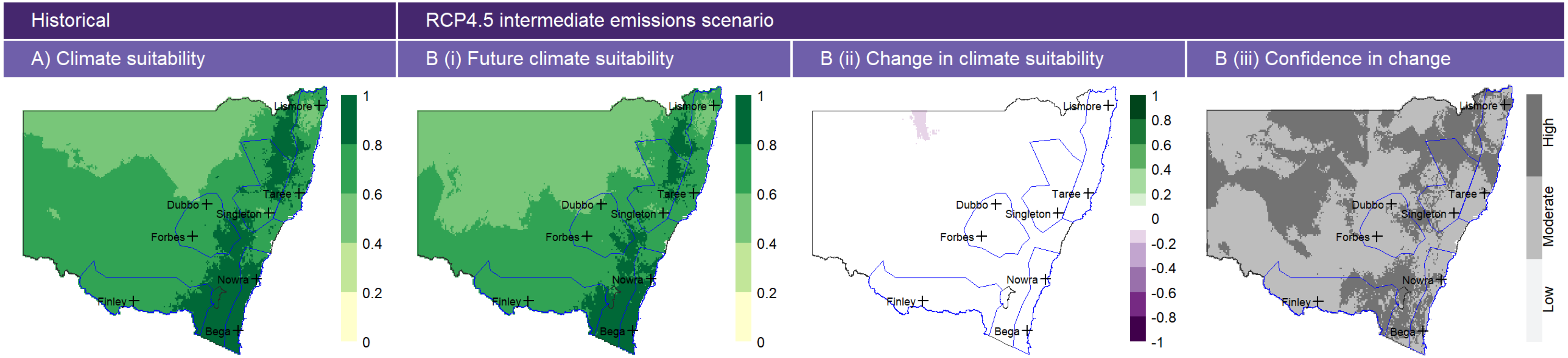
Figure 13: Climate suitability calendar for the calf growth component of the model, showing the monthly climate suitability value for the historical climate suitability (top row in each box) and future emissions scenarios (RCP4.5 and RCP8.5), for each key site. The climate suitability categories represent the median value within a 10km radius of each site.

Findings: Climate suitability varies throughout the year at different sites. Historically, very high climate suitability is expected to be maintained from October to May. Most sites experience a decrease in climate suitability during winter, where suitability is generally classified as high or moderate.

At the sites of Taree and Bega, under the high emissions scenario, climate suitability is expected to increase during spring, in September and October, respectively. Under the high emissions scenario around Nowra, climate suitability is expected to increase from May to September. These increases in suitability will benefit dairy businesses due to improved conditions for calf growth in these months.

Conversely, in Singleton and Finley, climate suitability is likely to increase during some summer months, particularly under the intermediate emissions scenario for Singleton. These increases potentially benefit dairy businesses with more favourable conditions for calf growth in the future.

Calf growth: climate suitability for calf heat stress in December



Findings: Under the intermediate emissions scenario, there is likely to be negligible change, meaning heat stress is expected to remain similar to historical conditions in December for all dairy regions. In contrast, under the high emissions scenario, central NSW may see a minimal decrease in climate suitability, affecting areas in the following dairy regions: Riverina Murray, Inland, Hunter, and isolated areas of the North and South Coast in December.

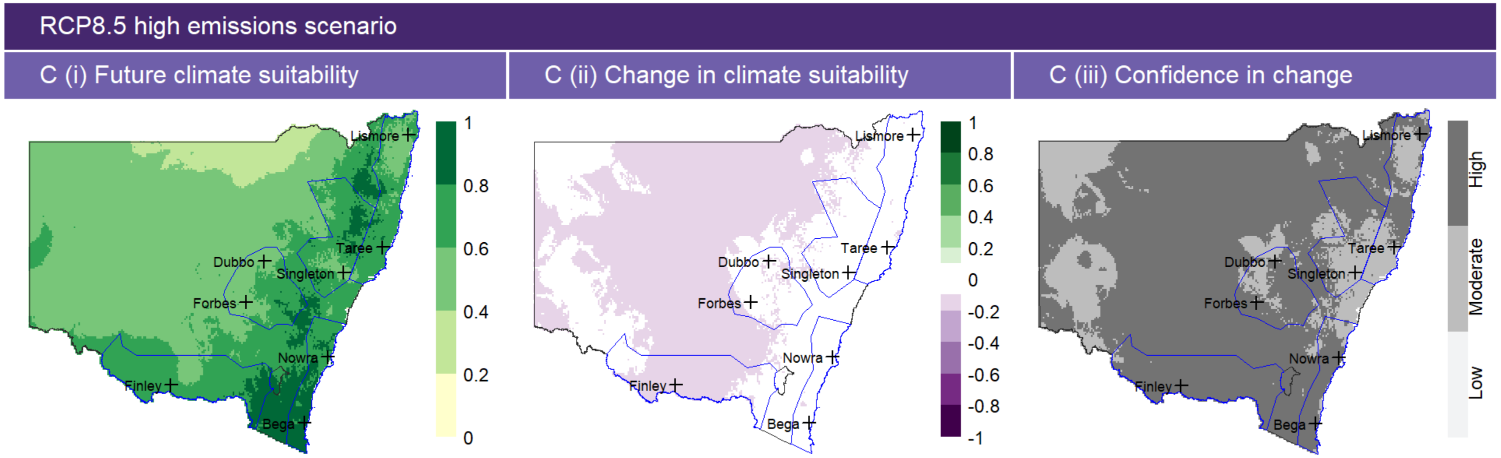


Figure 14: Climate suitability for calf growth heat stress in December in NSW. The panel is comprised of 7 maps: A) shows the historical climate suitability; B) and C) show future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability; (ii) shows the projected future change in climate suitability as negligible (white), positive (green) or negative (purple) change, and (iii) shows the level of model confidence associated with this change (low, moderate or high). Polygons and key sites are displayed on each map to indicate the areas where the dairy is currently produced.

Heifer growth

Heifers are vulnerable to both heat and cold stress. When heifers experience stress, one serious consequence is reduced dry matter intake, and their energy is redirected towards thermoregulation instead of growth and development. Research has indicated that heat stress during the development of heifers can have long-lasting effects on future lactations, resulting in smaller body weights and reduced mammary gland development[10]. Changes to monthly climate suitability during heifer growth are likely to lead to a minimal decrease in climate suitability during some summer months.

The number of highly suitable months for each year for heifer growth (Figure A2) is likely to decrease by 0.5 to 2 months across most western NSW (*moderate to high confidence*). Areas along the Great Dividing Range to the coast are likely to retain historical numbers of highly suitable months under both emissions scenarios (*moderate to high confidence*). The area south and west of Lismore and west of Singleton are likely to experience a 1- to 2-month decrease in suitable months, which is more pronounced under the high emissions scenario (*moderate to high confidence*).

Figure 15, the heifer growth calendar, shows the expected change in monthly climate suitability throughout the year at the dairy sites. These changes in climate suitability are

- **Increased climate suitability in some areas** is likely to occur in the intermediate emissions scenario. Under this scenario, there is likely to be a minimal suitability increase around Singleton in January (*high confidence*), indicating that there may be a slight reduction in the impact of heat stress on heifer growth in this month.
- **Decreased climate suitability** in the high emissions scenario is likely to occur during November or December around Dubbo, Forbes and Finley (Figure 15) (*moderate to high confidence*). These minimal reductions in climate suitability during heifer growth suggest that by 2050, there is likely to be greater heat stress in some summer months. The decreases in climate suitability in December mostly occur in regions not currently used for dairy production (Figure 16 map C (ii)). These changes are expected to impact parts of the Riverina Murray, Inland and Hunter regions in some summer months (*moderate to high confidence*).
- **Historical very high climate suitability is likely to be maintained** throughout winter, early spring, and late autumn across most dairy sites under both emissions scenarios, with Bega maintaining very high suitability throughout the year (*moderate to high confidence*). It is important to note that historically, at all sites except for Bega, there are some months from November to March where climate suitability is categorised as high or moderate. While future projections do not indicate a further decline in climate suitability during some of these months, it is essential to implement strategies to continue to manage heat stress during this period.

[10] Dairy Australia Cool Cows: Strategies for managing heat stress in dairy cows. August 2023 https://cdn-prod.dairyaustralia.com.au/-/media/project/dairy-australia-sites/national-home/climate_environment/coolcows/files/cool-cows-manual-booklet-2023.pdf?rev=77ae102be4924292b03906a5a7f64199

Heifer growth: climate suitability calendar

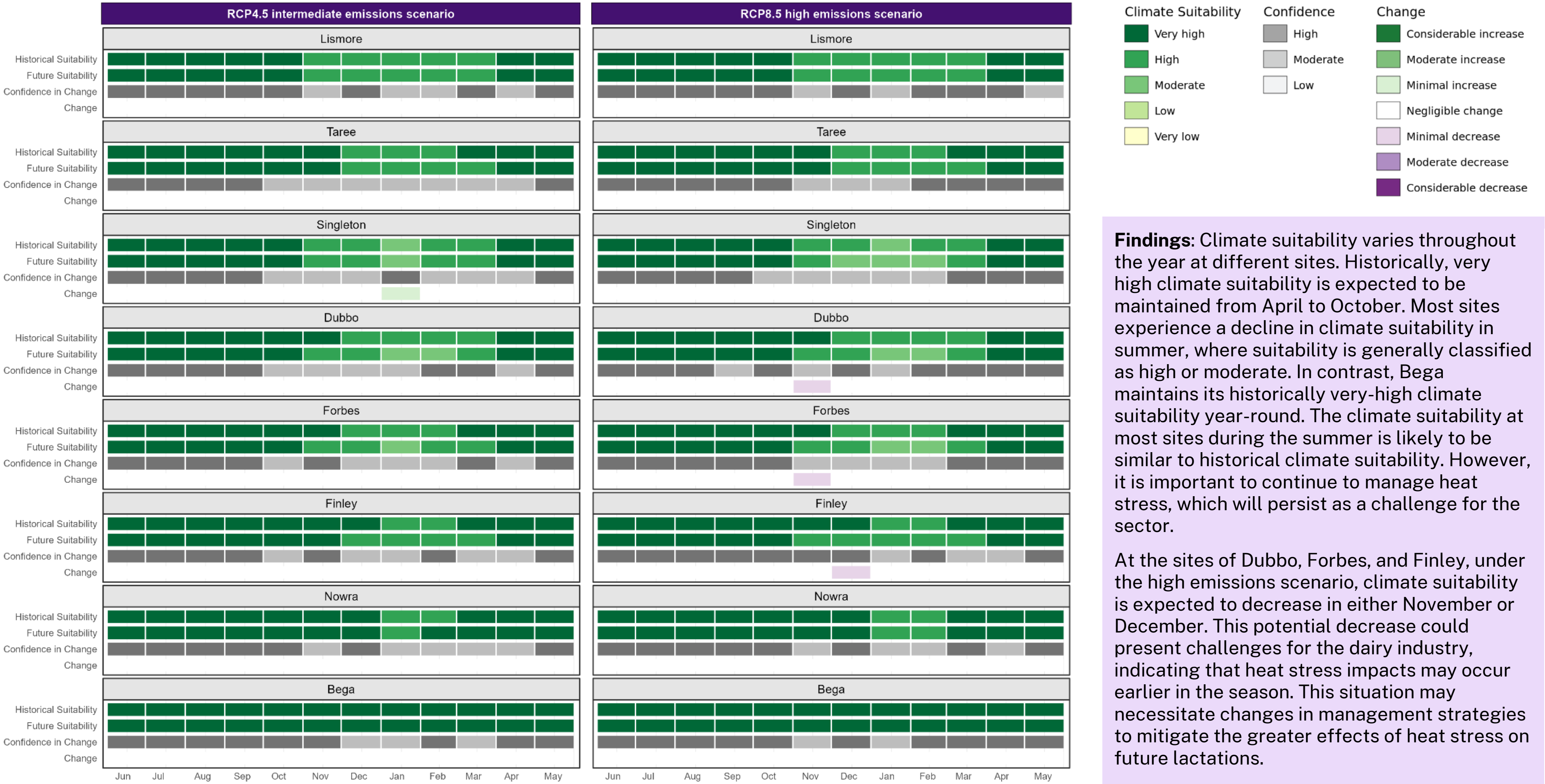


Figure 15: Climate suitability calendar for the heifer growth component of the model, showing the monthly climate suitability value for the historical climate suitability (top row in each box) and future emissions scenarios (RCP4.5 and RCP8.5), for each key site. The climate suitability categories represent the median value within a 10km radius of each site.

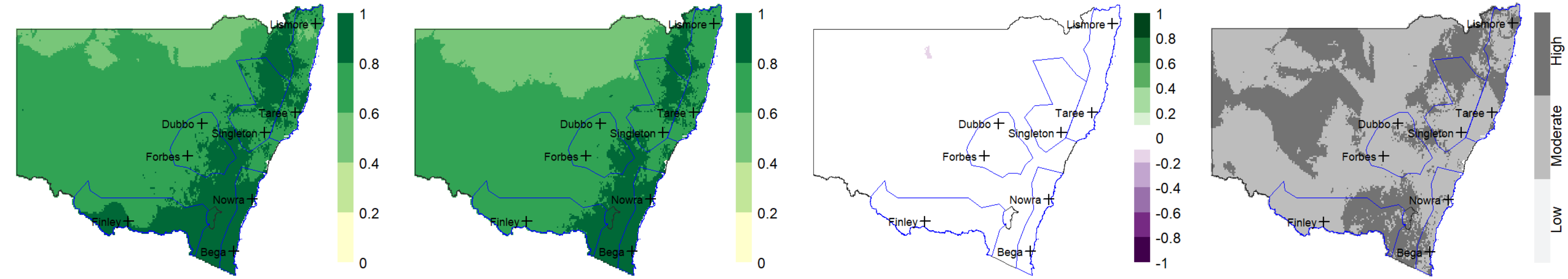
Findings: Climate suitability varies throughout the year at different sites. Historically, very high climate suitability is expected to be maintained from April to October. Most sites experience a decline in climate suitability in summer, where suitability is generally classified as high or moderate. In contrast, Bega maintains its historically very-high climate suitability year-round. The climate suitability at most sites during the summer is likely to be similar to historical climate suitability. However, it is important to continue to manage heat stress, which will persist as a challenge for the sector.

At the sites of Dubbo, Forbes, and Finley, under the high emissions scenario, climate suitability is expected to decrease in either November or December. This potential decrease could present challenges for the dairy industry, indicating that heat stress impacts may occur earlier in the season. This situation may necessitate changes in management strategies to mitigate the greater effects of heat stress on future lactations.

Conversely, in Singleton, climate suitability is likely to increase under an intermediate emissions scenario in January, potentially benefiting dairy businesses by providing slightly improved conditions for heifer growth.

Heifer growth: climate suitability in December

Historical	RCP4.5 intermediate emissions scenario		
A) Climate suitability	B (i) Future climate suitability	B (ii) Change in climate suitability	B (iii) Confidence in change



Findings: Under the intermediate emissions scenario, there is likely to be negligible change, meaning heat stress is likely to remain similar to historical conditions in December for all dairy regions. In contrast, under the high emissions scenario, central NSW may see a minimal decrease in climate suitability, affecting areas in the following dairy regions: Riverina Murray, Inland, and Hunter. This potential decrease could pose a challenge for the dairy business, indicating that heat stress impacts may occur earlier in the season.

RCP8.5 high emissions scenario		
C (i) Future climate suitability	C (ii) Change in climate suitability	C (iii) Confidence in change

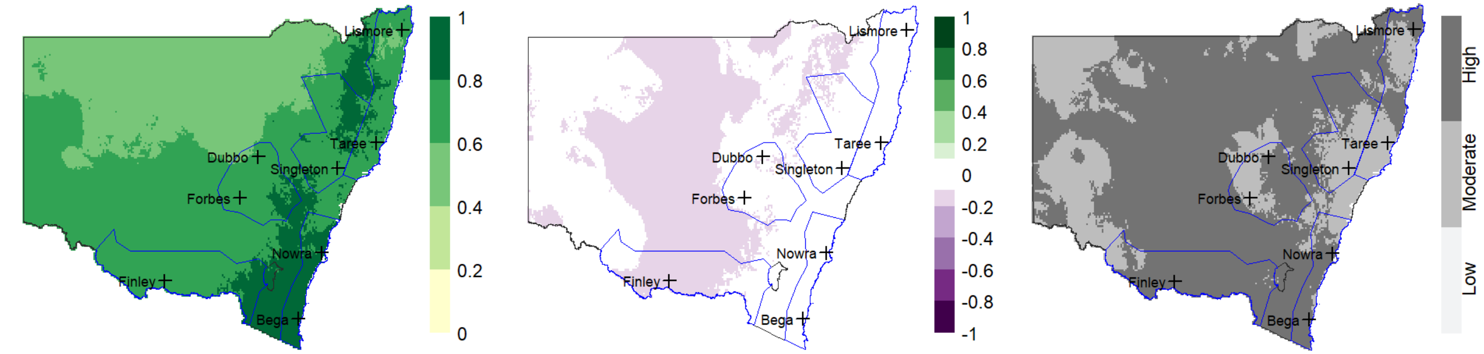


Figure 16: Climate suitability for the dairy cow heifer growth production stage in December across NSW. The panel is comprised of 7 maps: A) shows the historical climate suitability; B) and C) show future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability; (ii) shows the projected future change in climate suitability as negligible (white), positive (green) or negative (purple) change, and (iii) shows the level of model confidence associated with this change (low, moderate or high). Polygons and key sites are displayed on each map to indicate the areas where the dairy is currently produced.

