Department of Primary Industries
and Regional Development

Cattle Tick

(*Rhipicephalus australis*)

Results Report

Climate Vulnerability Assessment

NSW GOVERNMENT

Authors

Department of Primary Industries and Regional Development Climate Vulnerability Assessment and Biosecurity teams.

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Acknowledgement of Country

The 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

Primary industries in New South Wales operate a wide variety of production systems within diverse landscapes, while facing the challenges of a changing and highly variable climate. The Primary Industries Climate Change Research Strategy invested $29.2 million in projects to help the state's primary industries adapt to climate change. As part of this work, the Climate Vulnerability Assessment Project undertook impact assessments for primary industries in the broadacre cropping, marine fisheries, forestry, extensive livestock, and horticulture and viticulture sectors, and key related biosecurity risks, to improve our understanding of the impacts of climate change.

The Climate Vulnerability Assessment has delivered consistent and comparable understandings of potential climate change impacts across the state, providing a deep insight into sectoral impacts. This strategic information is invaluable for policymakers and industry bodies, providing insights into 28 commodities and 14 biosecurity risks considered valuable or important to NSW.

This comprehensive assessment allows primary industries to understand the risks ahead, to prepare for and adapt to identified climate vulnerabilities, and to take advantage of future opportunities to expand in NSW.

Purpose of this report

This report contains the results of the cattle tick model from the Climate Vulnerability Assessment. The report introduces cattle tick in NSW and provides an overview of the model and its key features, assumptions, and exclusions. The main results and findings provide insights into future increases and decreases in climate suitability for cattle tick.

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.

A changing climate is impacting primary industries

Australia has one of the most variable climates, and its primary producers have always managed climate variability. Now, they are planning 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 variable rainfall patterns, alongside increasing challenges from extreme events.

This $23.1 billion 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 limited adaptation to climate change in this sector. Climate change is likely to worsen the impact of biosecurity risks in NSW by altering their range and potential distribution and their ability to spread. Industries with permanent plantings or geographic constraints are particularly vulnerable.

Adapting to these challenges requires a deep understanding of how climate change affects both commodities and the associated biosecurity risks. More research is needed to assess additional biosecurity risks, including those not currently present in NSW, to strengthen the resilience of primary industries in the face of climate change.

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.

Biosecurity risks have been well-researched in Australia. It is, nonetheless, challenging to draw a consistent and comprehensive understanding of the effects of climate change from these studies because of differences in methodology, assumptions and future climate projection data used[1]. A literature review of research into the impacts of climate change on primary industries found that biosecurity research was dominated by weed and insect threats (41 of 55 papers) whilst overlooking some important biosecurity risks to Australia altogether[1]. The studies we reviewed have revealed significant collective impacts of climate change. As temperatures increase, we can expect the range of pest species to move southward[2,3] and to see species which are currently restricted to lower altitudes by the warmer temperatures there to move into higher altitude areas as they warm[3,4]. Climate change is likely to extend the range of some biosecurity risks while further constraining others. The literature on this topic has largely overlooked how these changes may impact primary industries, which will be affected by evolving biosecurity risks under climate change[5].

Assessing the impacts of climate change

To address these issues, the Climate Vulnerability Assessment studied the potential impacts of climate change on a wide range of economically important primary industry commodities and biosecurity risks. This enabled us to identify those industries most at risk and therefore most in need of adaptation strategies, as well as industries where climate change might bring new opportunities and relief from existing challenges.

[1] 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.
[2] McFadyen, R. (2007). Invasive plants and climate change. Briefing notes. Cooperative Research Centre for Australian Weed management, Adelaide. 2 pp.
[3] Bellard, C., Jeschke, J.M., Leroy, B., Mace, G.M. (2017). Insights from modelling studies on how climate change affects invasive alien species geography. Ecoloby and Evolution 8:5688-5700.
[4] Taylor, S., Kumar, L., Reid, N. and Kriticos, D.J. (2012). Climate change and the potential distribution of an invasive shrub, Lantana camara L. PLoS (Public Library of Science) One 7, e35565.
[5] De La Rocque, S., Rioux, J.A. & Slingenbergh, J. 2008. Climate change: effects on animal disease systems and implications for surveillance and control. Rev. sci. tech. Off.int. Epiz. (2) 339-354.

Cattle tick in NSW

Cattle tick (*Rhipicephalus australis*) is a pest which has the potential to cause significant harm to beef and dairy cattle in NSW. An infestation of the parasite can damage livestock health and productivity, causing harm to animals, facilitating the transmission of disease and imposing associated treatment costs and restrictions on livestock movement. Cattle tick infestations are primarily found in the far north-east of the state (Figure 1), where warmer temperatures and high humidity create favourable conditions for tick survival and reproduction.

The lifecycle of cattle tick is divided into two distinct stages: the parasitic and non-parasitic stages. During the parasitic stage, the tick resides on the host, feeding and developing. The female ticks engorge on blood before detaching and falling to the ground to lay eggs in the grass of the pasture, beginning the non-parasitic stage. The eggs hatch into larvae which then begin their quest for a new host by climbing to the top of blades of grass and waiting for a host to walk past. They attach to the host and the lifecycle begins again.

The parasites are responsible for a range of detrimental effects on cattle, including blood loss, decreased weight gain and a weakening of the immune system which makes the animals more susceptible to disease. Additionally, cattle ticks are themselves vectors for several diseases, including cattle tick fever which can cause spontaneous abortion in pregnant cattle and is often fatal in its own right.