Lactation

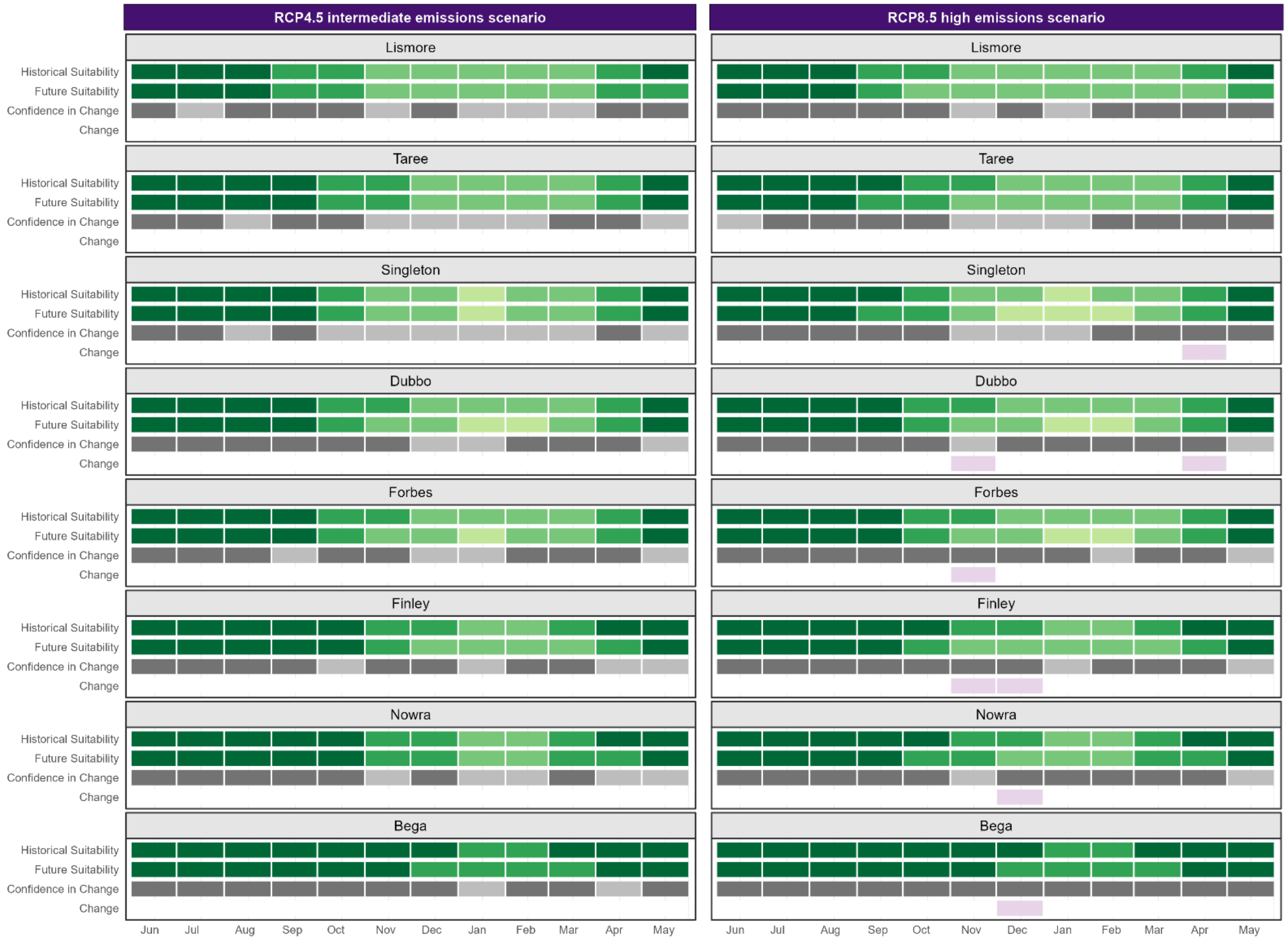
Milk production is particularly susceptible to heat stress, which can negatively impact farm productivity and profitability. Heat stress can lead to reduced reproductive performance, impaired temperature regulation, reduced milk yields, and increased health issues. Under the lactation stage, the impacts of heat stress on early and late lactation were explored. Notably, heat stress impacts in early lactation also sheds light on how heat stress affects feed intake and joining, as similar climatic thresholds influence these factors. Changes to monthly climate suitability during lactation are likely to lead to a minimal decrease in climate suitability during some of the warmer months.

The number of highly suitable months in each year for the lactation stage is likely to decrease by 0.5 to 2 months across most of NSW (*moderate to high confidence*) (see Figure A3). In parts of the North Coast around Taree and the Hunter region on the western edge, there could be a reduction of up to 3 months under the high emissions scenario (*high confidence*). However, some areas along the Great Dividing Range are expected to retain their historical number of highly suitable months under both emissions scenarios (*moderate to high confidence*).

Figure 17, the lactation climate suitability calendar, shows the expected change in monthly climate suitability throughout the year at the dairy sites. These changes in climate suitability are:

- **Decreased climate suitability** under the high emissions scenario is expected in November, December and April around Dubbo, Singleton, Forbes, Nowra, Finley and Bega, as shown in Figure 17: Climate suitability calendar for the lactation component of the model, showing the monthly climate suitability value for the historical climate suitability (top row in each box) and future emissions scenarios (RCP4.5 and RCP8.5), for each key site. The climate suitability categories represent the median value within a 10km radius of each site. (*moderate to high confidence*). These minimal reductions in climate suitability during lactation indicate that by 2050, there is likely to be increased heat stress in late spring and early autumn. Figure 18 map C (ii) shows a minimal decrease in climate suitability during November, which extends across the Riverina Murray, Inland and Hunter regions (*moderate to high confidence*). These changes are expected during early and late lactation (data not shown). In Figure 19 map C (ii), we show the result for early lactation in April. These minimal decreases in climate suitability are expected to impact parts of the Inland, Hunter and North Coast regions (*moderate to high confidence*).
- **Historical very high climate suitability is likely to be maintained** throughout winter, early spring, and late autumn across most dairy sites under both emissions scenarios (*moderate to high confidence*). It is important to note that historically, there are some months from September to May where climate suitability has been high or moderate, or in the case of Singleton, low in January. While future projections do not indicate a further decline in climate suitability during some of these months, it is essential to continue to implement strategies to manage heat stress during this period.

Lactation: climate suitability calendar



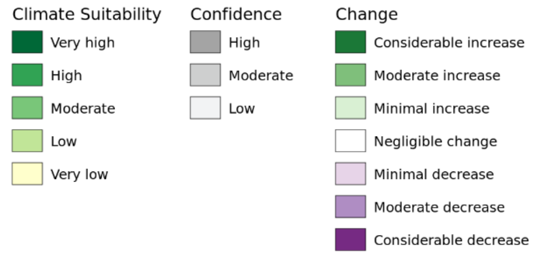


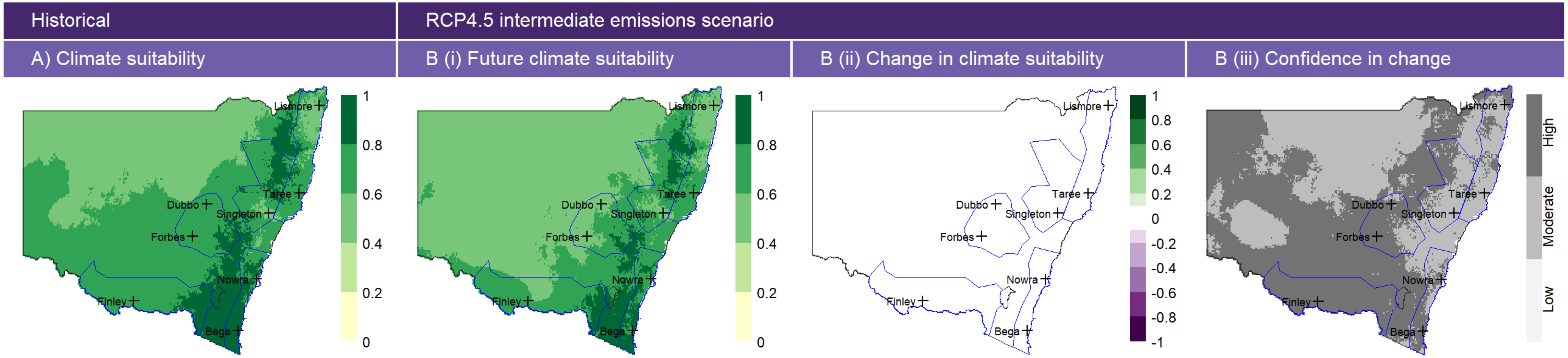
Figure 17: Climate suitability calendar for the lactation component of the model, showing the monthly climate suitability value for the historical climate suitability (top row in each box) and future emissions scenarios (RCP4.5 and RCP8.5), for each key site. The climate suitability categories represent the median value within a 10km radius of each site.

Findings: Climate suitability varies throughout the year at different sites. Historically, very high climate suitability is expected to be maintained from May to September. Most sites experience a decline in climate suitability from late spring through early autumn, where suitability is generally classified as high or moderate. Notably, Singleton maintains a historically low climate suitability in January.

The climate suitability at most sites during the summer is likely to be similar to historical climate suitability. However, it is important to continue to implement strategies to manage heat stress as a significant driver of reduced suitability during this period.

Around the sites of Dubbo, Singleton, Forbes, Nowra, Finley, and Bega, under the high emissions scenario, climate suitability is expected to decrease in November, December, and/or April. This potential decrease could present challenges for the dairy industry, indicating that heat stress impacts may occur earlier in spring and later in autumn in the future. This situation may necessitate changes in management strategies to manage the effects of heat stress on lactation.

Lactation: climate suitability for lactation overall in November



Findings: Under the intermediate emissions scenario, there is expected to be a negligible change in heat stress levels during lactation in November across all dairy regions. In contrast, under the high emissions scenario, central NSW may experience a minimal decrease in climate suitability, affecting parts of the Riverina Murray, Inland, and Hunter dairy regions in November. This indicates that heat stress impacts may worsen in the future during late spring.

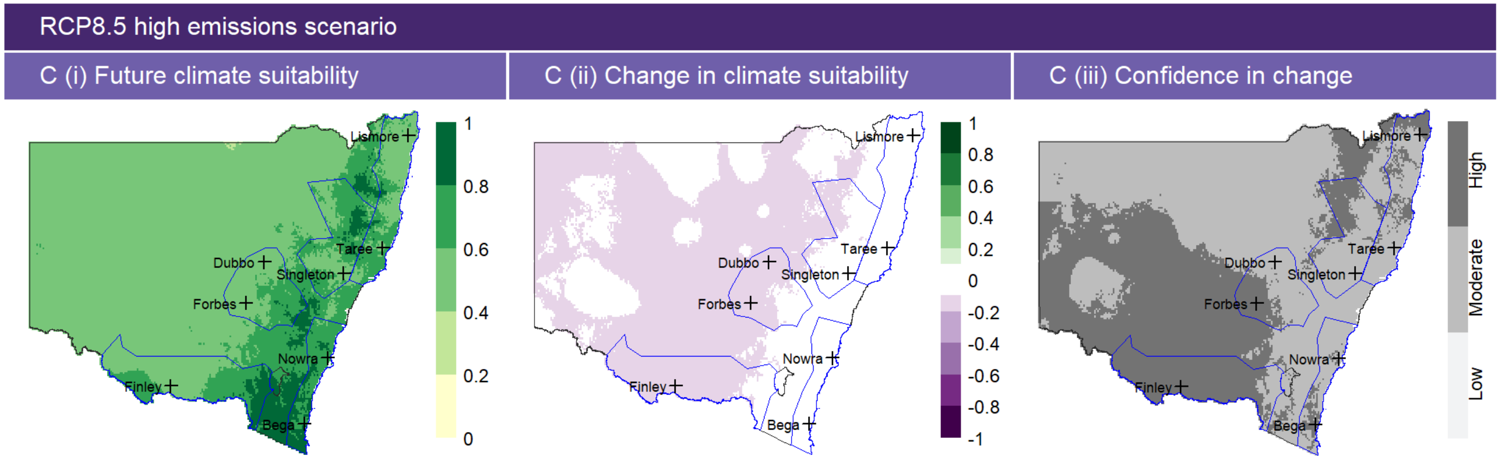
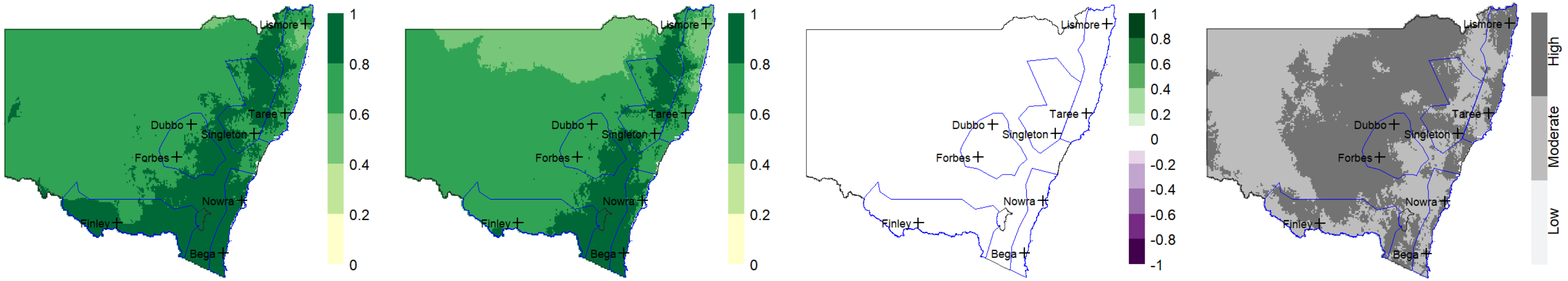


Figure 18: Climate suitability for the dairy cow lactation production stage in November across NSW. The panel is comprised of 7 maps: A) shows the historical climate suitability; B) and C) show future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability; (ii) shows the projected future change in climate suitability as negligible (white), positive (green) or negative (purple) change, and (iii) shows the level of model confidence associated with this change (low, moderate or high). Polygons and key sites are displayed on each map to indicate the areas where the dairy is currently produced.

Lactation: climate suitability for early lactation in April

Historical	RCP4.5 intermediate emissions scenario		
A) Climate suitability	B (i) Future climate suitability	B (ii) Change in climate suitability	B (iii) Confidence in change



Findings: Under the intermediate emissions scenario, there is likely to be a negligible change in climate suitability across all dairy regions. In contrast, under the high emissions scenario, central NSW from the coast to the western border may experience a minimal decrease in climate suitability. This change will affect parts of all regions, particularly the Inland, Hunter, and North Coast dairy regions. This indicates that heat stress impacts may worse in the future during autumn.

RCP8.5 high emissions scenario		
C (i) Future climate suitability	C (ii) Change in climate suitability	C (iii) Confidence in change

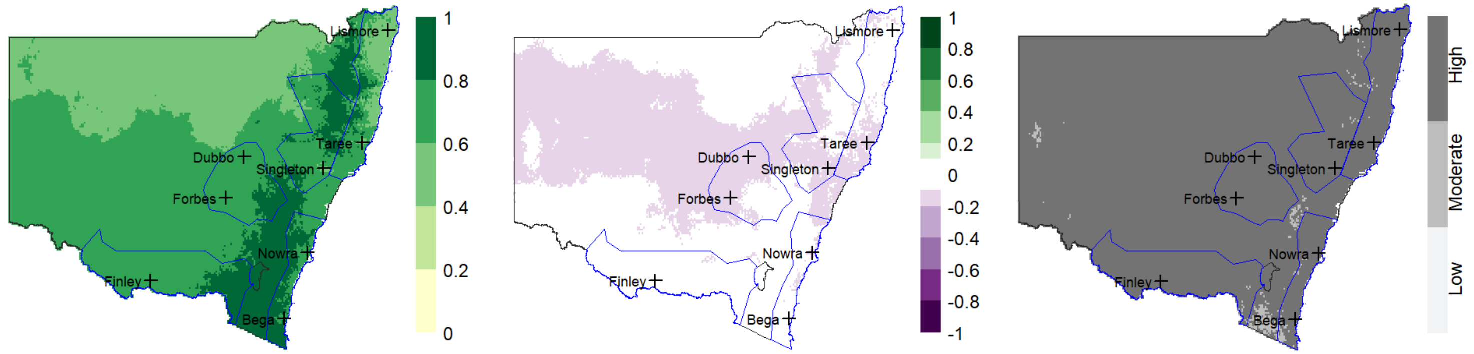


Figure 19: Climate suitability for the dairy cow early lactation production stage in April across NSW. The panel is comprised of 7 maps: A) shows the historical climate suitability; B) and C) show future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability; (ii) shows the projected future change in climate suitability as negligible (white), positive (green) or negative (purple) change, and (iii) shows the level of model confidence associated with this change (low, moderate or high). Polygons and key sites are displayed on each map to indicate the areas where the dairy is currently produced.

Dry period

The dry period is important for the recovery and long-term productivity of dairy cows. Heat stress during this stage can lead to reduced milk yield during the subsequent lactation, lower calf birth weights and calves which are less productive and fertile in the future[11]. Changes to monthly climate suitability during the dry period are likely to lead to a minimal decrease in climate suitability during some warmer months.

The number of highly suitable months for each year for the dry period is likely to decrease by 0.5 to 2 months across most of NSW (*moderate to high confidence*) (Figure A4). In some parts of the far northern Hunter and the western edge of the Inland regions, there may be a reduction of up to 3 months under a high-emissions scenario (*high confidence*). However, regions along the Great Dividing Range and the South Coast are projected to maintain the same number of highly suitable months under both emissions scenarios as in the past (*moderate to high confidence*).

The dry period climate suitability calendar (Figure 20) shows the expected change in monthly climate suitability throughout the year at the dairy sites. These changes in climate suitability are:

- **Decreased climate suitability** under the high emissions scenario in some of the months from November to March around Lismore, Dubbo, Forbes and Finley sites (*moderate to high confidence*). These minimal reductions in climate suitability during the dry period suggest that by 2050, heat stress is likely to increase, from late spring through summer into early autumn. It is important to note that, as shown in Figure 21, these sites have historically experienced reduced climate suitability during the summer months, and the projected changes indicate a further decline. Figure 21 C (ii) shows the minimal decrease in climate suitability during January, impacting all dairy regions except for the South Coast region, under the high emissions scenario (*moderate to high confidence*). In the Riverina Murray dairy region, under the intermediate emissions scenario, some areas may also experience minimal decreases (*moderate to high confidence*).
- **Historical very high climate suitability is likely to be maintained** throughout winter, early spring, and late autumn across most dairy sites under both emissions scenarios, with Bega maintaining very high suitability throughout the year (*moderate to high confidence*). It is important to note that historically, at all sites except for Bega, there are some months from November to March where climate suitability is categorised as high or moderate. While future projections do not indicate a further decrease in climate suitability around Taree, Singleton, and Nowra during these months, it is essential to continue to implement strategies to manage the heat stress during this period.

[11] Dahl, G. E., Tao, S., & Monteiro, A. P. A. (2016). Effects of late-gestation heat stress on immunity and performance of calves. *Journal of Dairy Science*, *99*(4), 3193-3198.

Dry period: climate suitability calendar

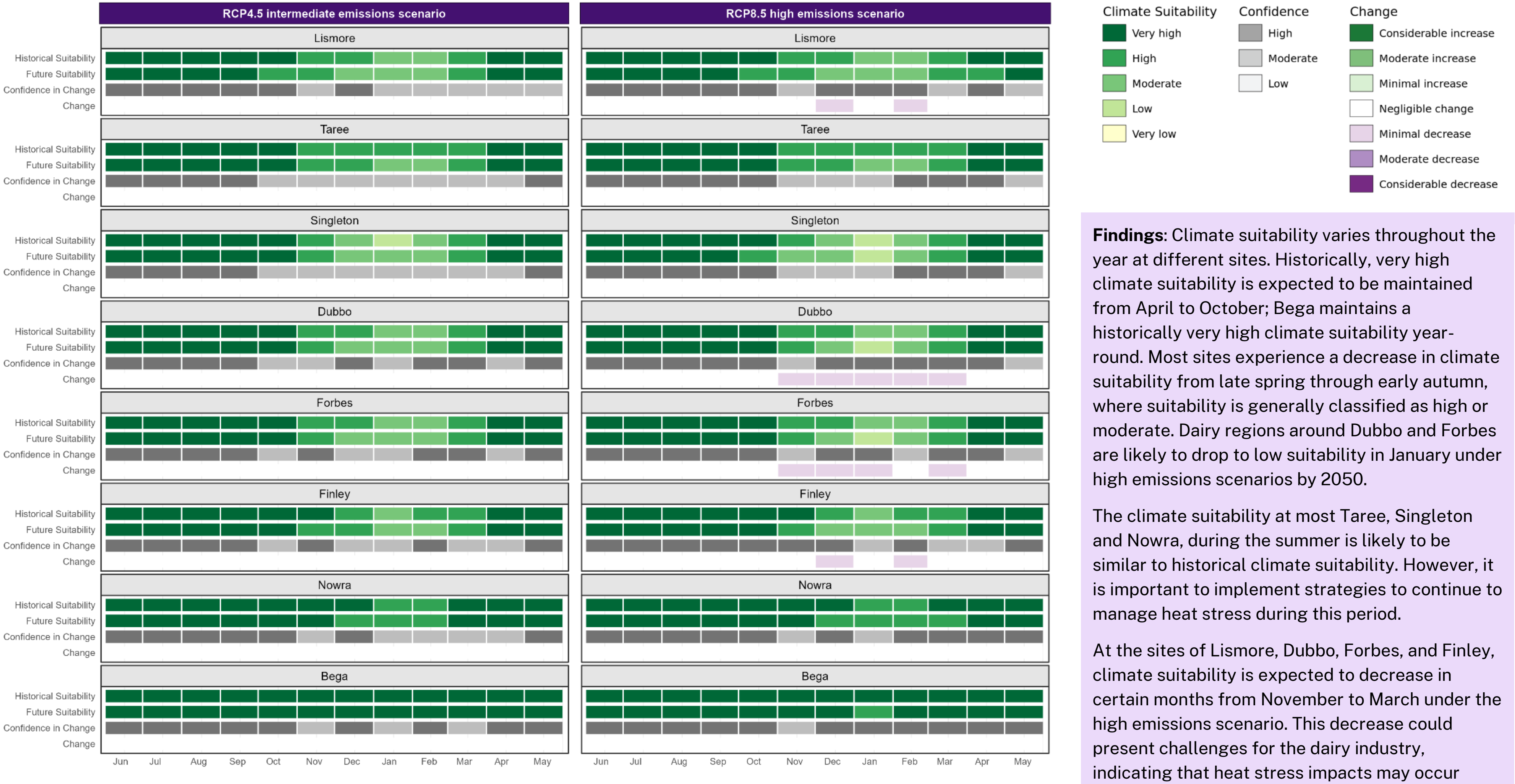


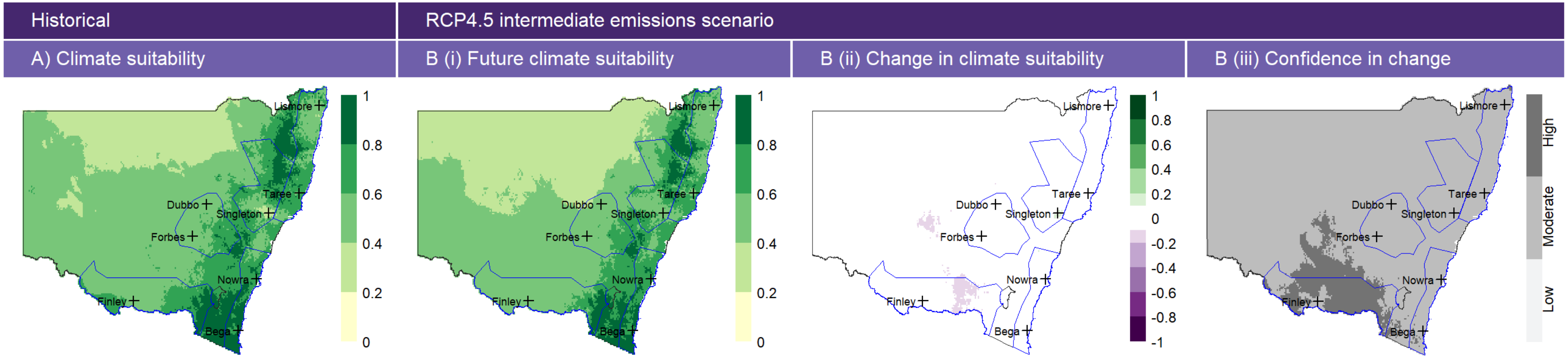
Figure 20: Climate suitability calendar for the dry period component of the model, showing the monthly climate suitability value for the historical climate suitability (top row in each box) and future emissions scenarios (RCP4.5 and RCP8.5), for each key site. The climate suitability categories represent the median value within a 10km radius of each site.

Findings: Climate suitability varies throughout the year at different sites. Historically, very high climate suitability is expected to be maintained from April to October; Bega maintains a historically very high climate suitability year-round. Most sites experience a decrease in climate suitability from late spring through early autumn, where suitability is generally classified as high or moderate. Dairy regions around Dubbo and Forbes are likely to drop to low suitability in January under high emissions scenarios by 2050.

The climate suitability at most Taree, Singleton and Nowra, during the summer is likely to be similar to historical climate suitability. However, it is important to implement strategies to continue to manage heat stress during this period.

At the sites of Lismore, Dubbo, Forbes, and Finley, climate suitability is expected to decrease in certain months from November to March under the high emissions scenario. This decrease could present challenges for the dairy industry, indicating that heat stress impacts may occur earlier in spring and later in autumn in the future. This situation may necessitate changes in management strategies to manage the effects of heat stress on dry cows.

Dry period: climate suitability in January



Findings: in the intermediate emissions scenario, negligible change is expected in most dairy regions, except the Riverina Murray, which may experience minimal decrease. In contrast, under the high emissions scenario, there are likely to be a minimal decrease in climate suitability, affecting all dairy regions except for the South Coast. This indicates that, in the future, heat stress is likely to impact more regions, more intensely in January during the dry period.

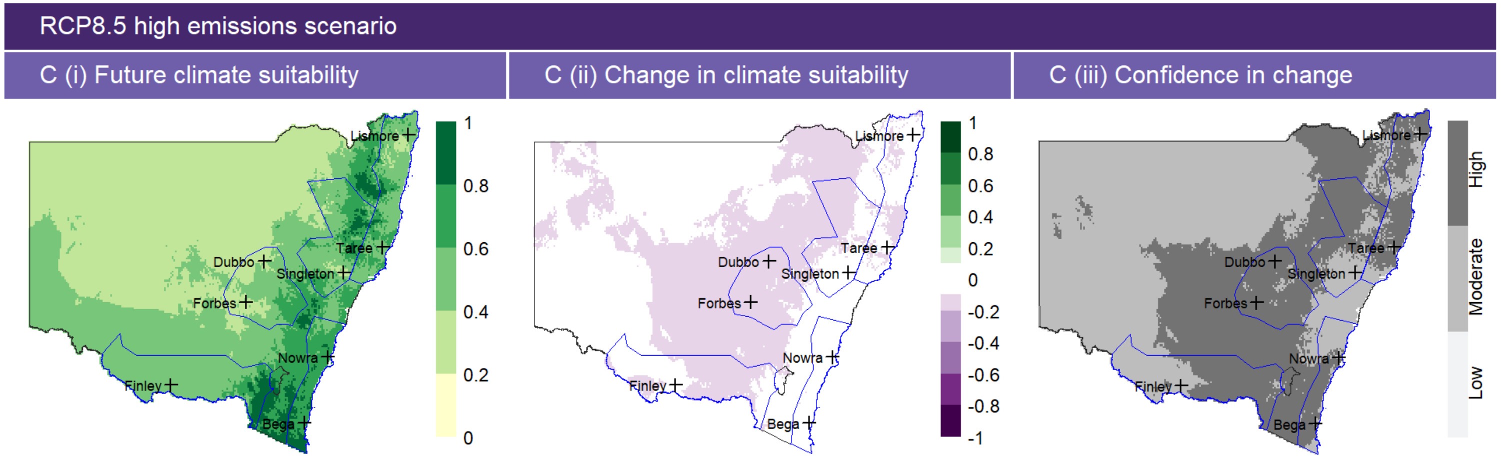


Figure 21: Climate suitability for the dairy cow dry period in January for NSW. The panel is comprised of 7 maps: A) shows the historical climate suitability; B) and C) show future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability; (ii) shows the projected future change in climate suitability as negligible (white), positive (green) or negative (purple) change, and (iii) shows the level of model confidence associated with this change (low, moderate or high). Polygons and key sites are displayed on each map to indicate the areas where the dairy is currently produced.

Key regional findings from a changing climate

The results of this study provide valuable insights into the historical and potential future climate suitability of dairy cows, with important implications for each dairy region. In the following sections, we will explore the changes impacting each dairy region within NSW. This analysis has been undertaken to reflect the differences in climate, production systems, and the timing of management practices in each region, allowing the findings from the climate impact assessment to be more tailored to each region.

It is important to note that all dairy regions experience negligible changes in climate suitability under the intermediate emissions scenario across nearly all production stages. However, under the high emissions scenario, all regions are likely to experience some minimal increases or decreases in suitability during certain production stages. These changes are primarily related to increased heat stress during the summer and decreased cold stress in the winter. The following section will describe the specific changes anticipated for each region.

Key insights and implications for the Inland dairy region

The Inland region has approximately 20 dairy farms, which are mostly larger herds exceeding the state average of 338 cows. This area experiences a more variable climate and sometimes faces harsher climate extremes. Farming practices in the region range from pasture-based systems to a more intensive system that utilises total mixed rations (TMR). Due to the climate conditions, many farms depend on irrigation and/or TMR systems to ensure that cows receive a balanced diet of forage and concentrate. As a result, the region relies more on irrigation and supplementary feeding to maintain productivity.

Figure 22: The key dairy production regions in NSW, with the Inland dairy region coloured in purple. Locations marked by black dots show towns nearby to dairy farms.

Appendix Figure A17 shows the Inland region climate suitability calendar for Dubbo, Cowra and Forbes, detailing monthly changes in climate for the overall model, calf growth, heifer growth, lactation, and dry periods.

Historical and future trends

The climate suitability for dairy cows in this region is expected to remain moderate to very high overall for all stages, except for heifer growth, which is projected to be high to very high under both emissions scenarios (*moderate to high confidence*). These findings indicate that climate conditions will continue to be suitable for dairy cows by 2050.

Future climate opportunities

The changing climate is not likely to provide any opportunities in respect to the animal, across all production stages, for the inland region.

Future climate vulnerabilities

During the lactation and the dry period stages, climate suitability for some or all months from November to March is expected to decrease minimally under the high emissions scenario (*moderate to high confidence*). The projected decreases in climate suitability are due to warmer temperatures combined with changes in humidity, which increase heat stress. Historically, summer and some months in late spring and early autumn at all sites have reduced climate suitability levels due to heat stress. Dairy businesses in the region should take action to address this challenge. Implementing strategies that address the historically reduced climate suitability and projected future decline is needed to avoid potential losses in milk production, reduced reproductive performance, and health issues in cows. The section 'Adapting to the Changing Climate' (page 37) outlines various options for managing heat stress that can be adopted in this region to reduce these impacts. This region is shifting from pasture-based dairy systems to TMR systems, with businesses recognising more variable and harsher climate conditions in their area and adapting to them. These projected changes may lead to a greater adoption of this approach due to increased heat stress.

Key insights and implications for the North Coast dairy region

The North Coast region is home to approximately 180 dairy farms. These farms typically have herds close to the state average of 338 cows or fewer. The region's subtropical climate supports year-round pasture growth, characterised by high rainfall, mild temperatures, and fertile soils. Dairy operations primarily rely on pasture-based systems supplemented with concentrate, silage and hay.

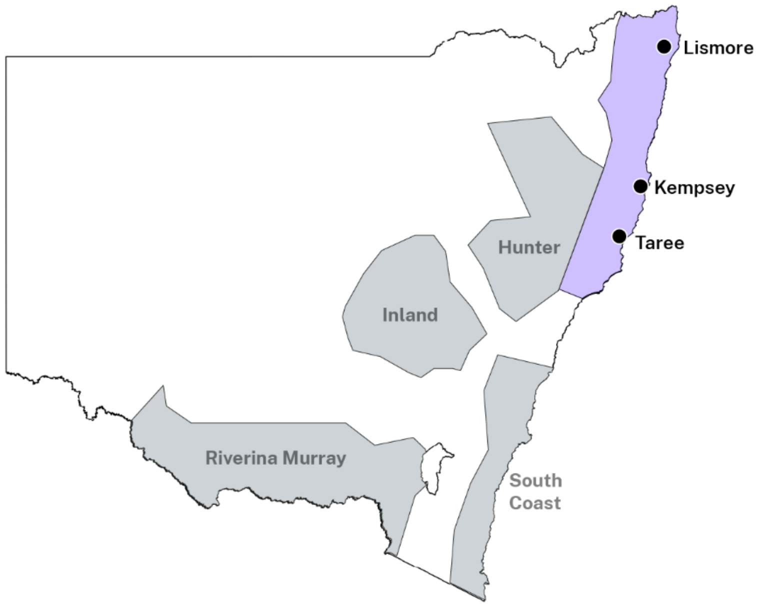


Figure 23: The key dairy production regions in NSW, with the North Coast dairy region coloured in purple. Locations marked by black dots show towns near dairy farms.

Appendix Figure A18 shows the North Coast climate suitability calendar for Lismore, Kempsey, and Taree, detailing monthly changes in climate for overall model, calf growth, heifer growth, lactation, and dry periods.

Historical and future trends

Climate suitability for dairy cows in this region is expected to remain moderate to very high for the overall model, including the lactation and dry periods, under both emissions scenarios (*moderate to high confidence*). Climate suitability is projected to be high to very high for the calf growth and heifer stages (*moderate to high confidence*). These findings suggest that climate conditions will remain suitable for dairy cows by 2050.

Future climate opportunities

During the calf growth stage, climate suitability in September at Kempsey and Taree is likely to minimally increase as cold stress is expected to be reduced under the high emissions scenario (*high confidence*). Decreased cold stress could benefit calf health, welfare, and growth. While future risks of colder days appear reduced, it is crucial to maintain strategies like housing calves, which provide extra protection from extreme events not considered in this analysis.

Future climate vulnerabilities

During the lactation and the dry period stage, climate suitability for some months from September to February is expected to decrease minimally under the high emissions scenario at Kempsey and Lismore (*moderate to high confidence*). The projected decreases in climate suitability are due to warmer temperatures combined with changes in humidity, which increase heat stress. Historically, summer and some months in late spring and early autumn at all sites have reduced climate suitability levels due to heat stress. Dairy businesses in the region should take action to address this challenge. Implementing strategies that address the historically reduced climate suitability and projected future decline is needed to avoid potential losses in milk production, reduced reproductive performance, and health issues in cows.

Key insights and implications for the South Coast dairy region

The South Coast region has approximately 130 dairy farms. Many of these businesses maintain herd sizes close to or below the state average of 338 cows. The temperate climate of the South Coast is ideal for dairy farming. This region predominantly uses pasture-based systems, with some supplementary feeding of silage and hay during drier periods. Irrigation is also used in low rainfall areas such as the far south coast.

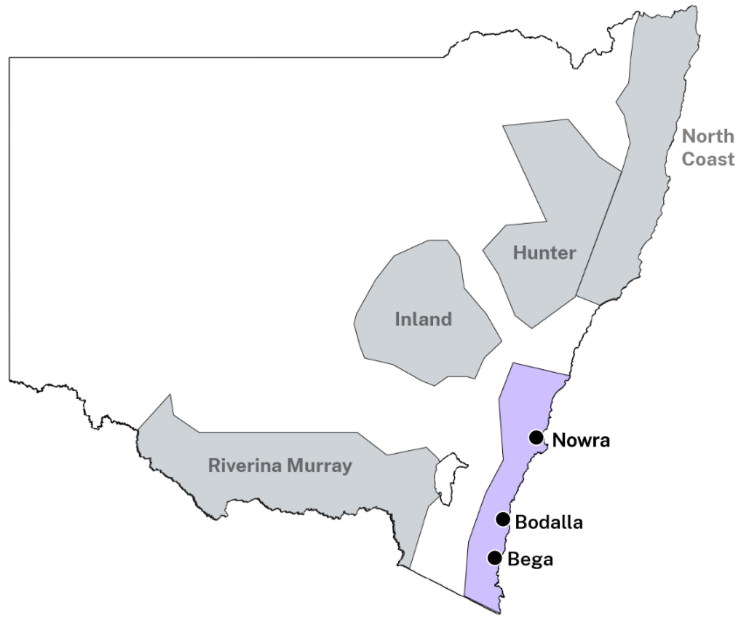


Figure 24: The key dairy production regions in NSW, with the South Coast coloured in purple. Locations marked by black dots show towns near dairy farms.

Appendix Figure A19 shows the South Coast climate suitability calendar for Bega, Nowra, and Bodalla, detailing monthly changes in climate for the overall model, calf growth, heifer growth, lactation, and dry periods.

Historical and future trends

The climate suitability is expected to remain very high for the overall dairy cows, heifer and dry period stages under both emissions scenarios throughout the year across this region (*moderate to high confidence*). These findings suggest that climate conditions will continue to be suitable for dairy cows in this region by 2050.

Future climate opportunities

During the calf growth stage, climate suitability in some months within autumn, winter, and spring is likely to minimally increase as warmer temperatures are expected to reduce cold stress under the high emissions scenario (*moderate to high confidence*). Decreased cold stress could benefit calf health, welfare, and growth by 2050. While future risks of colder days appear reduced, it's crucial to maintain strategies like housing calves, which provide extra protection from extreme weather events not considered in this analysis.

Future climate vulnerabilities

During the lactation stage, climate suitability in December is likely to decrease as warmer temperatures combined with changes in humidity are expected to increase heat stress during this month under the high emissions scenario at Bega and Nowra (*moderate to high confidence*). Increases in heat stress during December suggest that dairy businesses in this region should take action to address this challenge. Historically, summer has seen reduced levels of climate suitability for all sites, due to heat stress. Implementing strategies that address the historically reduced climate suitability and projected future decline is needed to avoid potential losses in milk production, reduced reproductive performance, and health issues in cows. The section 'Adapting to the Changing Climate' outlines (page 37) various options for managing heat stress that can be adopted in this region to reduce these impacts.

Key insights and implications for the Riverina Murray dairy region

The Riverina Murray dairy region has approximately 61 dairy farms, which are mostly larger herds exceeding the state average of 338 cows. This area experiences a more variable climate and sometimes faces harsher climate extremes. Farming practices in the region range from pasture-based systems to a more intensive total mixed rations (TMR) system. Due to the climate conditions, many farms depend on irrigation and/or TMR systems to ensure that cows receive a balanced diet of forage and concentrate. As a result, the region relies more on irrigation and supplementary feeding to maintain productivity.

Figure 25: The key dairy production regions in NSW, with the Riverina Murray dairy region coloured in purple. Locations marked by black dots show towns near dairy farms.

Appendix Figure A20 **shows the Riverina Murray region climate suitability calendar for Deniliquin, Finley and Wagga Wagga, detailing monthly changes in climate for the overall model, calf growth, heifer growth, lactation, and dry periods.**

Historical and future trends

The climate suitability for dairy cows in this region is expected to remain moderate to very high for all production stages under both emissions scenarios (*moderate to high confidence*). These findings indicate that climate conditions will continue to be suitable for dairy cows by 2050.

Future climate opportunities

During calf growth from spring through to autumn, climate suitability is likely to minimally increase due to fewer cold days under the high emissions scenario (*high confidence*). Decreased cold stress could benefit calf health, welfare, and growth. While future risks of colder days appear reduced, it's crucial to maintain strategies like housing calves, which provide extra protection from extreme weather events.

Future climate vulnerabilities

During lactation, the dry period, and heifer growth stages, climate suitability for some months from November to March is expected to minimally decrease under the high emissions scenario (*moderate to high confidence*). The projected decreases in climate suitability are due to warmer temperatures combined with changes in humidity. Historically, summer, late spring and early autumn have reduced climate suitability levels due to heat stress. Dairy businesses in the region should continue to take action to address this challenge as it is likely to persist. Implementing strategies that address projected future heat stress is needed to avoid potential losses in milk production, reduced reproductive performance, and health issues in cows. This region is beginning to see a shift from pasture-based dairy systems to more housed TMR systems, as well as increased use of shade structures and other adaptation measures to manage heat stress. These projected changes may lead to a greater adoption of this approach due to increased heat stress.