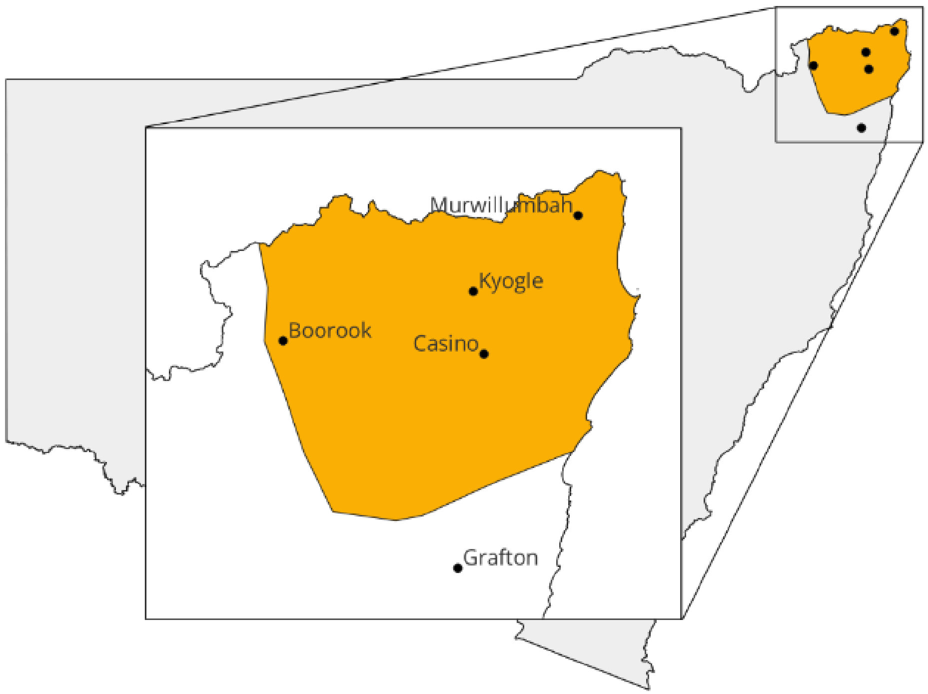


Figure 1: cattle tick infestations primarily occur in the far north-east of NSW (yellow); important sites are indicated by black dots.

Climate Vulnerability Assessment framework

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 commodities and biosecurity risks in a consistent and, therefore, comparable way.

Figure 2: Outline of expert engagement for framework developed by the Climate Vulnerability Assessment. Internal and external experts were involved throughout the process, helping to develop and refine the models of primary industry commodities and biosecurity risks in their area of expertise.

The assessment framework, outlined in Figure 2, provides a rigorous, flexible and transparent process for assessing vulnerability to climate change. The first step is a literature review, used to inform an initial 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.

Over 100 Department of Primary Industries and Regional Development staff contributed to this process, and almost 200 additional experts participated in focus groups to support the review and refinement of the models. External experts were drawn from industry bodies, producers, academia and elsewhere.

MCA modelling approach

The steps in the framework developed for the Climate Vulnerability Assessment were 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.

An MCA model with defined assumptions and exclusions was developed for each biosecurity risk, using a combination of published data, empirical evidence and expert judgment. In the hierarchical structure of an MCA model, the biosecurity risk sits at the top level, with the key life stages forming the level below. The next level of the model then associates one or more climate variables with each of the life stages.

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

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

The MCA model was not designed as a distribution 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].

Using the model, an assessment of climate suitability (ranging from ‘unsuitable’ to ‘very high’) can be made for each life stage, for each climate variable, and for the overall model. Climate suitability was assessed for both historical (recent past) conditions and for projected (near future) climate to understand how the climate suitability for the biosecurity risk may be affected by climate change.

An expert focus group 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 cattle tick and key results showing important changes to future climate suitability for cattle tick, 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 scope and exclusions are briefly summarised to the right, and the cattle tick model-specific assumptions are summarised on the next page.

Project limitations

The scope was limited to the assessment of vulnerability to future climate change. The assessment captures the response of cattle tick 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:

- soil properties and topography,
- other non-biophysical parameters, and
- socio-economic factors.

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

Project exclusions

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, flood and bushfire 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 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 cattle tick model

For more information on models and methodology, see the Climate Vulnerability Assessment Methodology Report.

Climate variables

The climate variables used in this model were minimum temperature (Tmin, °C), mean temperature (Tmean, °C), maximum temperature (Tmax, °C) and relative humidity (RH, %).

Categorising climate variables

The hierarchical structure of the MCA model (Figure 3) categorises climate variables to assess their impact on cattle tick. Each category (for example, a temperature between 20 and 27°C) is assigned a rating, R, between 0 and 1, that indicates how well it suits cattle tick, from unfavourable (R=0) to optimal (R=1). This is repeated for each life stage.

Modules used in the cattle tick MCA model

The cattle tick 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 month.
- **Threshold module:** examines the number of days spent below or above a key climate threshold during the given month.
- **Lethal conditions**: defines extreme climate conditions that are fatal to the life stage. If these limits are reached, then the life stage dies (indicated by R = –2 in Figure 3). During each month, if the threshold for lethal conditions is reached, then climate suitability is set to zero for that entire month.
- **Matrix module**: matrices capture the interaction between two climate variables. For adults, these were monthly mean temperature and relative humidity. This module was used for life stages that are particularly sensitive to the interplay between two climate variables. The matrix categories define different combinations of climate conditions, for example, temperatures between 20 and 27°C with relative humidity greater than 70%. The matrix ratings identify the suitability of each specific combination from unfavourable to optimal conditions.

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 cattle tick.

Cattle tick model assumptions

In addition to the global assumptions and exclusions, the cattle tick model also contains the following:

- a specific organism is described,
- susceptible host available,
- ticks successfully attach to the host and
- no treatment or control for cattle tick is applied to host.

The exclusions for the cattle tick model include:

- parasitic stage was not modelled (only the non-parasitic stages were assessed), and
- microclimates (adults on host) were not included.

Cattle tick life stages

The cattle tick model has been divided into key life stages, and the model has been repeated each month, as the lifespan of cattle tick is short, allowing multiple cycles to occur within a month (Figure 3). Using model monthly outputs allows us to assess the influence of climate during any given month on the cattle tick individual life stages and to explore potential changes in population dynamics. Furthermore, the fine temporal scale allows for an assessment of how changing climate suitability may impact cattle tick hosts, informing planning for future education and management.