Key insights and implications for the Hunter dairy region

In the Hunter dairy region, there are approximately 40 dairy farms. This region has a temperate climate, reliable water sources, and fertile soils supporting productive pastures and fodder crops. The Hunter dairy region primarily utilises pasture-based systems, although some irrigation is used to maintain pasture quality. Supplementary feeding with concentrates, hay, and silage is common to ensure consistent milk production and manage drier conditions.

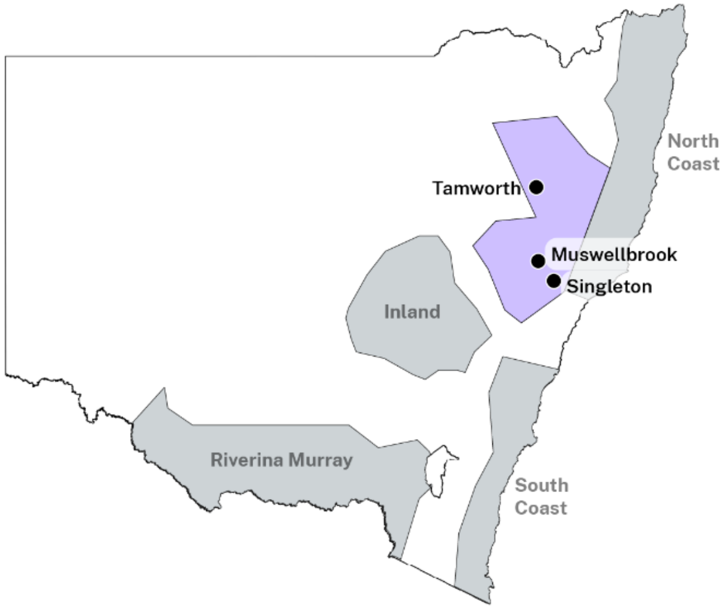


Figure 26: The key dairy production regions in NSW, with the Hunter dairy region coloured in purple. Locations marked by black dots show towns near dairy farms.

Appendix Figure A21 shows the Hunter region climate suitability calendar for Muswellbrook, Singleton and Tamworth, detailing monthly changes in climate for the overall model, calf growth, heifer growth, lactation, and dry periods.

Historical and future trends

The climate suitability for dairy cows in this region is expected to remain moderate to very high overall for all stages, except for lactation and dry period, which is projected to be low in the summer months and very high in the winter months under both emissions scenarios (*moderate to high confidence*). These findings indicate that climate conditions will continue to be suitable for dairy cows by 2050.

Future climate opportunities

During the calf growth stage, climate suitability for some months from September to January will minimally to moderately increase as warmer temperatures at Muswellbrook and Singleton are expected to reduce cold stress under both emissions scenarios (*high confidence*). Decreased cold stress could benefit calf health, welfare, and growth by 2050. While future risks of colder days appear reduced, it's crucial to maintain strategies like housing calves, which provide extra protection from extreme events not considered in this analysis.

Future climate vulnerabilities

During the heifer growth, lactation and dry period stages, climate suitability for one or most months from October to April is expected to decrease minimally under the high emissions scenario at Singleton and Tamworth (*moderate to high confidence*). The projected decreases in climate suitability are due to warmer temperatures combined with changes in humidity, which increase heat stress. Historically, summer and some months in late spring and early autumn at all sites have reduced climate suitability levels due to heat stress. Dairy businesses in the region should take action to address this challenge. Implementing strategies that address the historically reduced climate suitability and projected future decline is needed to avoid potential losses in milk production, reduced reproductive performance, and health issues in cows.

Adapting to the changing climate

Assessing future climate impacts helps inform planning and the development of adaptation strategies for primary industries. Understanding these changes is important for supporting livestock production under changing climate conditions. As outlined in this report, many projected shifts in climate suitability for dairy cows relate to increasing heat stress, particularly during late spring, summer and early autumn. The section below summarises a range of heat-stress management strategies.

Dairy cow producers could investigate strategies such as:

- providing shade, using sprinklers or fans in the dairy or yards,
- ensuring drinking water is available in all paddocks/areas,
- adjusting supplementary feed rations to include easier-to-digest (low NDF) feed and providing it at cooler times of the day, and
- adjusting milking times plus reducing cow movements during hotter periods.

Strategic decision-making changes could also include:

- adjusting timing of key events (calving, joining etc) to different times of the year to avoid warmer periods,
- using ABV's to select for heat-tolerant cows,
- planting trees for shade/shelter in future years, and
- investing in on-farm infrastructure such as shade shelters and free stall barns.

For more information on heat stress management strategies, see Dairy Australia's Cool Cows resources.

Tools for informed heat management

Forecasts for managing heat stress: Understanding the forecast heat stress (THI, temperature humidity index) for your region is now easier than ever with a new, freely available tool. This resource allows you to see forecast heat stress and make informed management decisions, helping you mitigate heat stress's effects on your cows.

You can access the thermal stress forecasts at https://nacp.org.au/cattle_thermal_stress_forecasts

Heatwave forecasts: The Bureau of Meteorology's weather forecasts predict heatwaves up to 7 days in advance. Warnings for severe or extreme heatwaves are issued 4 days ahead of time. These warnings include detailed information on expected temperatures, and which areas will be affected.

You can access the heatwave warnings through the BOM weather app or at http://www.bom.gov.au/australia/heatwave/knowledge-centre/heatwave-service.shtml

Buffalo fly snapshot: what are the projected changes for NSW?

Parasites significantly impact livestock health and productivity. Both internal parasites, such as worms, and external parasites, such as ticks and flies, pose serious threats. They can reduce the productivity and health of grazing animals, leading to lower weight gains. Some parasites can also cause skin irritations and transmit disease, further impacting livestock health.

The external life stages of parasites are influenced by climate conditions that can change their development and survival rates. Climate vulnerability assessments have also been completed for several livestock parasites, and these should be considered alongside the dairy cow climate vulnerability assessment.

Buffalo fly | *Haematobia irritans exigua*

Changes in buffalo fly climate suitability are likely to create challenges for the dairy industry. By 2050, climate change will increase the climate suitability for all life stages of the buffalo fly in north-eastern NSW during spring and autumn, especially under the high emissions scenario. Summer is likely to continue to be highly suitable for the flies in this region.

Impact on dairy cows

The increased climate suitability for buffalo fly in spring and autumn is likely to support the flies spreading further south and west into inland NSW. This could lead to significant impacts on the dairy industry in these previously unaffected areas. *Bos taurus* breeds found in southern NSW are more susceptible to buffalo fly.

Management practices used in the current endemic region for buffalo fly in far north-eastern NSW are also likely to be effective in southern and inland regions. Industry and government can play a role in supporting these regions by providing education on the expected southward and inland expansion of buffalo fly and by assisting with the adoption of management strategies in newly impacted areas.

For more information

Further modelling of livestock parasites including cattle tick, and biting midge (*Culicoides brevitarsis)* are available online.

The full reports for buffalo fly and other biosecurity risks can be found in the Climate Vulnerability Assessment Summary Report or online website.

Dairy cow: where to from here?

Future priorities

The results presented in this report have identified changes in climate suitability for dairy cows that are likely to impact the dairy industry in NSW and are expected to require changes to maintain productivity. More research is needed to best advise the industry on managing dairy cows looking forward to 2050.

The next stage of work is to conduct a detailed assessment of adaptation options for the dairy industry. This will provide insights into the value of different adaptations for reducing the impacts of climate change. Effective management approaches must be carefully planned, evaluated and deployed to minimise disruptions and costs. The following merit initial consideration:

- Evaluate the effectiveness of different management practices and infrastructure improvements in reducing heat stress to determine their potential to reduce projected heat stress.
- Test the impacts of changing production system timings to avoid periods of heightened heat stress, while also considering constraints imposed by the dairy region and market forces, to assess whether these changes can effectively reduce the impact of heat stress or if additional approaches are necessary.
- Assess the benefits of using breeding values for heat tolerance to gradually improve a herd's ability to tolerate heat and assess breeds that may have a greater natural tolerance to heat stress.

Addressing the gaps, barriers and challenges

The information generated by this project has helped to identify future climate vulnerabilities of dairy cows. However, knowledge gaps were identified during the development of the MCA model.

A lack of knowledge about a particular organism and its optimal climate conditions leads to a risk of important climate factors being left out of the model. Additional research may lead to results which improve the dairy cow model used here. The following areas are deemed key knowledge gaps in need of further research:

- While THI limits are well understood, several different published methods of calculating THI exist, each producing slightly different results. This lack of standardisation is an inherent challenge for livestock industries in preparing for future management of THI risk. It should be a priority for future research in this space.
- Rainfall variables were considered for inclusion in the model. However, gaps and inconsistencies in the literature regarding appropriate rainfall metrics and their relationship to production outcomes prevented confidence in incorporation. This should be a priority for future research.
- Impacts of heat stress on calves.

This report highlights these gaps to assist in directing future research and project development. Consideration should also be given to modelling other significant or emerging dairy cow breeds as well as to expanding the current modelling to a national level.

Prioritisation of education about heat stress

To enhance the productivity and profitability of dairy businesses, it is important to prioritise education about the impacts of heat stress on dairy cows. Many producers may not fully understand the true impact of temperatures exceeding a critical temperature-humidity index (THI) threshold. Above this threshold, dairy cows begin to experience a decline in milk production if adequate cooling is not in place. This decline is not always immediately obvious, as production is also influenced by other factors, including feed intake, feed quality, animal health, environmental conditions and reproductive care.

Moreover, it is important to recognise that heat stress has impacts that extend beyond lactating cows to young replacement heifers and dry cows, which can have significant implications for future lactations and overall dairy production. During warmer periods, these animals often reduce their feed intake and divert energy to heat dissipation and away from growth and development.

To address these issues effectively, the dairy industry must continue to educate stakeholders on the importance of recognising and reducing the effects of heat stress, both now and into the future. Fortunately, many practical strategies are available for farmers to adopt and implement to reduce the impacts of heat stress on their cows.

Furthermore, it is important to note that current management strategies are likely to remain effective in 2050 across most of NSW and most stages of production, as future climate suitability is expected to be similar to historical climate suitability. However, this analysis does not consider the potential effects of extreme weather events, such as intense rainfall, heatwaves, storms, droughts, floods and bushfires, which may also require adaptive management.

Continued emphasis on education about the impacts of climate change in the dairy industry will assist in the adoption of adaptive practices, help to build resilience and help to ensure the long-term sustainability of the dairy industry in NSW.

Conclusion

This work provides important baseline information to support state, regional and strategic industry-level planning for climate change, highlighting where adaptation and investment should be prioritised to sustain and enhance livestock industries and limit climate change's impacts on dairy cows.

The results presented in this report provide a comprehensive assessment of how climate suitability is likely to shift under climate change for this key commodity in NSW. This research also sets out the challenges ahead, which will require investment in adaptation strategies and education to underpin the livestock industry's future growth and sustainability.

DPIRD will use these findings in partnership with industry to prioritise future efforts, strategic partnerships, and networks across the state to support effective policies and programs that keep primary industries resilient and productive in a changing climate.

For more information

For detailed information on the methodology and data used in this project please see the Climate Vulnerability Assessment Methodology Report.

Results from other commodities and biosecurity risk assessments can be found in the Climate Vulnerability Assessment Summary Report or online.

Other Climate Vulnerability Assessments that may be of particular interest are:

- Dairy pastures
- Biosecurity risks
- Broadacre cropping

An accompanying report on NSW Drought in a Changing Climate provides a comprehensive understanding of how drought frequency and duration will change as a result of climate change and it is recommended to read this report alongside the results presented for Dairy cows.

Contact us

For further information, please get in touch
with vulnerability.assessment@dpird.nsw.gov.au

Acknowledgements

We thank the experts who participated in the focus groups. These experts ensured that the model contents reflected published knowledge and lived experiences and determined the relative influence or importance of different climate variables in the model.

Thanks to all the NSW Department of Primary Industries staff who participated in the NSW DPI Dairy Team: Blake Cheer, Amanda Britton, Ken Garner and Zita Ritchie.

We would like to acknowledge the DPIRD Climate Vulnerability Assessment team that has driven the development of the assessment method; Jane Kelley, Bethany Ellis, David Allingham, Rachael Young, Paris Capell, James Lawson, Chris Nunn, Joanne Pardoe and past members of the CVA team.

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NSW GOVERNMENT

Appendix

Figure A1. Number of highly suitable months for calf growth

Number of highly suitable months per year for calf growth. This measures the months in which climate suitability is greater than or equal to 0.6. The panel is comprised of 7 maps: A) shows the historical number of highly suitable months; B) and C) show the future number of highly suitable months for the intermediate and high emissions scenarios, respectively; (i) shows future number of highly suitable months, (ii) shows the expected change in number of months as negligible (white), increasing (orange) or decreasing (purple) change, and (iii) shows the level of confidence in this change (low, moderate or high). Polygons and key sites are displayed on each map to indicate the areas where dairy production is predominantly carried out in NSW.

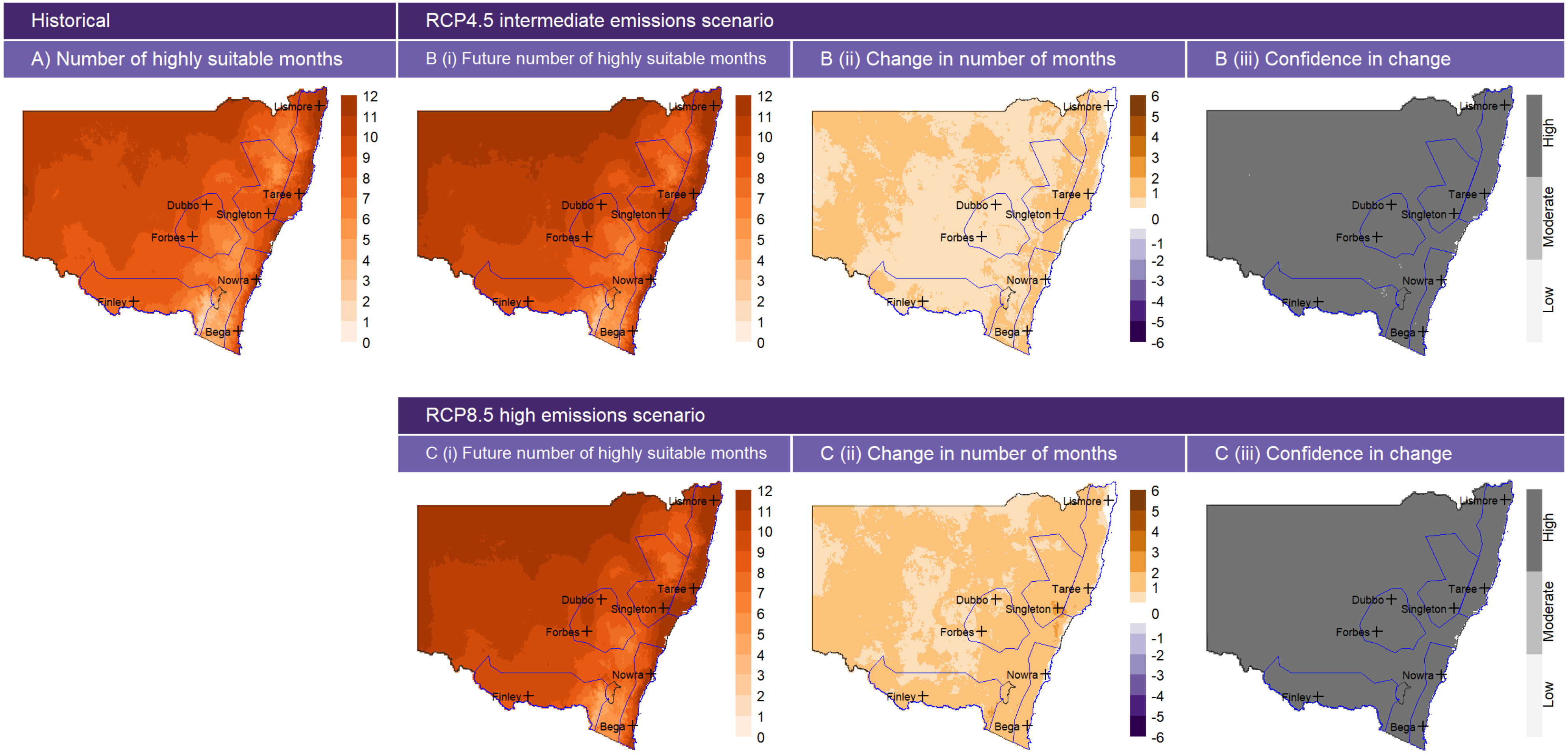


Figure A2. Number of highly suitable months for heifer growth

Number of highly suitable months per year for heifer growth. This measures the months in which climate suitability is greater than or equal to 0.6. The panel is comprised of 7 maps: A) shows the historical number of highly suitable months; B) and C) show the future number of highly suitable months for the intermediate and high emissions scenarios, respectively; (i) shows future number of highly suitable months, (ii) shows the expected change in number of months as negligible (white), increasing (orange) or decreasing (purple) change, and (iii) shows the level of confidence in this change (low, moderate or high). Polygons and key sites are displayed on each map to indicate the areas where dairy production is predominantly carried out in NSW.

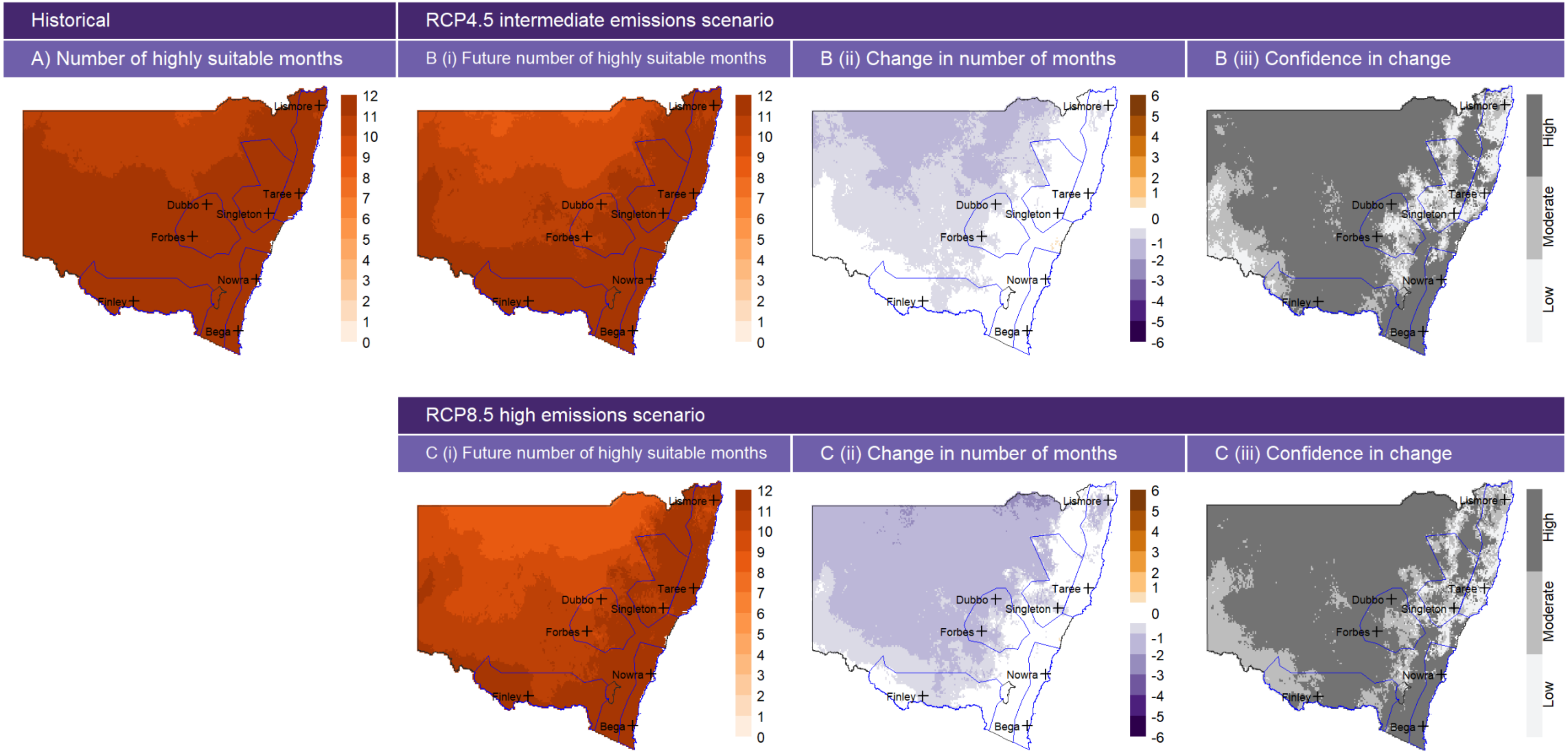


Figure A3. Number of highly suitable months for lactation

Number of highly suitable months per year for lactation. This measures the months in which climate suitability is greater than or equal to 0.6. The panel is comprised of 7 maps: A) shows the historical number of highly suitable months; B) and C) show the future number of highly suitable months for the intermediate and high emissions scenarios, respectively; (i) shows future number of highly suitable months, (ii) shows the expected change in number of months as negligible (white), increasing (orange) or decreasing (purple) change, and (iii) shows the level of confidence in this change (low, moderate or high). Polygons and key sites are displayed on each map to indicate the areas where dairy production is predominantly carried out in NSW.

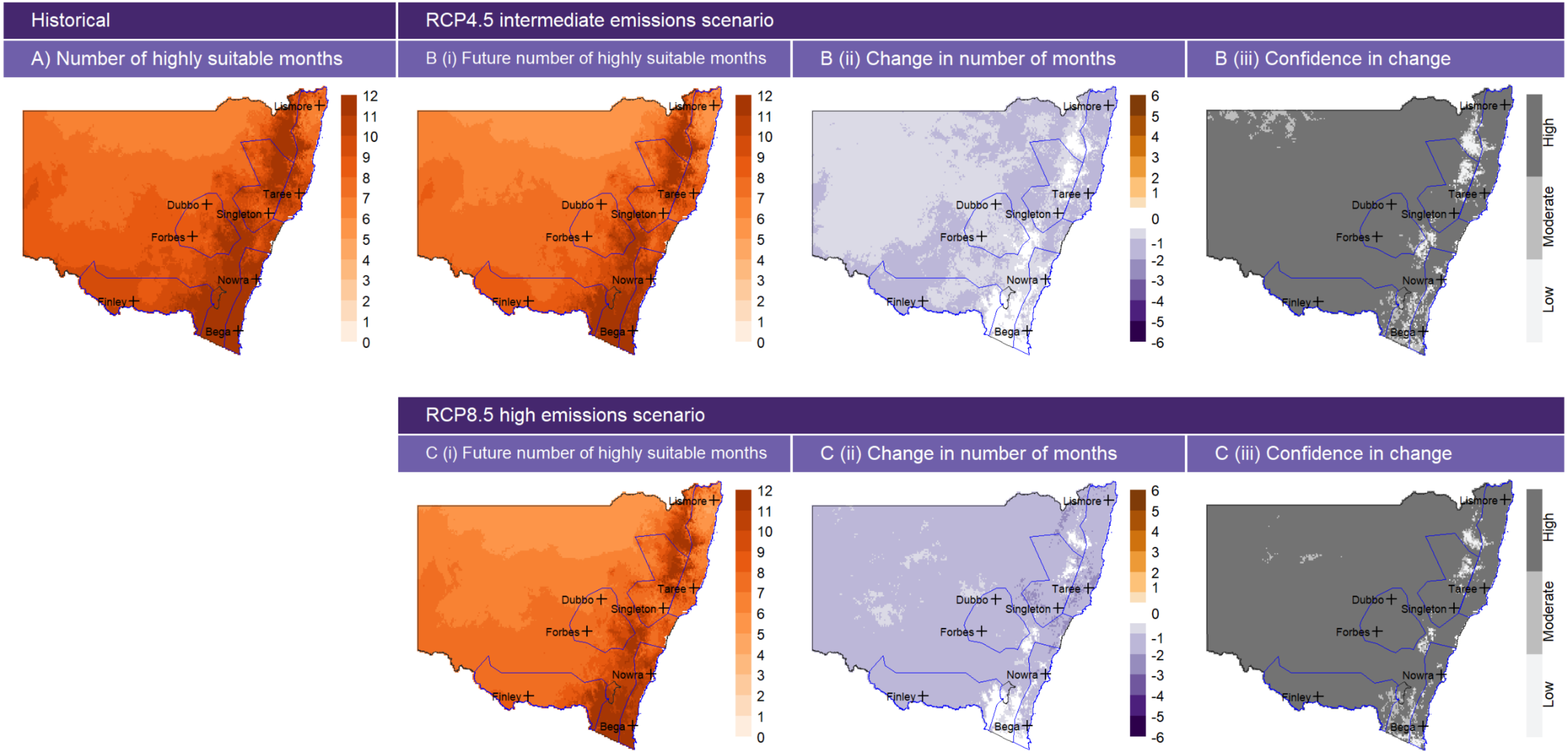


Figure A4. Number of highly suitable months for dry period

Number of highly suitable months per year for dry period. This measures the months in which climate suitability is greater than or equal to 0.6. The panel is comprised of 7 maps: A) shows the historical number of highly suitable months; B) and C) show the future number of highly suitable months for the intermediate and high emissions scenarios, respectively; (i) shows future number of highly suitable months, (ii) shows the expected change in number of months as negligible (white), increasing (orange) or decreasing (purple) change, and (iii) shows the level of confidence in this change (low, moderate or high). Polygons and key sites are displayed on each map to indicate the areas where dairy production is predominantly carried out in NSW.

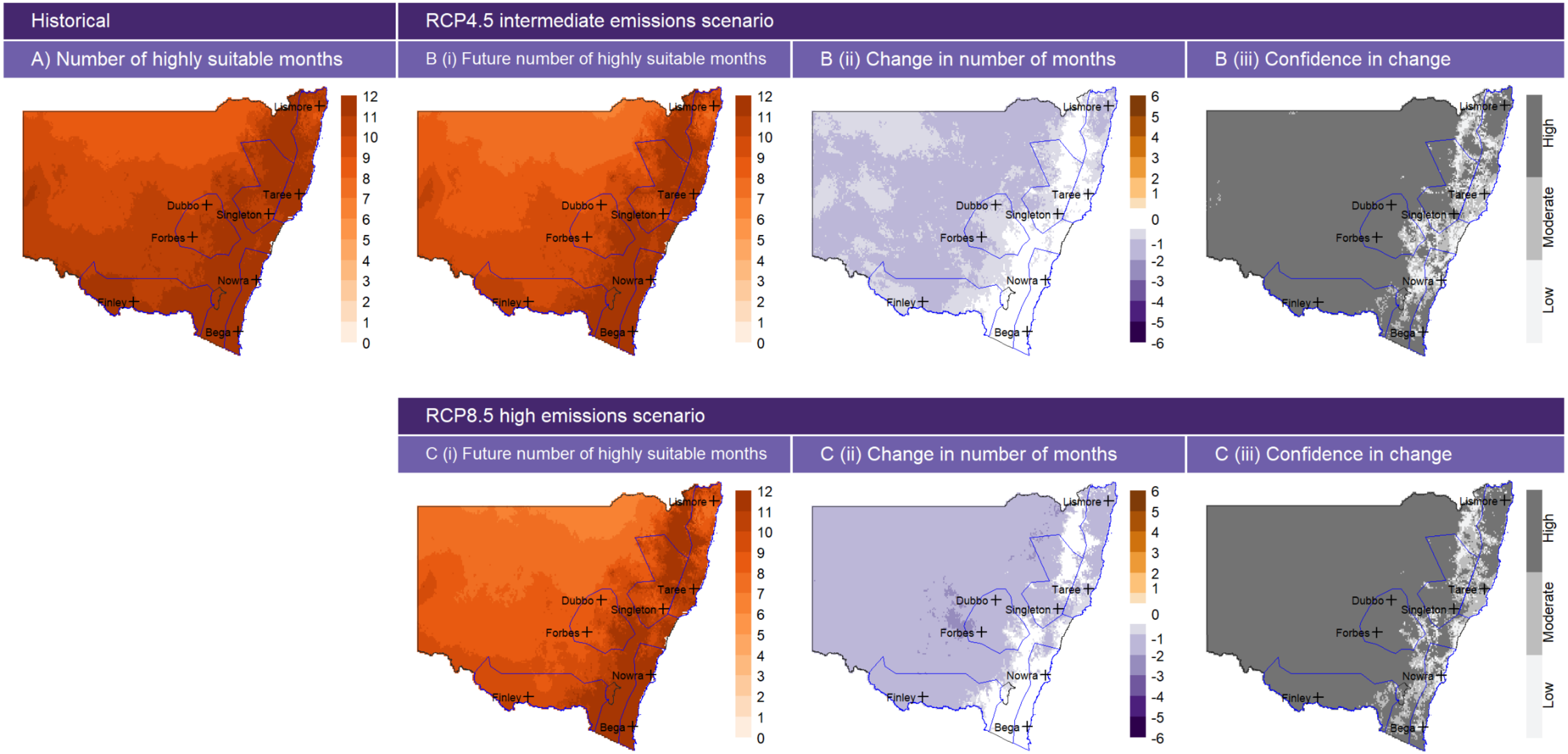


Figure A5. January climate suitability for dairy cows

The panel is comprised of 7 maps: A) shows the historical climate suitability; B) and C) show future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability, (ii) shows the projected future change in climate suitability as negligible (white), positive (green) or negative (purple) change, and (iii) shows the level of model confidence associated with this change (low, moderate or high). Areas where dairy is currently produced are marked by black crosses and blue polygons.

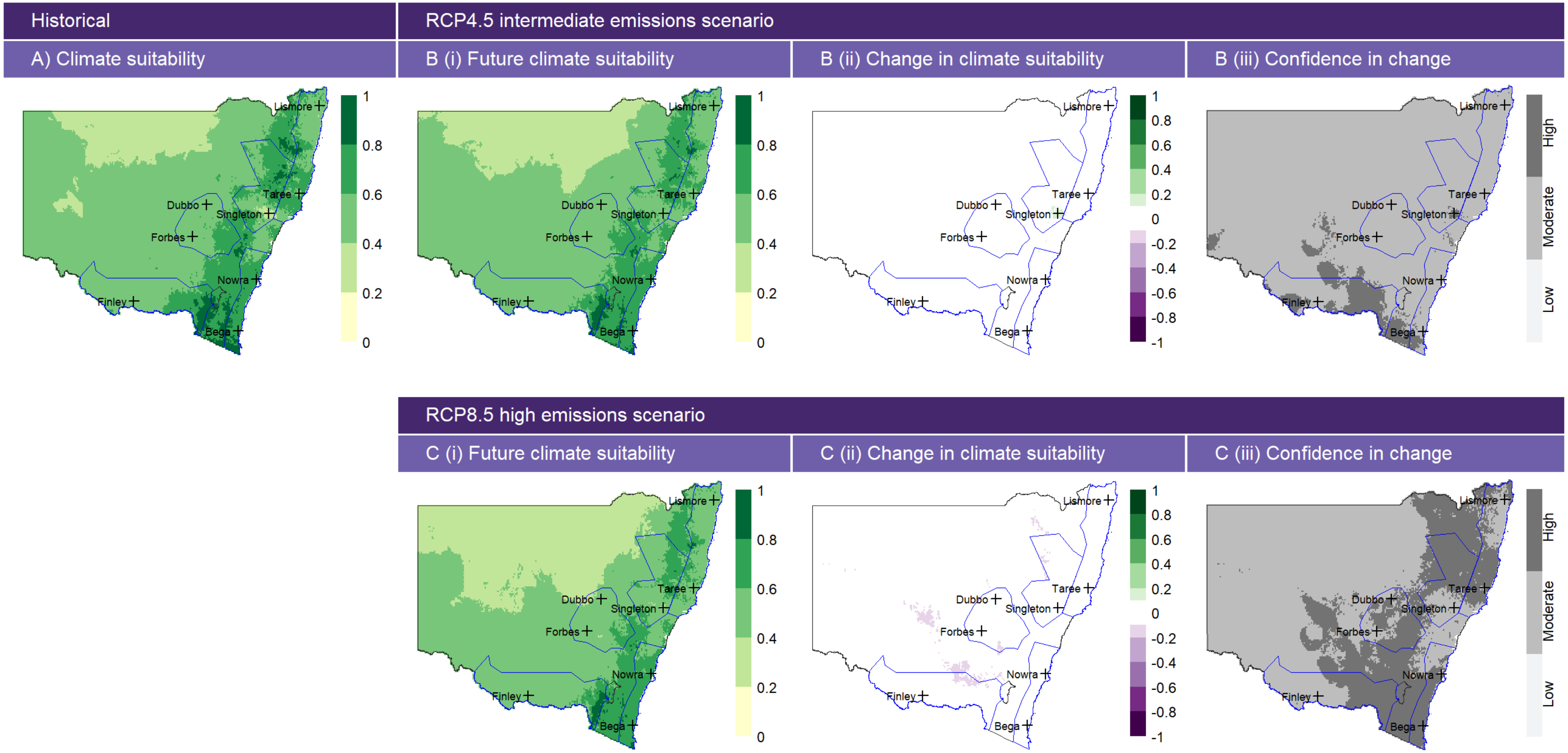


Figure A6. February climate suitability for dairy cows

The panel is comprised of 7 maps: A) shows the historical climate suitability; B) and C) show future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability, (ii) shows the projected future change in climate suitability as negligible (white), positive (green) or negative (purple) change, and (iii) shows the level of model confidence associated with this change (low, moderate or high). Areas where dairy is currently produced are marked by black crosses and blue polygons.

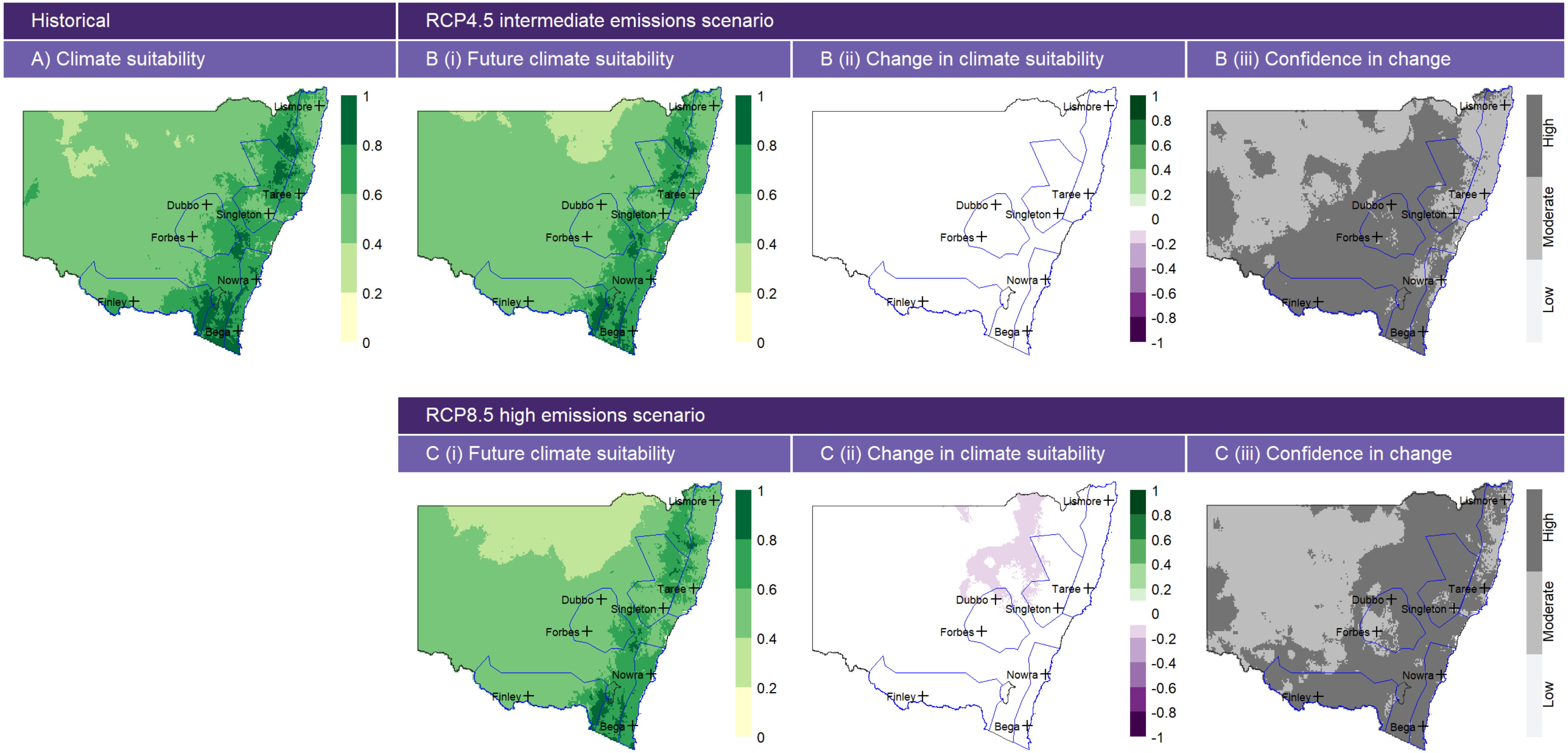


Figure A7. March climate suitability for dairy cows

The panel is comprised of 7 maps: A) shows the historical climate suitability; B) and C) show future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability, (ii) shows the projected future change in climate suitability as negligible (white), positive (green) or negative (purple) change, and (iii) shows the level of model confidence associated with this change (low, moderate or high). Areas where dairy is currently produced are marked by black crosses and blue polygons.