The parasitic stage consists of three phases: larvae, nymph, and adult. These stages were not assessed as they occur on the host animal, and the microhabitat of the host cannot be modelled in this project. The non-parasitic stage occurs within an external environment around the pastures and includes four phases: adults pre-egg and egg-laying (combined in the model), eggs, and larvae. It lasts from 2 to 9 months, depending on climatic conditions. The life stages used in this modelling were the non-parasitic adult, egg and larvae stages. Climate conditions were considered for each month and each life stage.

Table 1: The life stages of the cattle tick assessed in the model[8].

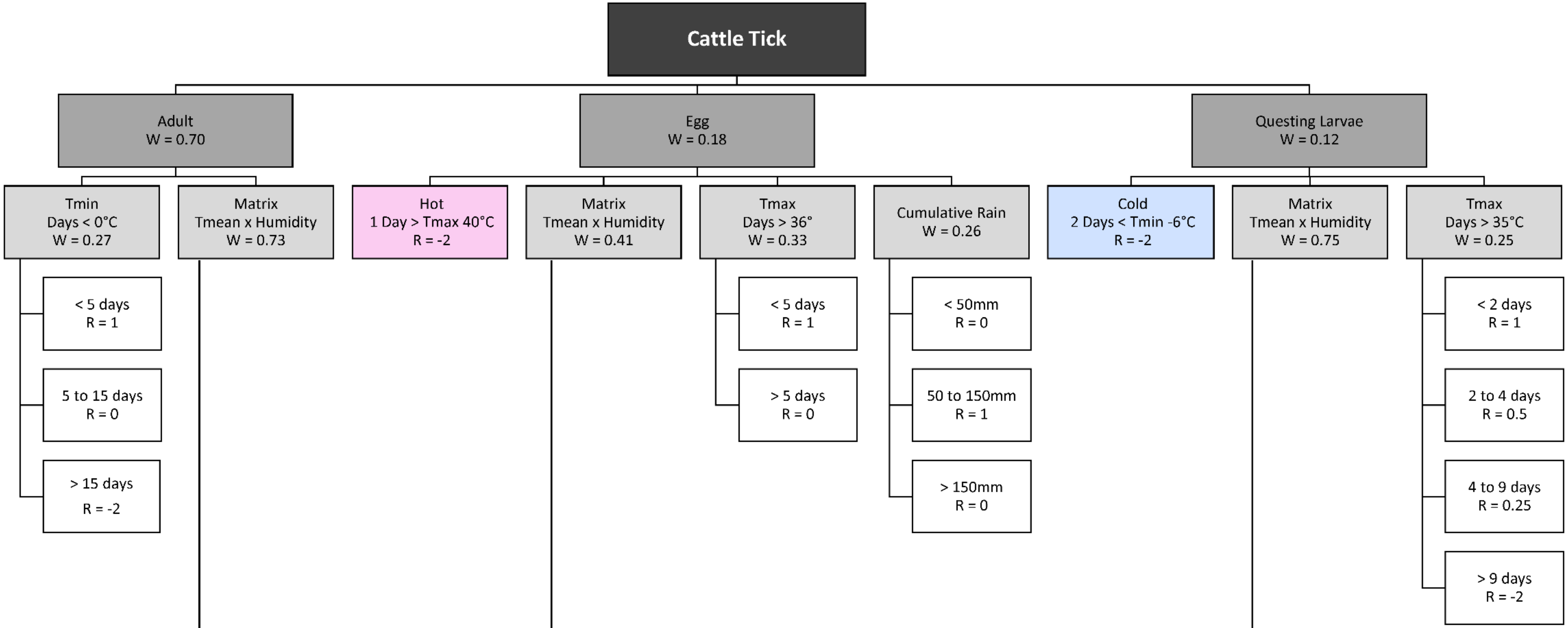
Life stage	Description
Adult	Pre-egg and egg-laying adults were combined because their sensitivity to climate conditions and exposure is the same.
Egg	The egg-laying process of adult ticks can take days to months, with environmental conditions affecting egg viability and timing of egg hatching.
Larva	The eggs develop and hatch into larvae. These questing larvae climb to the tops of grass blades in search of a host to attach to.

[8] DPI Prime Fact: Cattle tick – identifying the lifecycle stages

Final cattle tick model

The MCA model for cattle tick is shown in Figure 3. The model contains the key non-parasitic life stages for cattle tick: adult, egg and larva. Each life stage has a number of climate variables that impact climate suitability.

The interaction of mean monthly temperature and mean monthly relative humidity is important for all life stages and are presented as matrices in this model. Matrix ratings indicate whether the combination of temperature and relative humidity provides optimal, sub-optimal or inadequate conditions for cattle tick. The assigned rating for each temperature and relative humidity combination reflects how the different combinations impact the adult, egg and larvae stages, considering their sensitivity to climate and exposure. For more information, please refer to the Climate Vulnerability Assessment Methodology Report.



	Tmean (°C)				
	< 10	10 to 15	15 to 20	20 to 27	> 27
< 70% Humidity	0	0	0.1	0.3	0
> 70% Humidity	0	0.2	0.7	1	0.75

	Tmean (°C)			
	< 16	16 to 20	20 to 28	> 28
< 70% Humidity	0	0	0	0
> 70% Humidity	0.3	0.7	1	0.5

	Tmean (°C)				
	< 15	15 to 19	19 to 24	24 to 29	> 29
< 70% Humidity	0.1	0.2	0.5	0.3	0.1
> 70% Humidity	0.6	0.8	1	0.9	0.4

Figure 3: MCA model hierarchical structure and model components for cattle tick. The top level of the hierarchy is the biosecurity risk. The second level contains the life stages identified as climate-sensitive by the literature review and expert judgment. The third level contains climate variables which affect each life 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 the biosecurity risk is currently found in NSW or is of concern.

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[9] (GCMs), and the median of these models was used to produce ensemble future projection climate suitability maps.