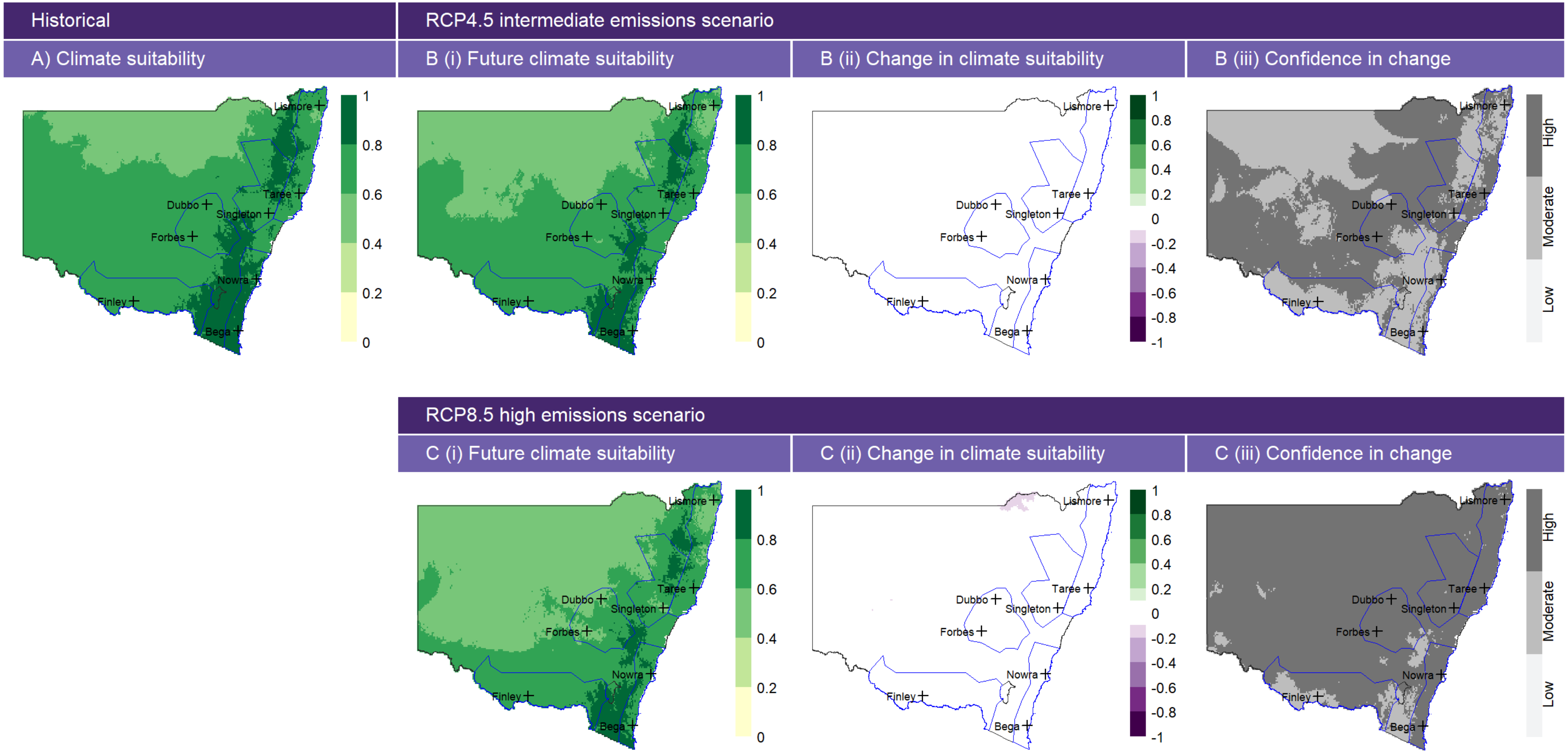


Figure A8. April climate suitability for dairy cows

The panel is comprised of 7 maps: A) shows the historical climate suitability; B) and C) show future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability, (ii) shows the projected future change in climate suitability as negligible (white), positive (green) or negative (purple) change, and (iii) shows the level of model confidence associated with this change (low, moderate or high). Areas where dairy is currently produced are marked by black crosses and blue polygons.

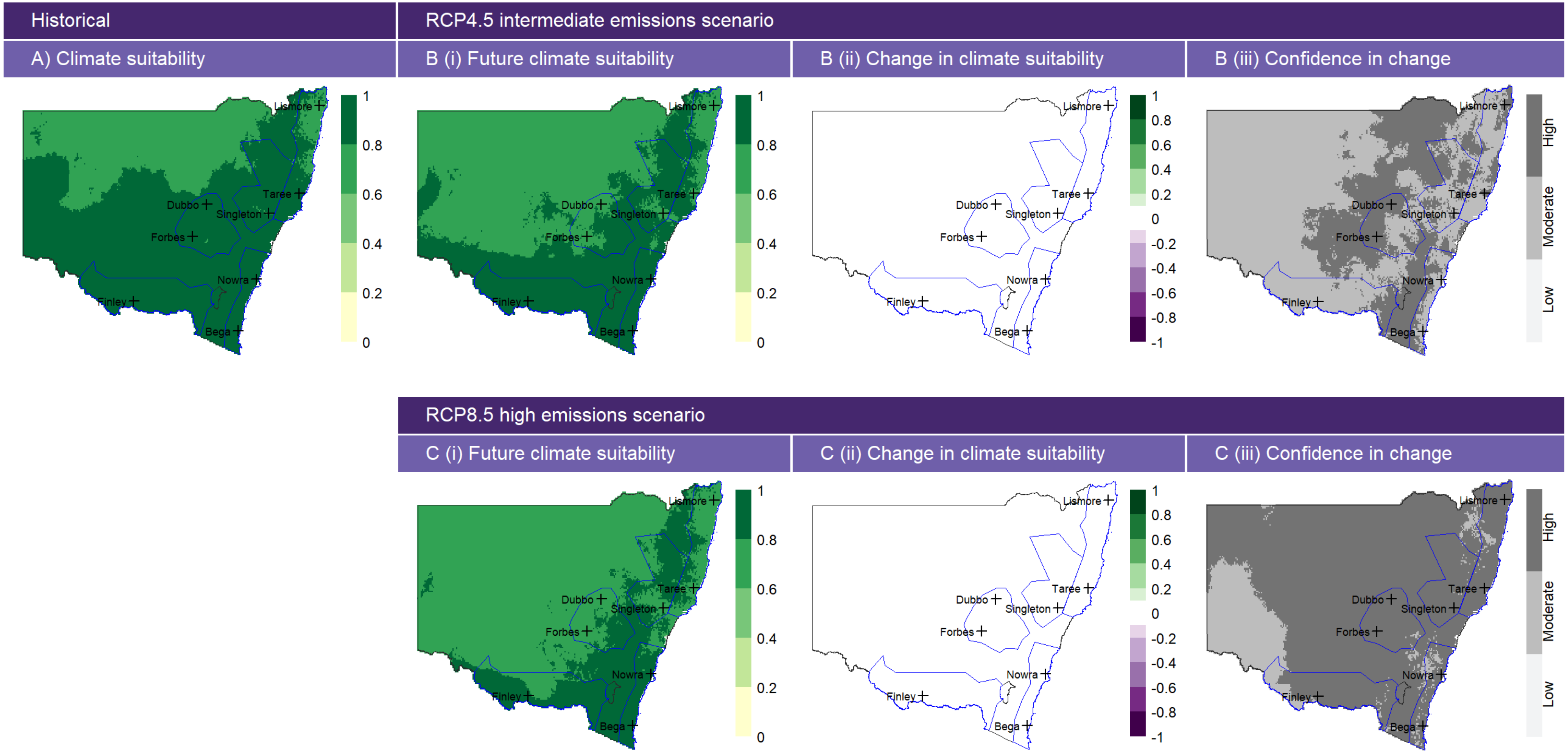


Figure A9. May climate suitability for dairy cows

The panel is comprised of 7 maps: A) shows the historical climate suitability; B) and C) show future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability, (ii) shows the projected future change in climate suitability as negligible (white), positive (green) or negative (purple) change, and (iii) shows the level of model confidence associated with this change (low, moderate or high). Areas where dairy is currently produced are marked by black crosses and blue polygons.

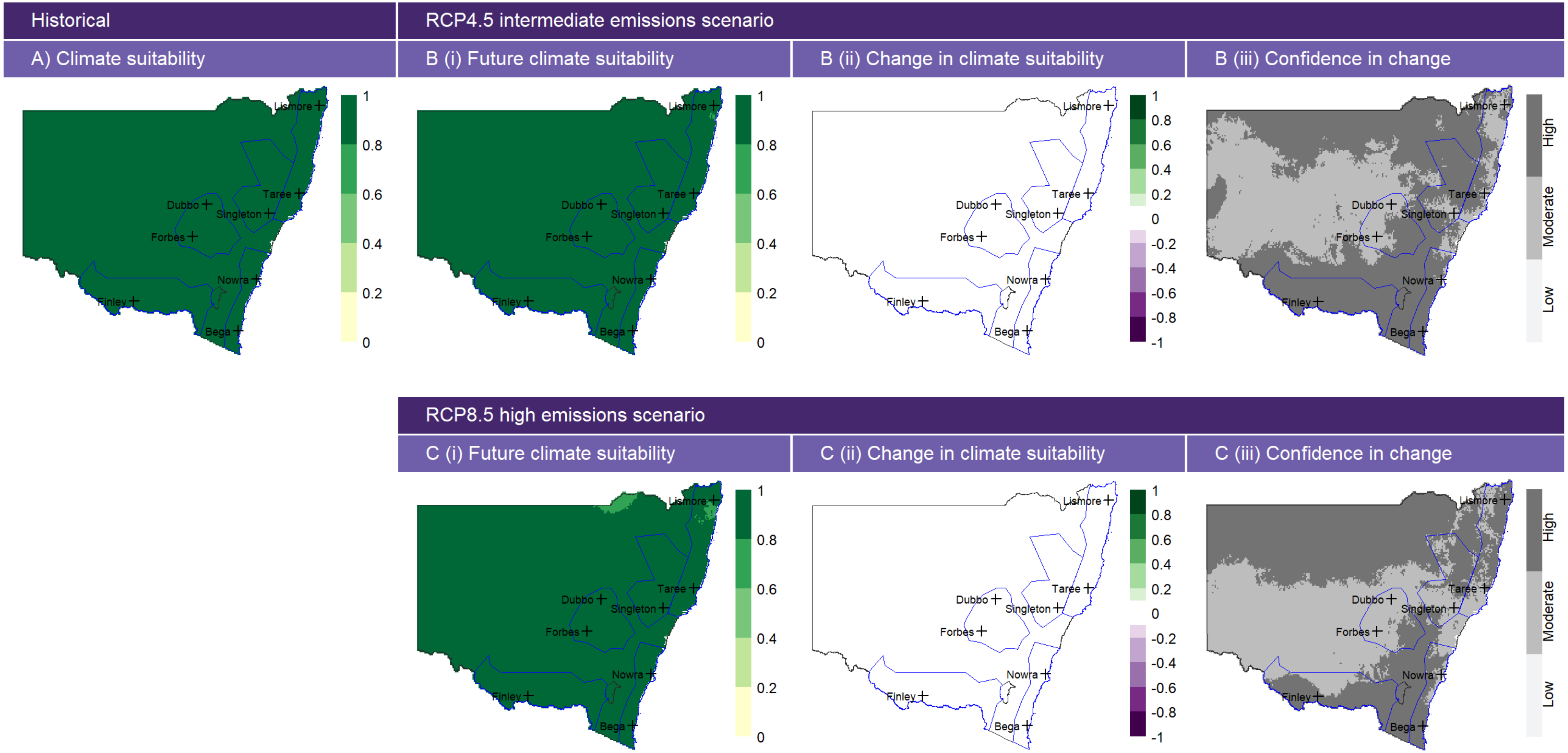


Figure A10. June climate suitability for dairy cows

The panel is comprised of 7 maps: A) shows the historical climate suitability; B) and C) show future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability, (ii) shows the projected future change in climate suitability as negligible (white), positive (green) or negative (purple) change, and (iii) shows the level of model confidence associated with this change (low, moderate or high). Areas where dairy is currently produced are marked by black crosses and blue polygons.

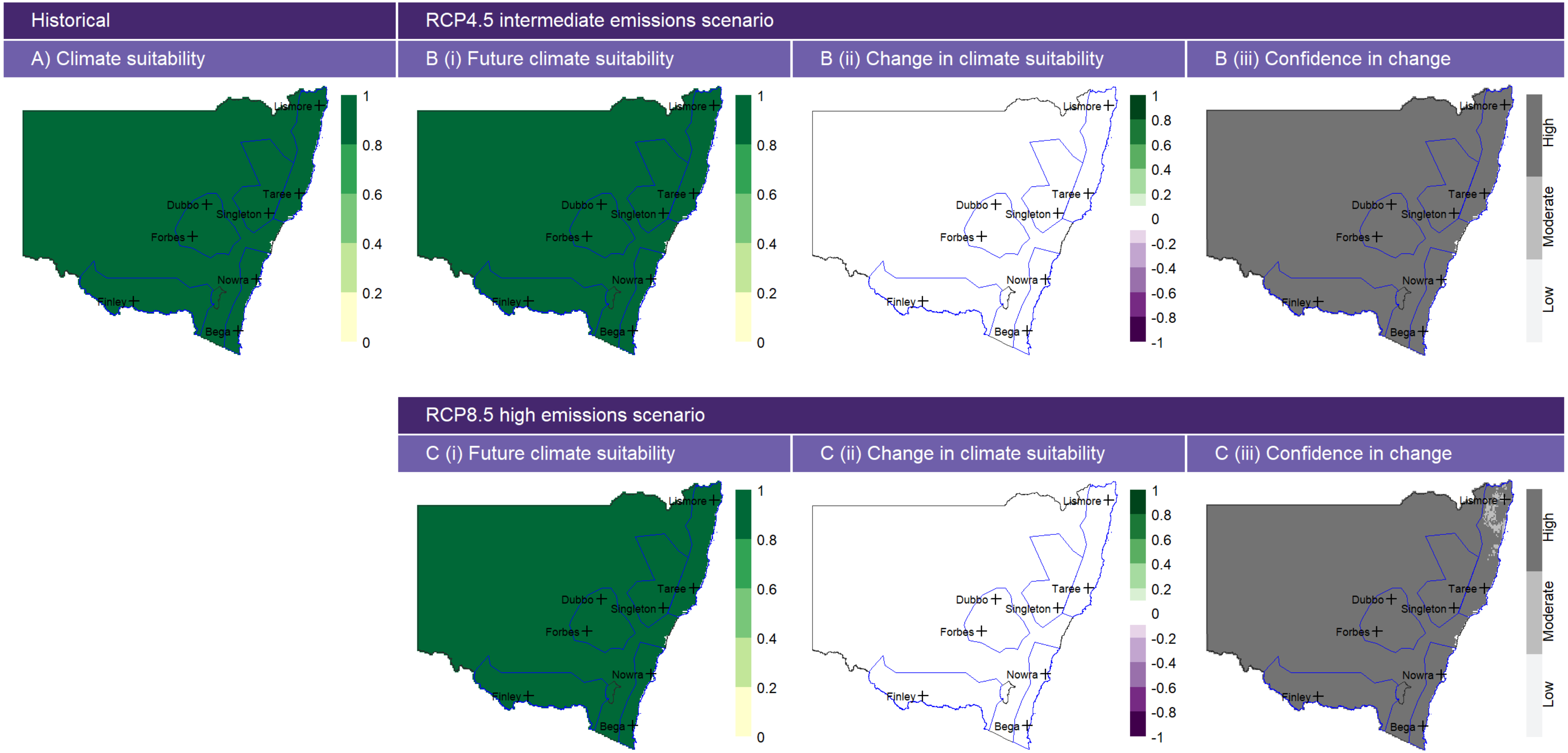


Figure A11. July climate suitability for dairy cows

The panel is comprised of 7 maps: A) shows the historical climate suitability; B) and C) show future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability, (ii) shows the projected future change in climate suitability as negligible (white), positive (green) or negative (purple) change, and (iii) shows the level of model confidence associated with this change (low, moderate or high). Areas where dairy is currently produced are marked by black crosses and blue polygons.

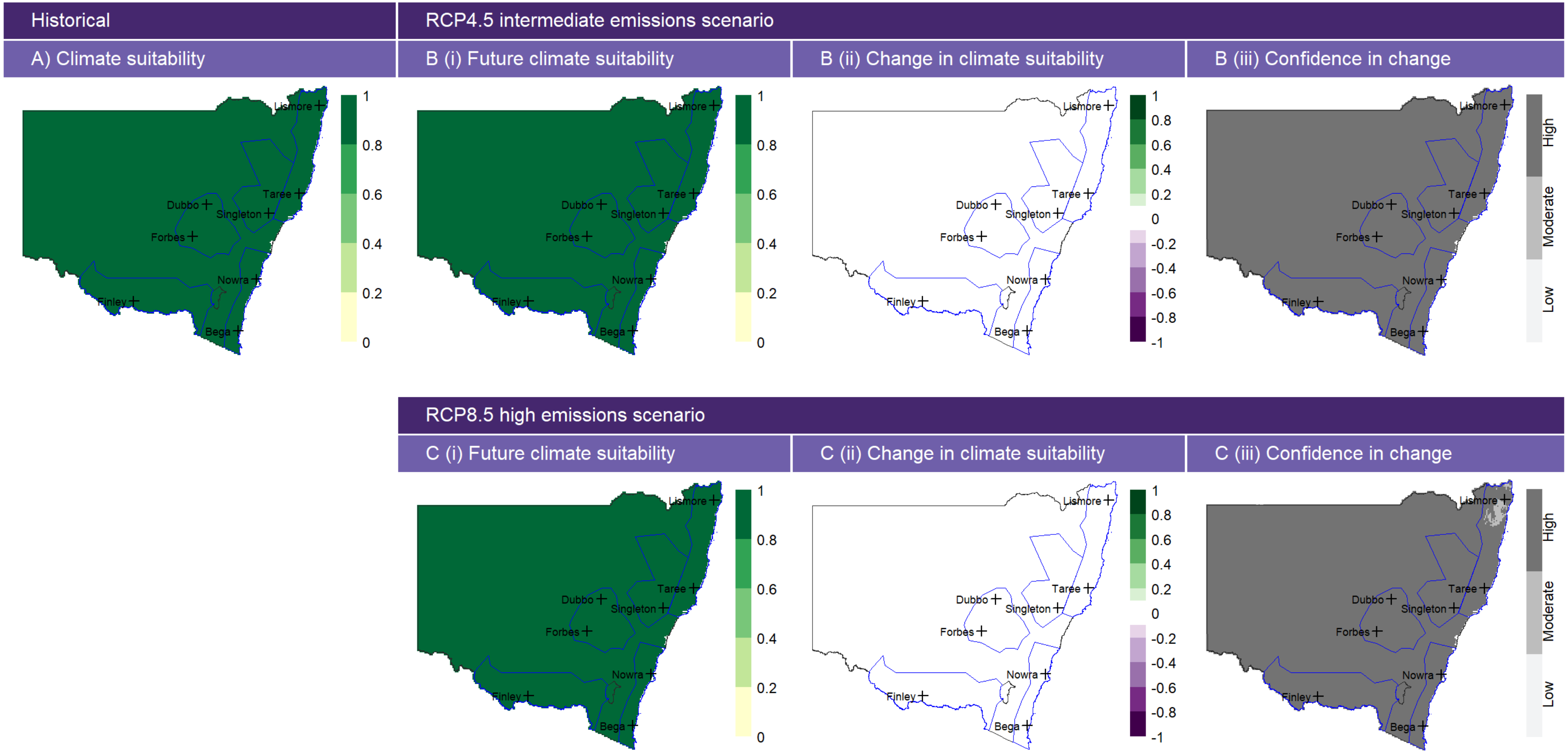


Figure A12. August climate suitability for dairy cows

The panel is comprised of 7 maps: A) shows the historical climate suitability; B) and C) show future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability, (ii) shows the projected future change in climate suitability as negligible (white), positive (green) or negative (purple) change, and (iii) shows the level of model confidence associated with this change (low, moderate or high). Areas where dairy is currently produced are marked by black crosses and blue polygons.

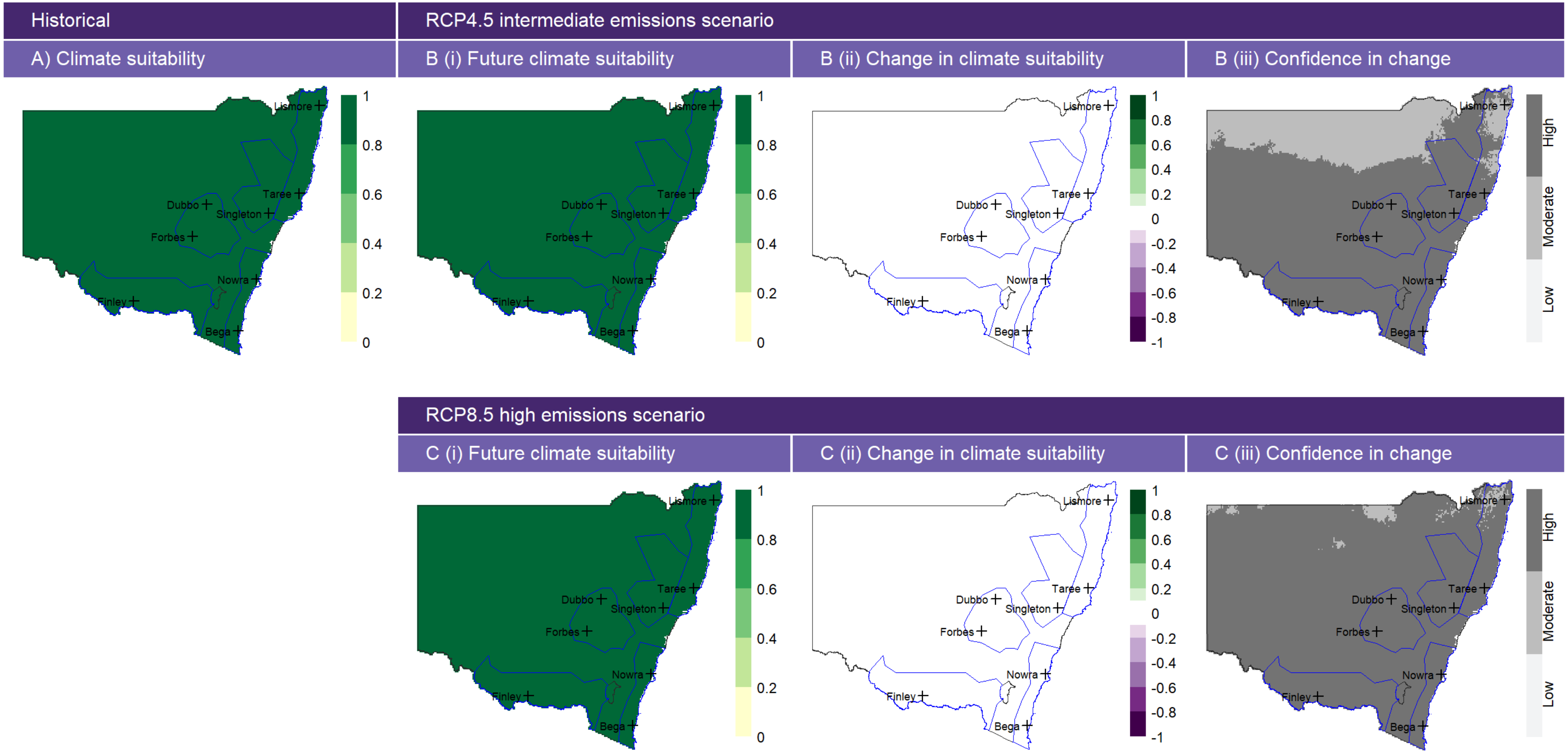


Figure A13. September climate suitability for dairy cows

The panel is comprised of 7 maps: A) shows the historical climate suitability; B) and C) show future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability, (ii) shows the projected future change in climate suitability as negligible (white), positive (green) or negative (purple) change, and (iii) shows the level of model confidence associated with this change (low, moderate or high). Areas where dairy is currently produced are marked by black crosses and blue polygons.

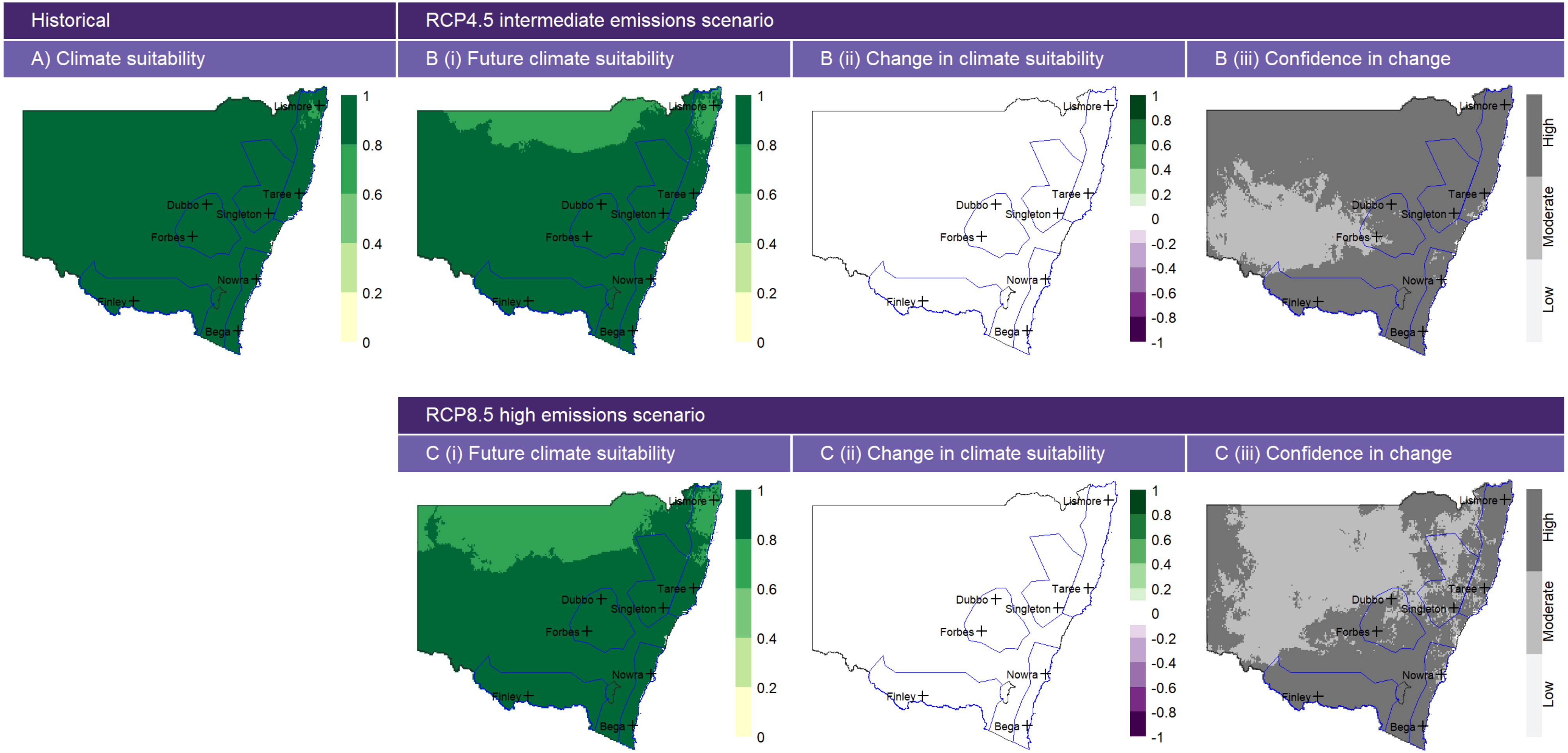


Figure A14. October climate suitability for dairy cows

The panel is comprised of 7 maps: A) shows the historical climate suitability; B) and C) show future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability, (ii) shows the projected future change in climate suitability as negligible (white), positive (green) or negative (purple) change, and (iii) shows the level of model confidence associated with this change (low, moderate or high). Areas where dairy is currently produced are marked by black crosses and blue polygons.

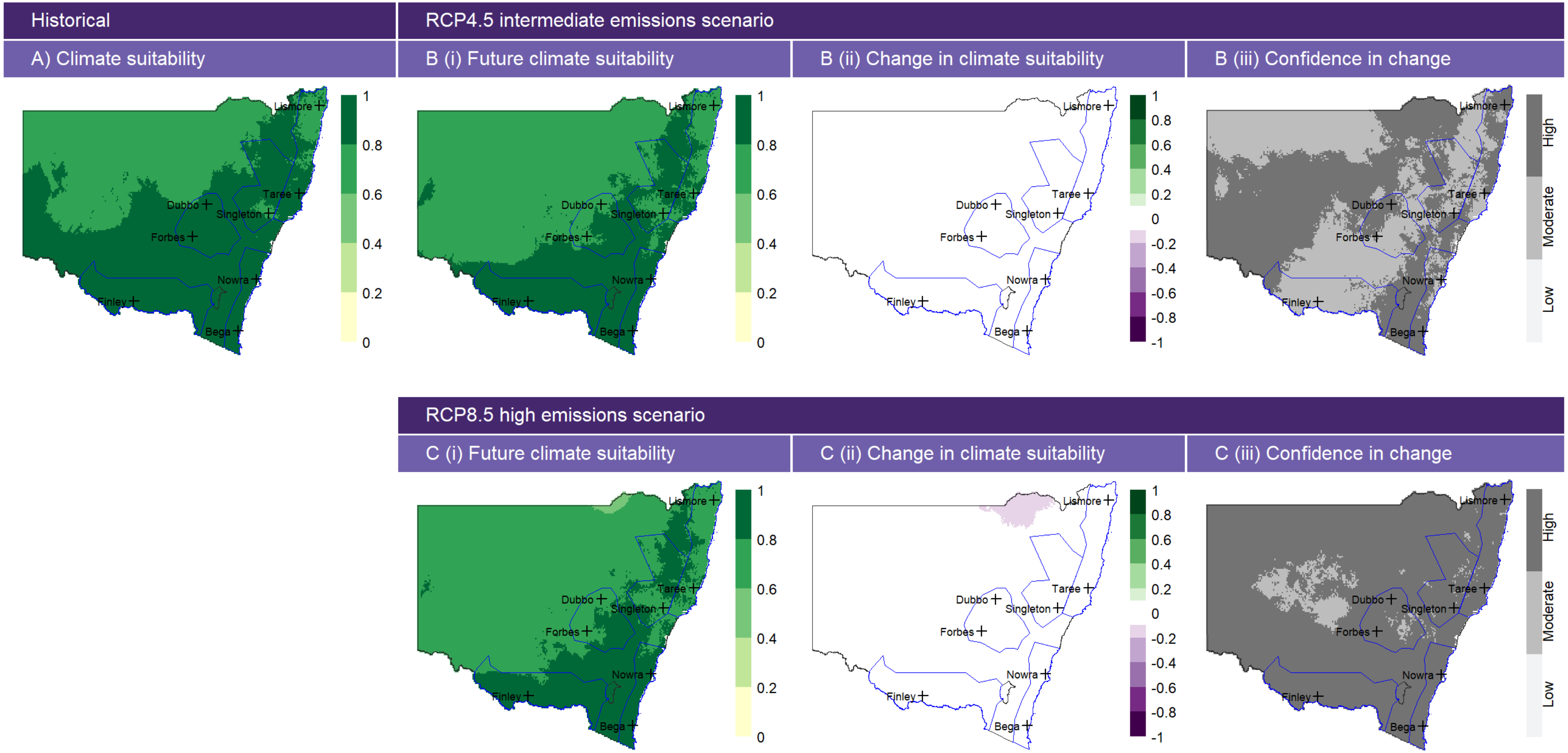


Figure A15. November climate suitability for dairy cows

The panel is comprised of 7 maps: A) shows the historical climate suitability; B) and C) show future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability, (ii) shows the projected future change in climate suitability as negligible (white), positive (green) or negative (purple) change, and (iii) shows the level of model confidence associated with this change (low, moderate or high). Areas where dairy is currently produced are marked by black crosses and blue polygons.

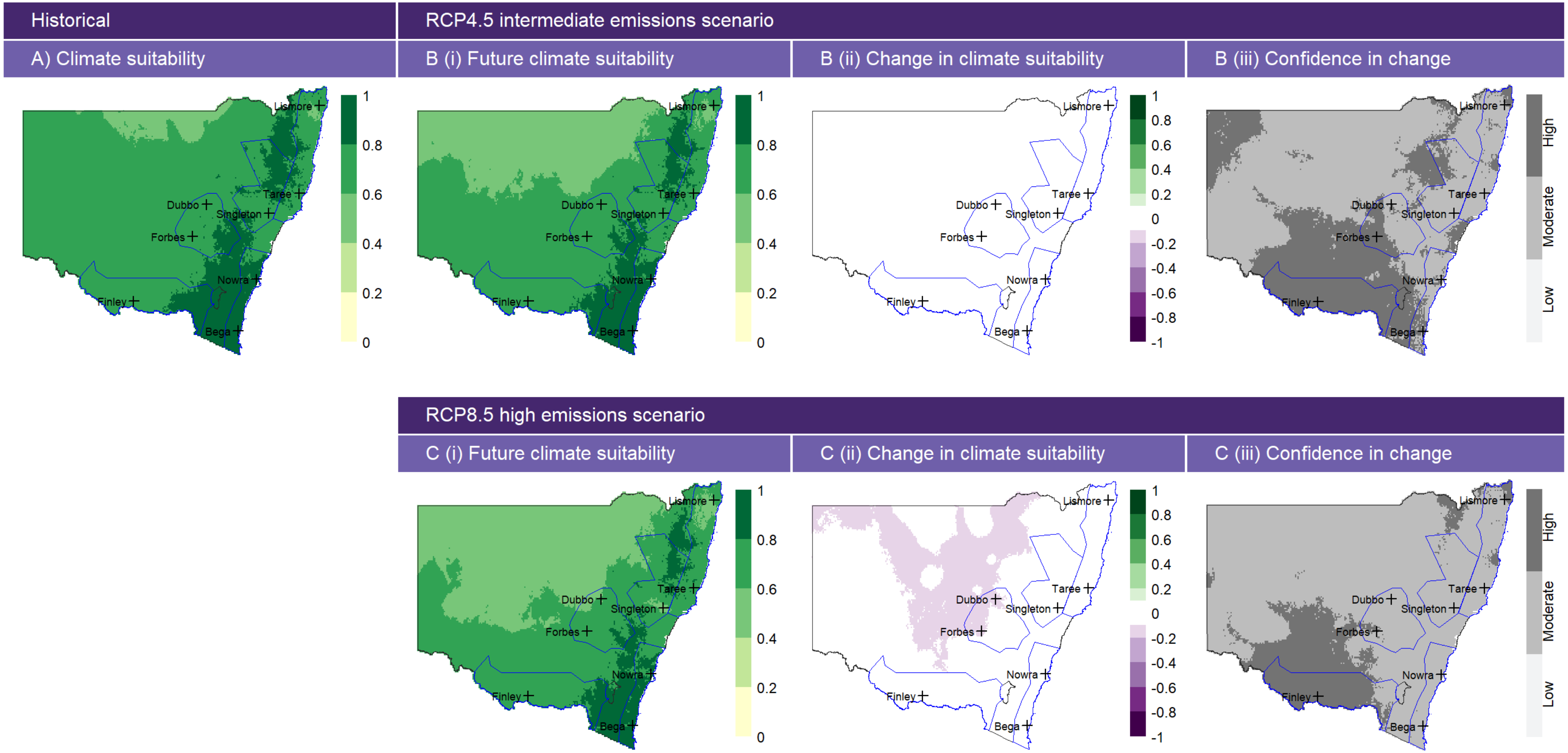


Figure A16. December climate suitability for dairy cows

The panel is comprised of 7 maps: A) shows the historical climate suitability; B) and C) show future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability, (ii) shows the projected future change in climate suitability as negligible (white), positive (green) or negative (purple) change, and (iii) shows the level of model confidence associated with this change (low, moderate or high). Areas where dairy is currently produced are marked by black crosses and blue polygons.

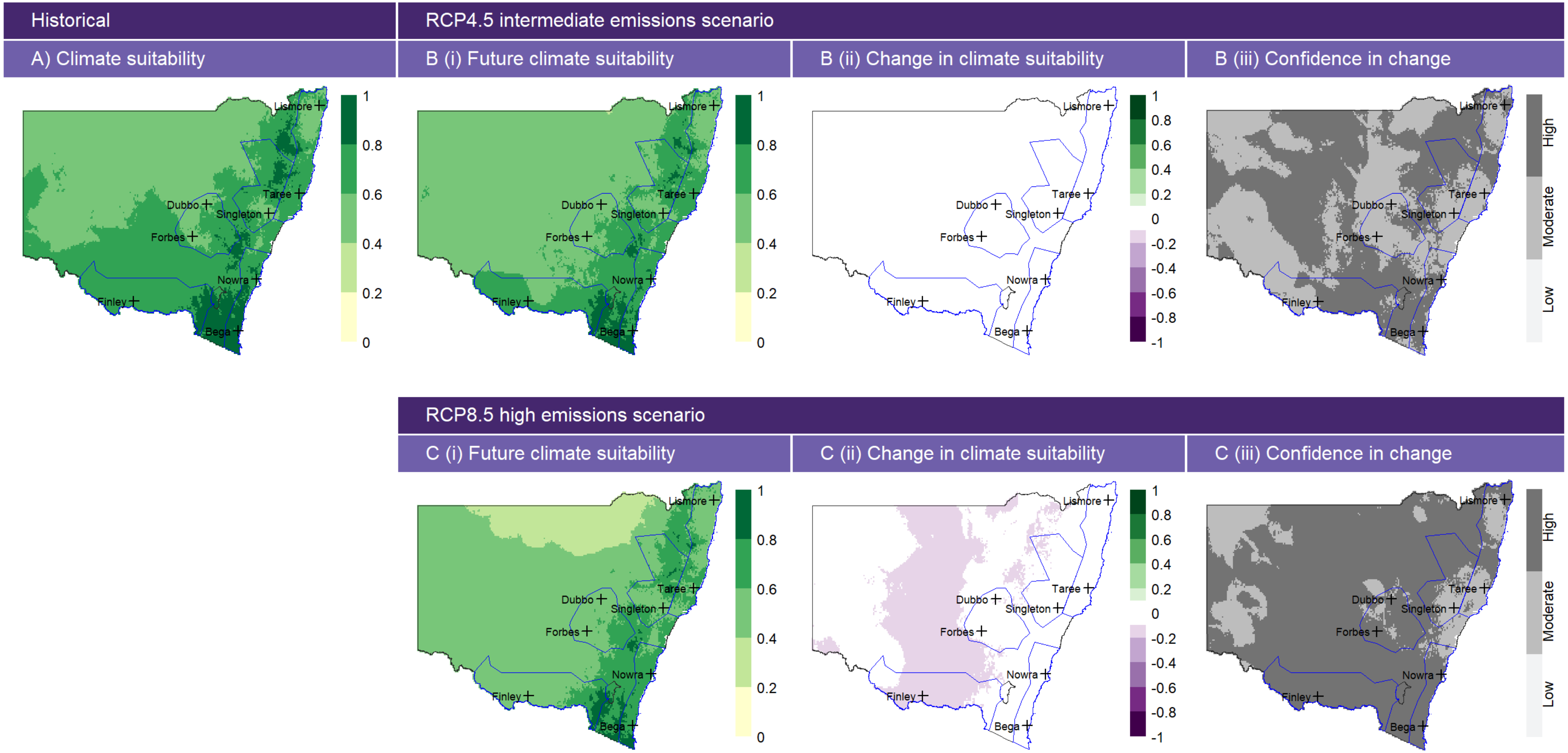


Figure A17: Inland regional comparison calendar for dairy cows overall and individual life stages