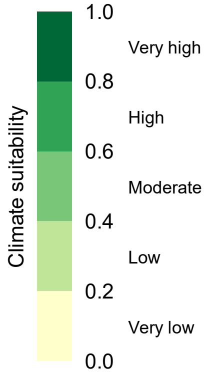


Figure 4: Colour scheme for the climate suitability maps

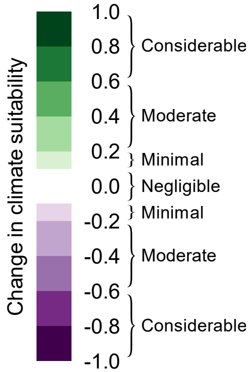


Figure 5: Colour scheme for the change in climate suitability maps

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

Historical and future 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, where the future climate becomes more suitable, is shown in shades of green; negative change is shown in shades of purple. Negligible change is represented by white and occurs for values between −0.1 and 0.1; in these areas, the future climate suitability will be very similar to the historical suitability.

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.

[9]Data was 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 each of the two emissions scenarios.

Maps of change in the number of highly suitable months (see colour scheme in Figure 8) and confidence (see colour scheme in Figure 9) in the change are also presented. Polygons and key sites are displayed on each map to indicate the areas where the biosecurity risk is currently found in NSW or is of concern.

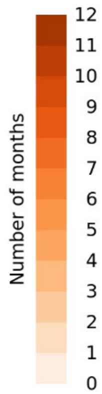


Figure 7: Colour scheme for the number of highly suitable months maps

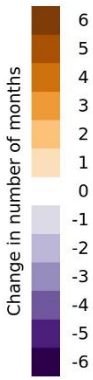


Figure 8: Colour scheme for the change in the number of highly suitable months maps

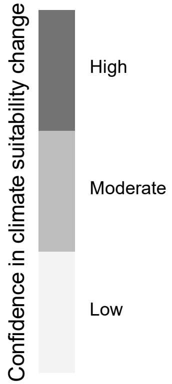


Figure 9: Colour scheme for confidence in the change in the number of highly suitable months maps

Historical and future 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 highly suitable months, and dark orange to a high number of highly suitable months. The values represent the mean over all years and thus may be any value between 0 and 12.

Change in the number of highly suitable months maps

The 'change in the number of highly suitable months' maps uses a purple-white-orange colour scheme with 11 categories ranging from 6 to -6. Shades of Orange indicate an increase in the number of highly suitable months; shades of purple indicate a decrease in the number of highly suitable months. 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 climate suitability calendars

Climate suitability calendars for biosecurity risks 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). Climate suitability calendars are included for the biosecurity risk overall and each life stage.

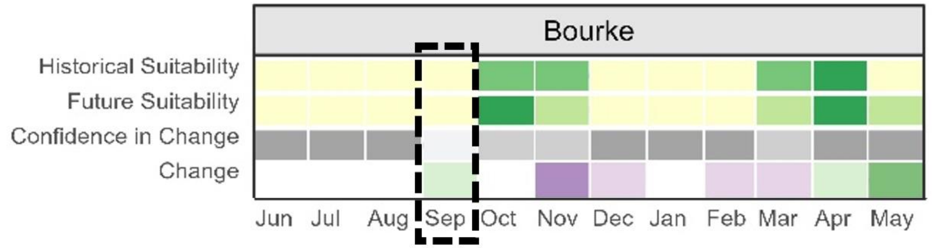
Climate suitability calendars use the same colour categorisation as the climate suitability panels (see page 10, 'Interpreting climate suitability colour schemes'), except that the 'change' scale uses 7 colours instead of 11, condensing them into the following categories: negligible, minimal, moderate and considerable.

There are two important points to note when interpreting climate suitability calendars:

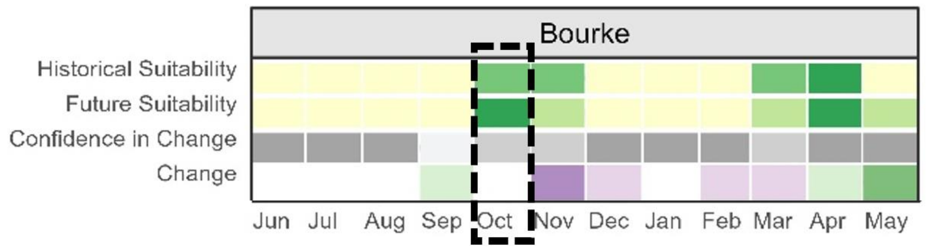
One occurs when the historical and future climate suitability categories are the same, but the 'change in suitability' is non-negligible (green or purple). This situation is shown in **Example 1** and has arisen from a historical September climate suitability of 0.000 and a future climate suitability 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 other occurs when the change from historical to future climate suitability is negligible (white), but the climate suitability is in different categories. This situation is shown in **Example 2** and has arisen from a historical October climate suitability of 0.577 and a future 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 climate suitability 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 climate suitability 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 cattle tick

Changes in climate suitability for cattle tick are likely to create challenges for the beef and dairy industries in NSW.

This section provides a selection of key results for the cattle tick climate vulnerability assessment. It begins with an overview of the overall climate impacts and a breakdown of the climate impacts on each life stage, followed by the relevant maps and climate suitability calendars. The interpretation and findings are provided in the text on the bottom left corner of each map panel and on the right side of the climate suitability calendar. The findings have been summarised with key figures, and additional maps are provided in the Appendix.

Analysis of the model outputs has been undertaken spatially across NSW, presented as maps, and monthly, presented as climate suitability calendars. Each map includes the outline (in blue) of where cattle tick infestations have occurred in NSW. This region is shown in Figure 10 and will be referred to as the cattle tick region throughout this report.

The locations shown in Figure 10 were used to study the future changes in climate suitability for cattle tick in the region most at risk. These sites were selected because they align with surveillance locations for cattle tick in NSW, and they represent some of the key areas where cattle tick is likely to have an impact.