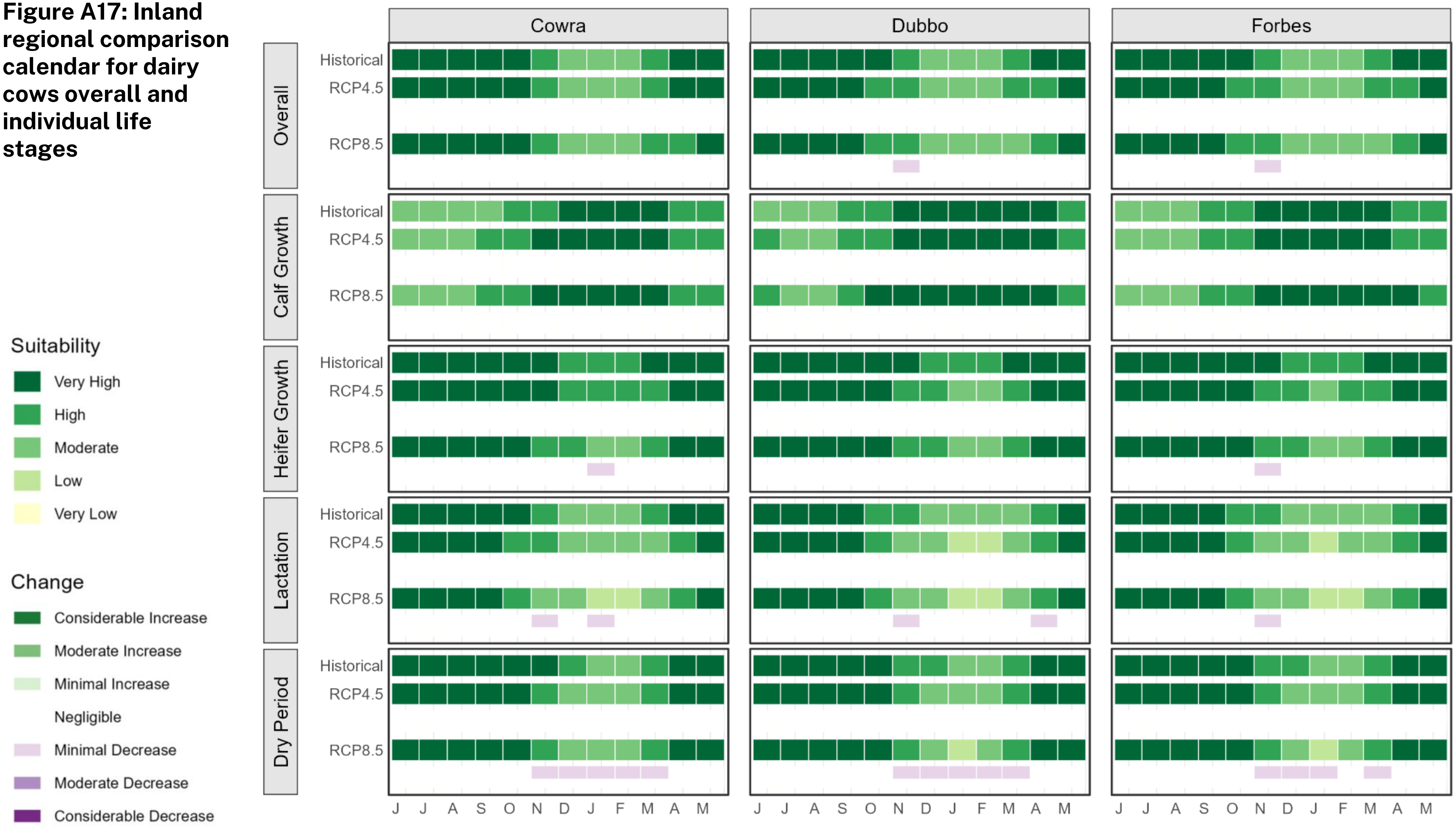


Figure A18: North Coast regional comparison calendar for dairy cows overall and individual life stages

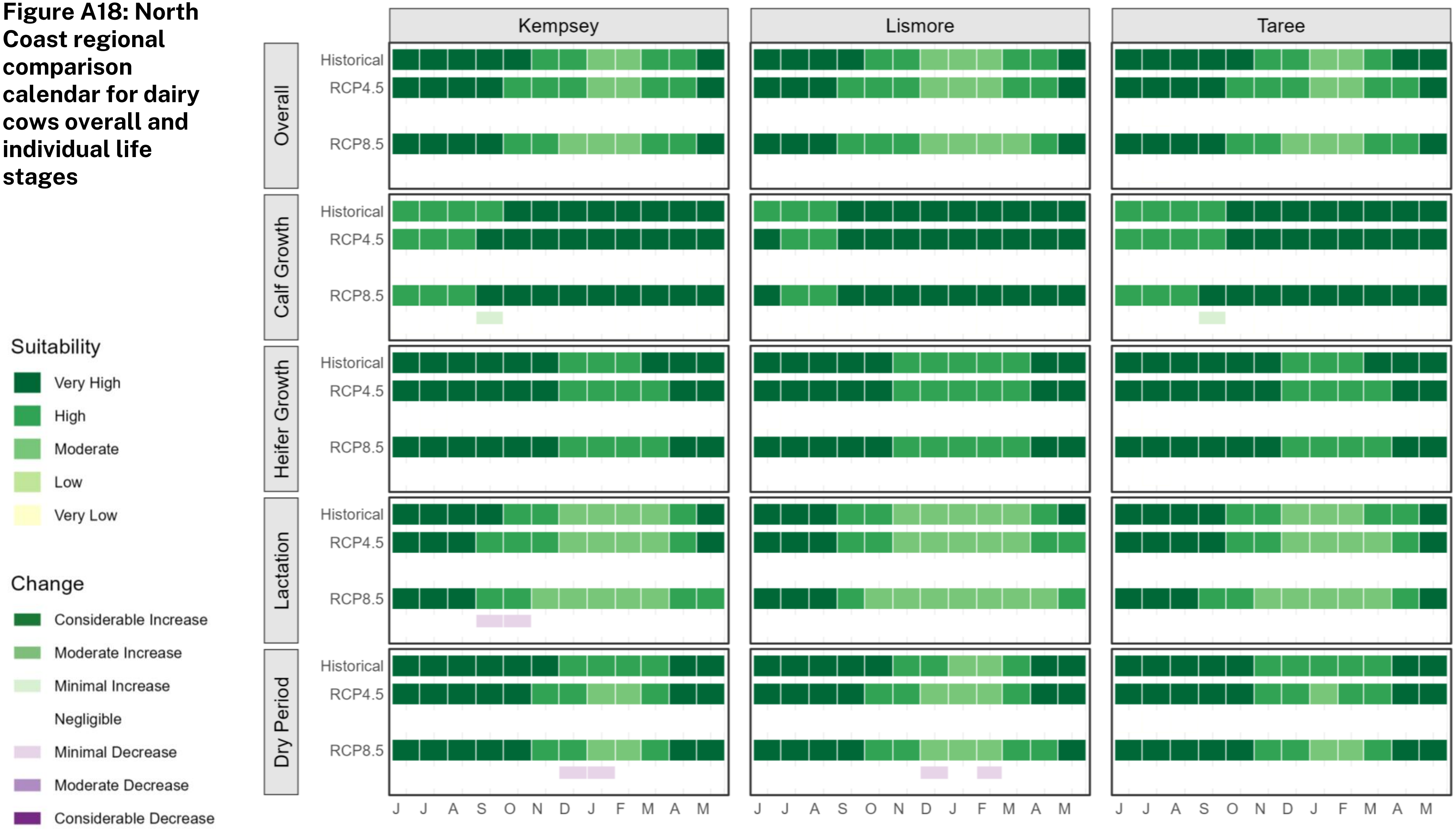


Figure A19: South Coast regional comparison calendar for dairy cows overall and individual life stages

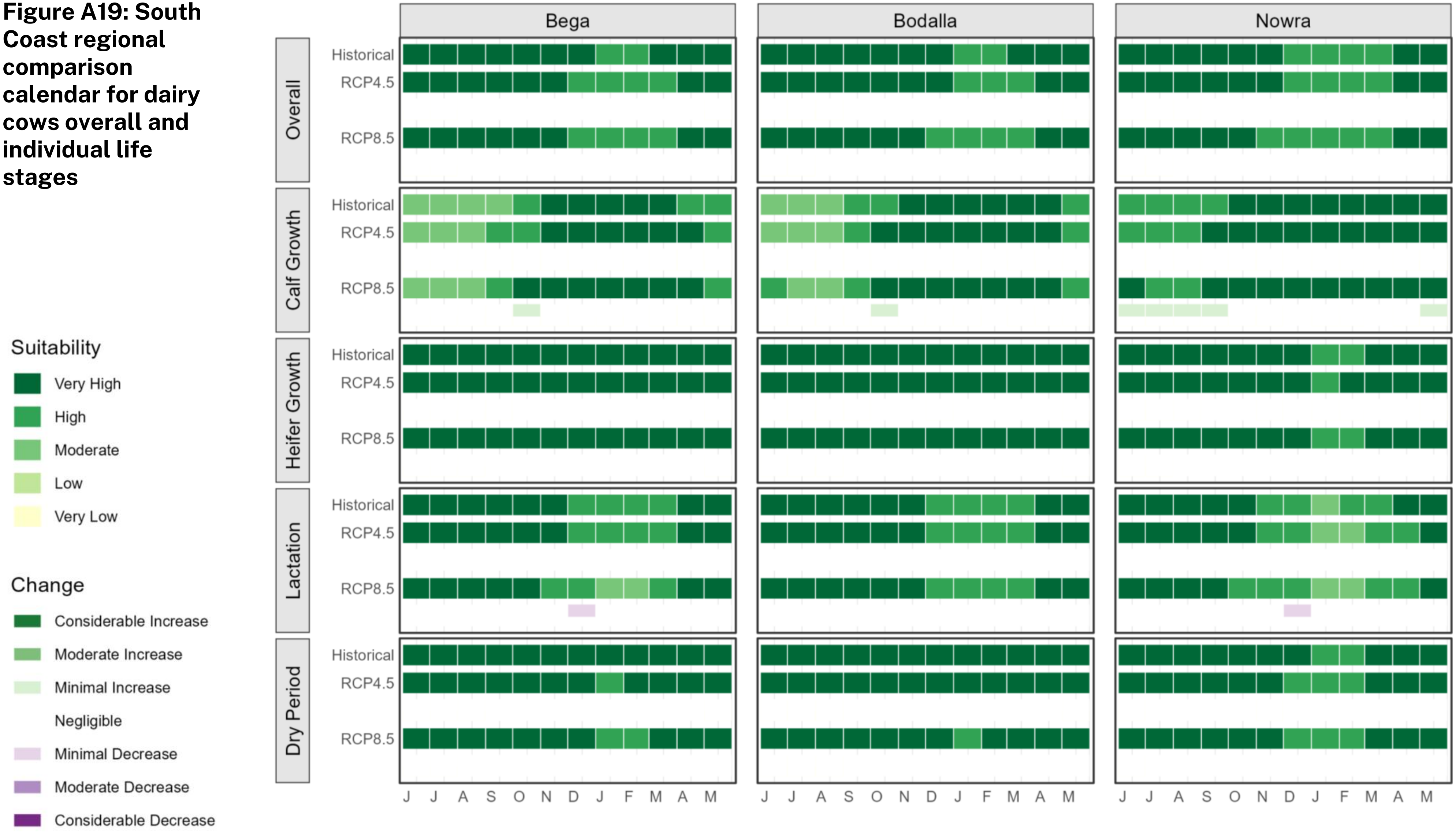


Figure A20: Riverina Murray regional comparison calendar for dairy cows overall and individual life stages

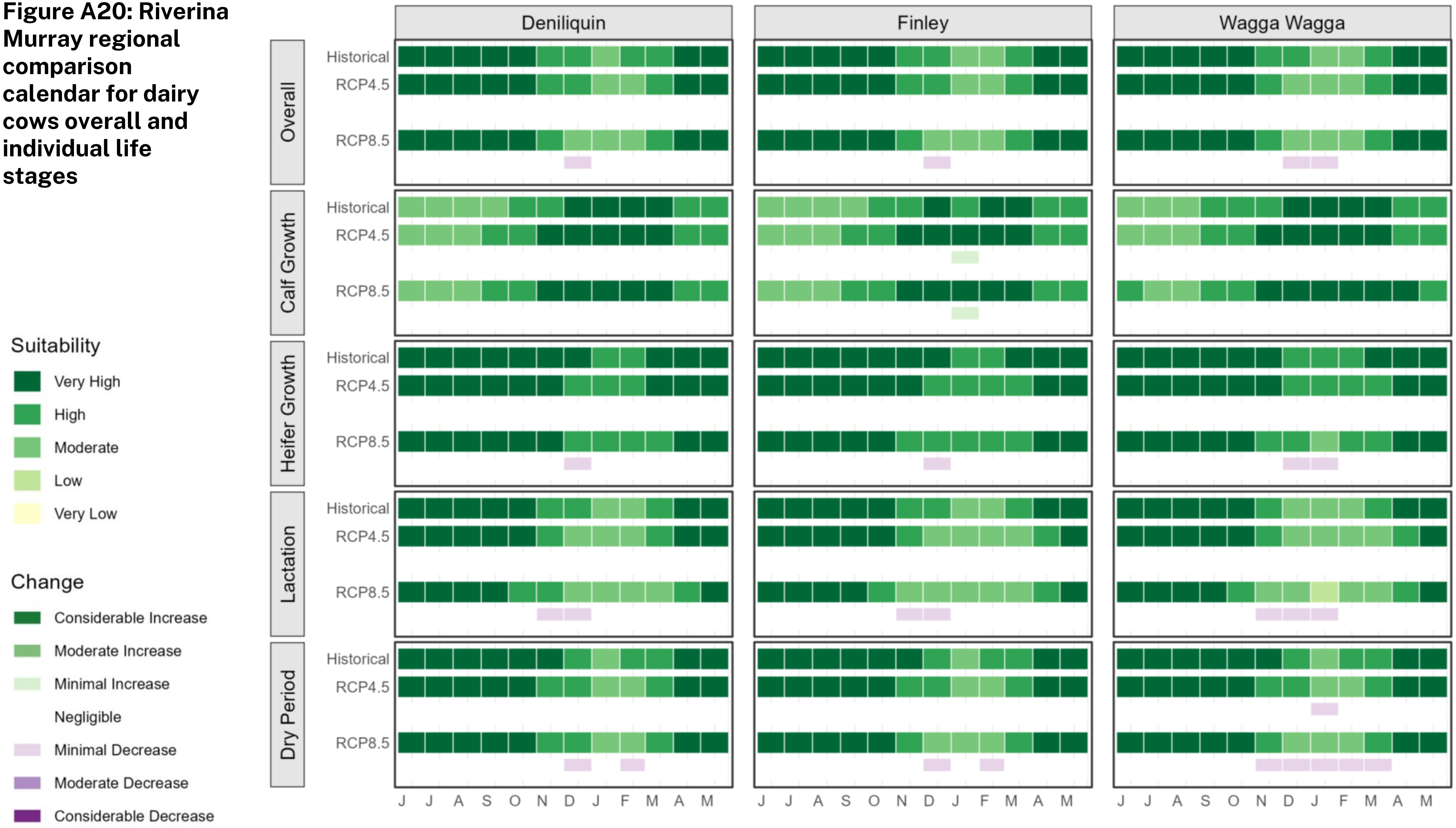
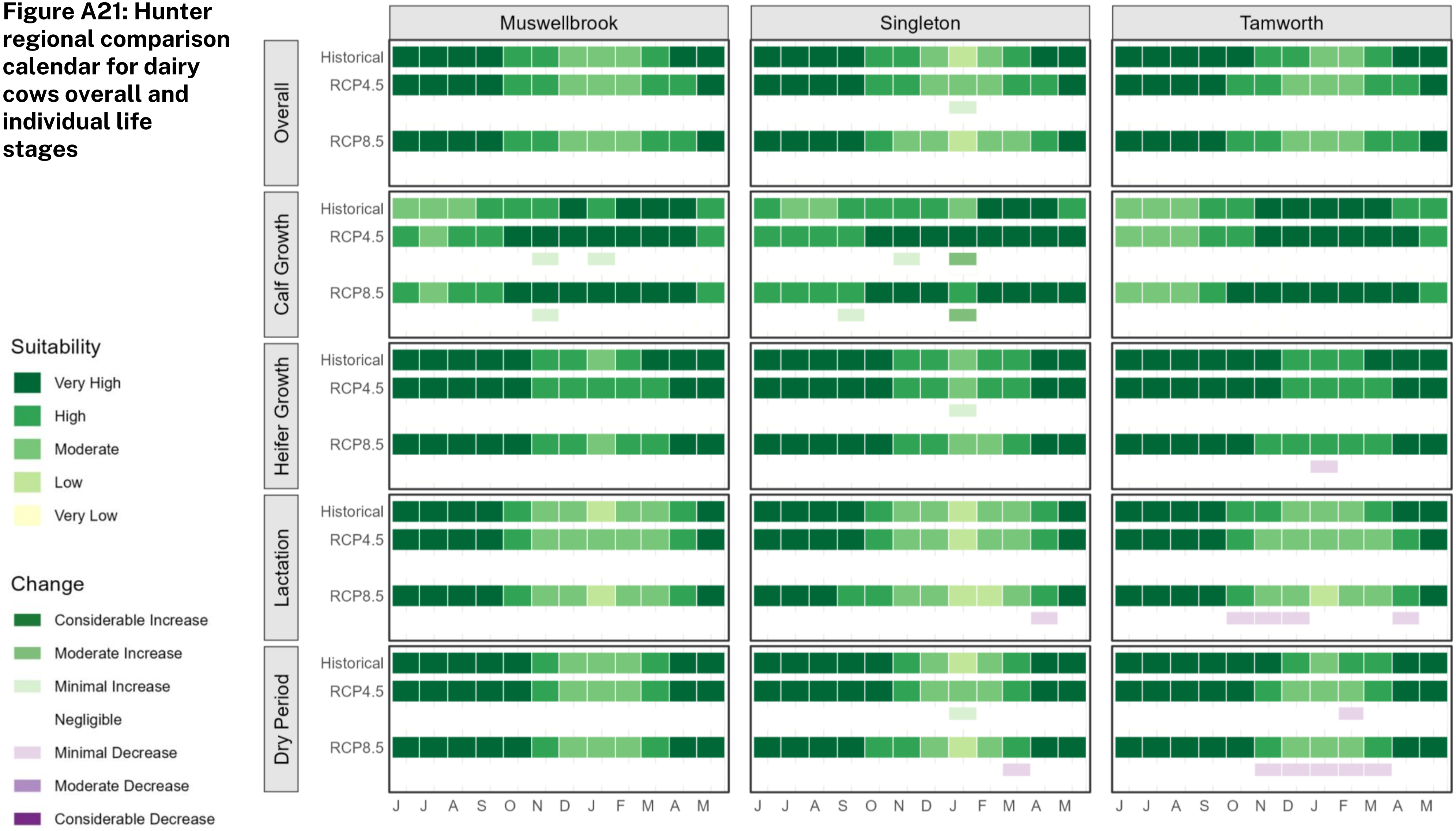


Figure A21: Hunter regional comparison calendar for dairy cows overall and individual life stages



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