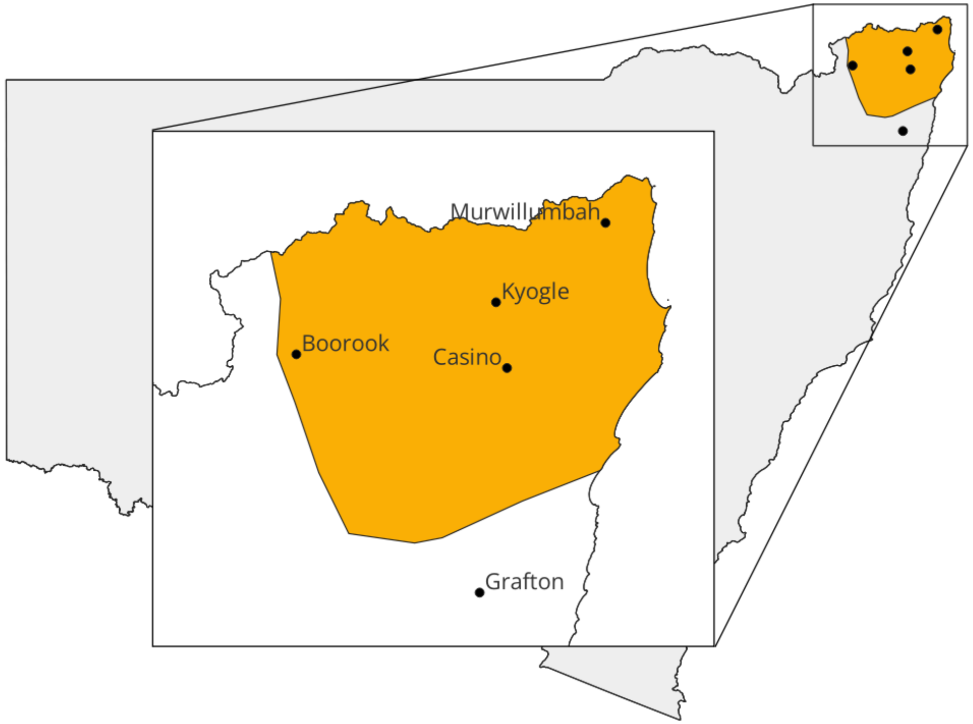


Figure 10: the cattle tick region, as defined by cattle tick infestations, is found in the far north-east of NSW (yellow); important sites are indicated by black dots.

Overall climate impacts

Annual climate suitability trends: impacts on different regions in NSW

Within NSW, different areas have variable suitable climate conditions for cattle tick. The number of months each year in which the climate suitability is classified as 'highly suitable' ('high' or 'very high') is used as a measure of overall climate suitability for cattle tick. This varies between different regions of the state, as shown in Figure 11.

Figure 11 shows that by 2050, the number of highly suitable months within the cattle tick region is likely to increase by 1 to 2 months per year under both emissions scenarios (*moderate to high confidence*).

Beyond the cattle tick region, the number of highly suitable months along the Great Dividing Range and the coast of NSW is likely to increase by 1 to 2 months per year under both emissions scenarios (*moderate to high confidence*). The rest of the state is likely to experience a negligible change, maintaining the historical range of 0-1 highly suitable months for cattle tick (*moderate to high confidence).*

Spatial trends in climate suitability for cattle tick

Climate change is likely to impact the potential range of cattle tick across NSW due to changes in climate suitability. These changes vary across the year. In this section, spatial changes to climate suitability for cattle tick are examined for key months of the year, focusing on the cattle tick region (Figure 1). Potential changes include:

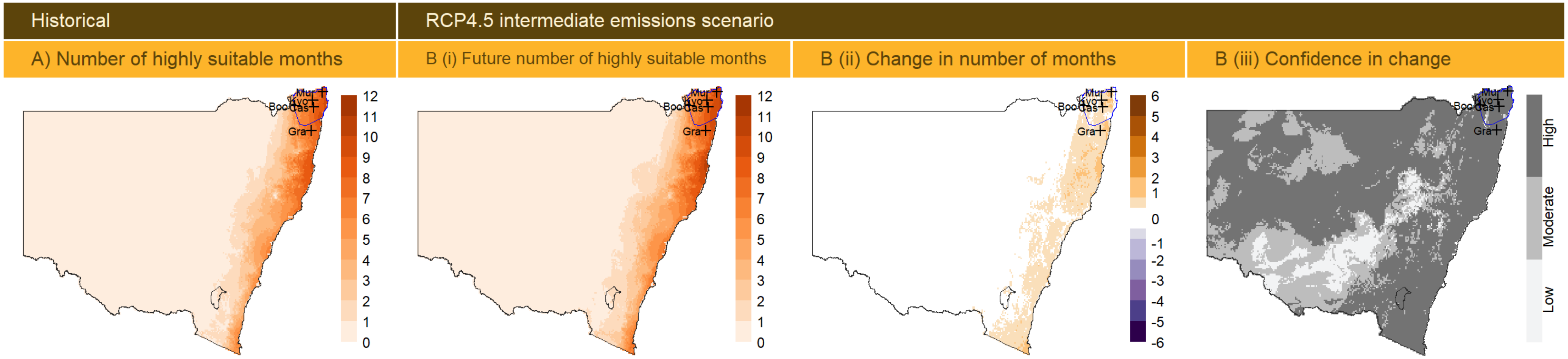
- **March to November** – there are likely to be minimal to moderate increases in climate suitability in the cattle tick region. The increase is likely to be greatest under the high emissions scenario (moderate to high confidence). For May and August, see Figure 12 and Figure 13, respectively; for other months, refer to Appendix Figure A7, Figure A9, Figure A10, Figure A12, Figure A13 and Figure A14.
- **December to February** – there are likely to be minimal to moderate decreases in climate suitability in the cattle tick region. The decrease is likely to be greatest under the high emissions scenario (low to high confidence): see Appendix Figure A15, Figure A4 and Figure A5.

Monthly climate suitability trends in the cattle tick region

The overall climate suitability calendar, Figure 14, shows the expected temporal change in monthly climate suitability throughout the year around sites of importance for cattle tick. Murwillumbah, Kyogle, Boorook, and Casino are in the cattle tick region and Grafton is south of the cattle tick region. An analysis of future climate suitability around these sites provides insights into potential future monthly trends by 2050.

- **Minimal to moderate increases** in climate suitability are likely in the autumn and winter months for all sites under both emissions scenarios (*moderate to high confidence*).
- **Historical climate suitability is likely to be maintained** during all remaining months across all the sites under both emissions scenarios (*moderate to high confidence*).

Cattle tick – number of highly suitable months



Findings: The number of highly suitable months for cattle tick varies across the state. In the cattle tick region and coastal NSW, most months have historically been highly suitable, which is expected to increase in the future. These changes are due to improved climate suitability in some months, and they could affect the timing of cattle tick activity and influence strategies for treating and controlling cattle ticks. In contrast, inland NSW is projected to experience negligible change, maintaining 0 to 1 highly suitable month for cattle ticks.

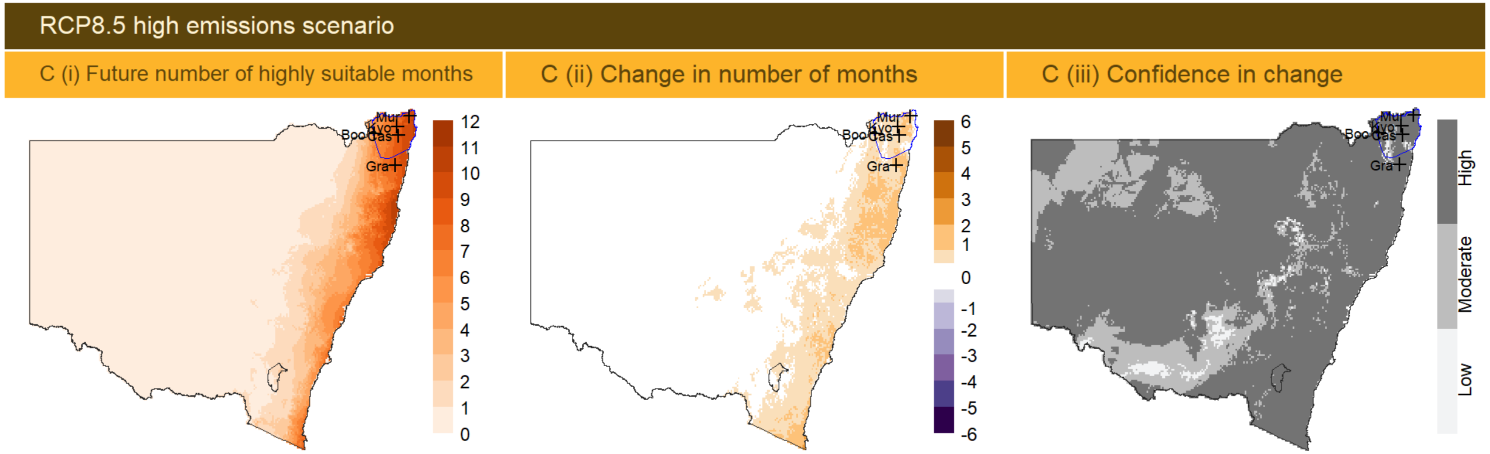
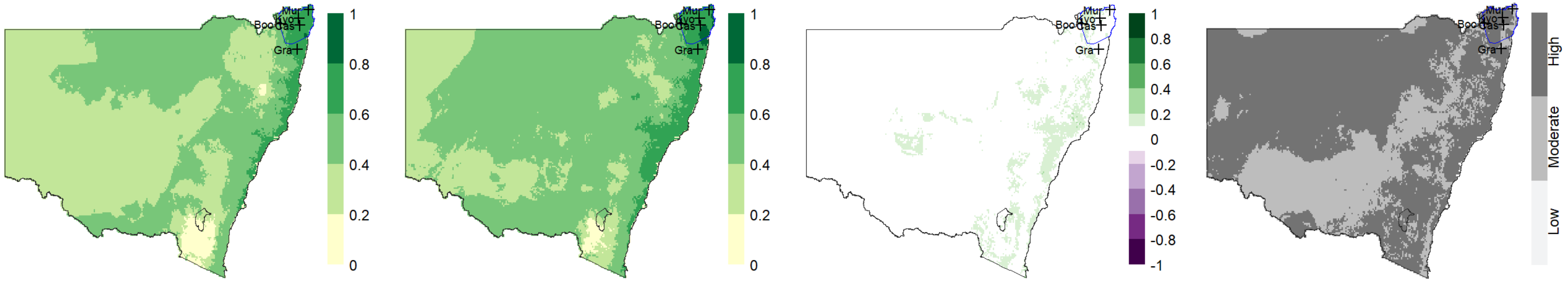


Figure 11: Number of highly suitable months for cattle tick, counting the months in which climate suitability is greater than or equal to 0.6. The panel is comprised of 7 maps: A) shows the historic number of highly suitable months; B) and C) show the future number of highly suitable months for the intermediate and high emissions scenarios, respectively; (i) shows future number of highly suitable months, (ii) shows the projected 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). Sites representing the cattle tick region are marked by black crosses, and the blue polygon shows the cattle tick region. The sites are Boorook (Boo), Kyogle (Kyo), Murwillumbah (Mur), Casino (Cas) and Grafton (Gra).

Cattle tick – overall climate suitability for May

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: Climate suitability is expected to minimally to moderately increase in the cattle tick region, along the coast and parts of inland NSW. Warmer mean temperatures and changes in relative humidity during all life stages of the ticks in the future, lead to this increase in May. These changes in this month are expected to extend the period when the climate remains highly suitable for ticks in the cattle tick region. This could potentially impact livestock industries and tick control within this region.

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

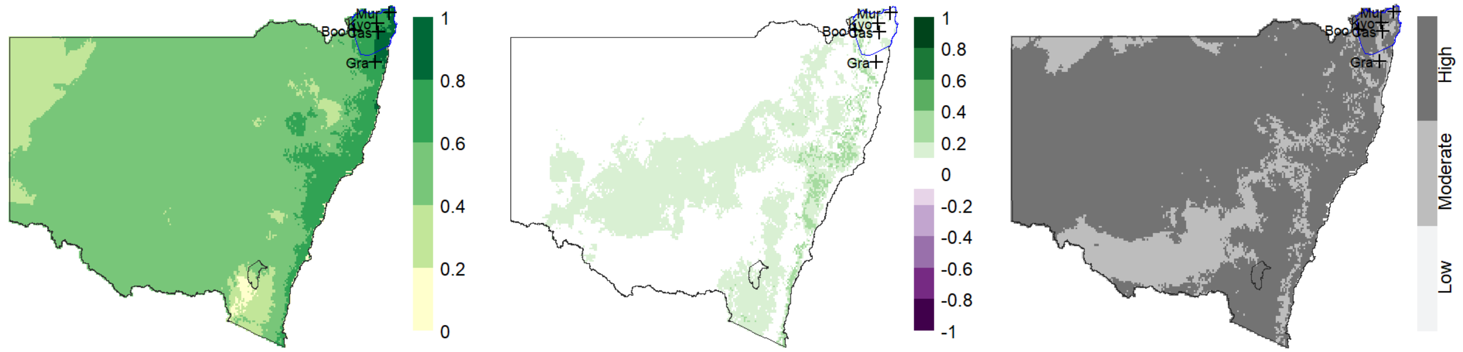
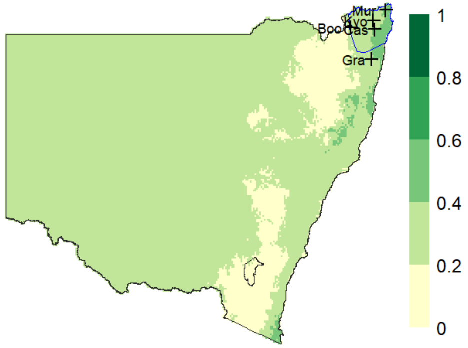


Figure 12: Overall climate suitability for cattle tick in May. The panel is comprised of 7 maps: A) shows the historic climate suitability; B) and C) shows future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability, (ii) shows the 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). Sites representing the cattle tick region are marked by black crosses, and the blue polygon shows the cattle tick region. The sites are Boorook (Boo), Kyogle (Kyo), Murwillumbah (Mur), Casino (Cas) and Grafton (Gra).

Cattle tick – overall climate suitability for August

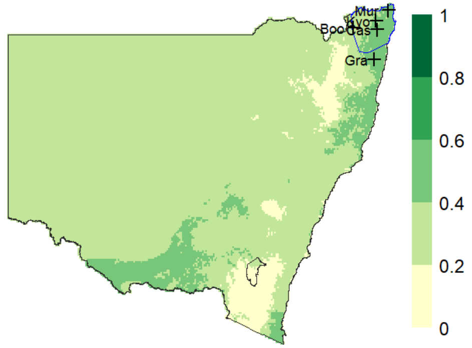
Historical

A) Climate suitability

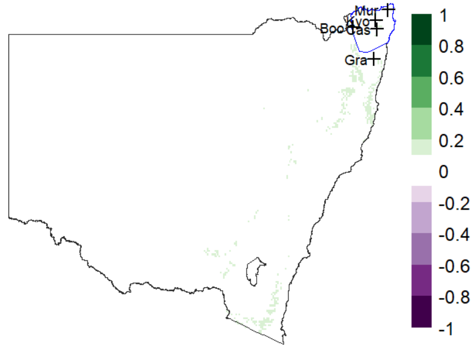


RCP4.5 intermediate emissions scenario

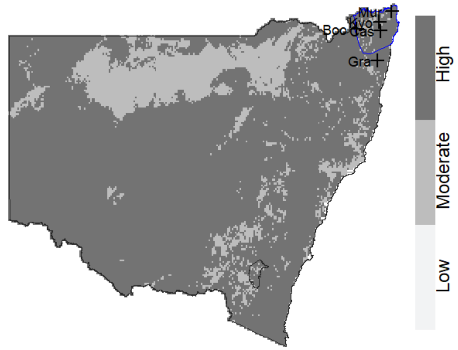
B (i) Future climate suitability



B (ii) Change in climate suitability



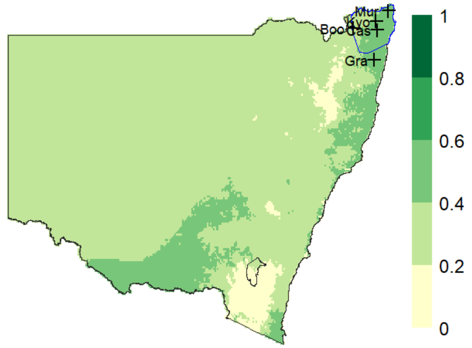
B (iii) Confidence in change



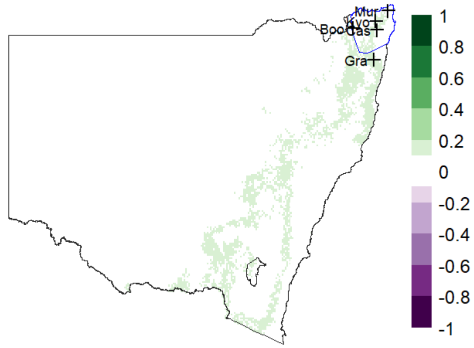
Findings: a minimal increase in climate suitability is expected in the cattle tick region, along the NSW coast and in parts of the Great Dividing Range. Warmer temperatures and changes in relative humidity during all life stages of the tick is expected to cause this increase in August, as well as in June and July. These changes suggest that the future winter climate will be more suitable for cattle ticks, leading to ticks becoming active earlier. This shift is likely to affect the region's livestock industries and tick control efforts.

RCP8.5 high emissions scenario

C (i) Future climate suitability



C (ii) Change in climate suitability



C (iii) Confidence in change

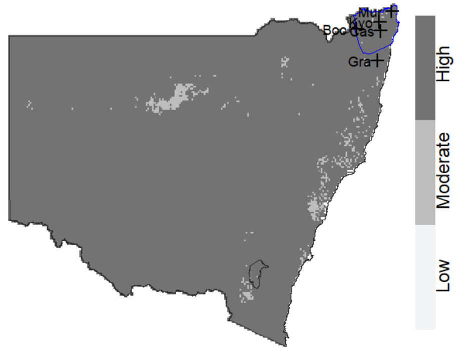


Figure 13: Overall climate suitability for cattle tick in August. The panel is comprised of 7 maps: A) shows the historic climate suitability; B) and C) shows future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability, (ii) shows the 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). Sites representing the cattle tick region are marked by black crosses, and the blue polygon shows the cattle tick region. The sites are Boorook (Boo), Kyogle (Kyo), Murwillumbah (Mur), Casino (Cas) and Grafton (Gra).

Cattle tick overall climate suitability calendar

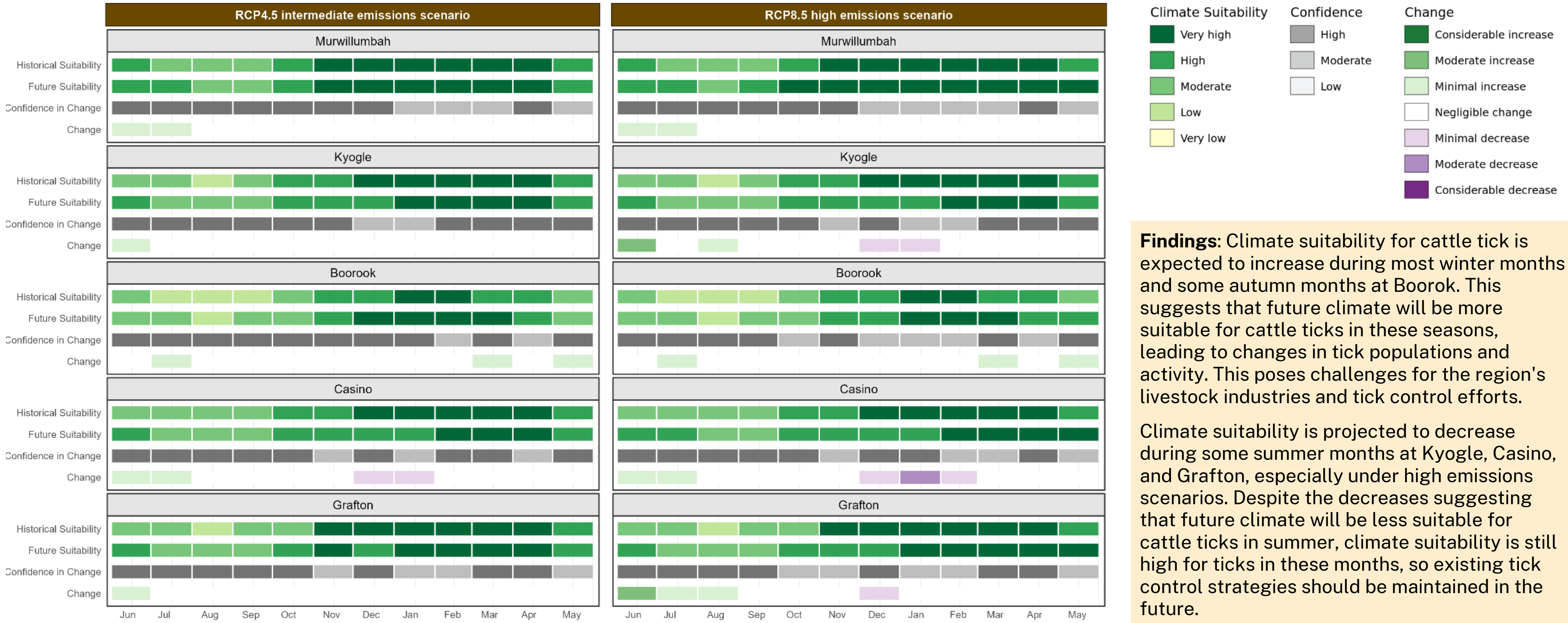


Figure 14: Climate suitability calendar for the overall cattle tick model. The climate suitability calendar displays the historical and future climate suitability, change in suitability and confidence in change for each site of interest. It shows two emissions scenarios, the intermediate emissions scenario, RCP4.5, on the left and the high emissions scenario, RCP8.5, on the right. The climate suitability categories represent median values within a 10km radius of each location.

Findings: Climate suitability for cattle tick is expected to increase during most winter months and some autumn months at Boorok. This suggests that future climate will be more suitable for cattle ticks in these seasons, leading to changes in tick populations and activity. This poses challenges for the region's livestock industries and tick control efforts.

Climate suitability is projected to decrease during some summer months at Kyogle, Casino, and Grafton, especially under high emissions scenarios. Despite the decreases suggesting that future climate will be less suitable for cattle ticks in summer, climate suitability is still high for ticks in these months, so existing tick control strategies should be maintained in the future.

Historically, cattle tick populations have not faced climatic restrictions from spring to autumn, and this is likely to be maintained in the future, with most sites having high to very high during these months at all sites. Livestock industries in these regions are likely to experience a similar impact from these ticks during these months as they have had in the past.

Climate impacts on life stages

Changes in climate suitability are likely across all key life stages of cattle tick by 2050 under both emissions scenarios.

Adult

The adult female tick detaches from its host and processes its blood meal into eggs, which may take a few days to a month, depending on temperature and humidity. A single female adult tick can lay up to 3000 eggs. Egg laying by the adult tick during the summer may take just a few days, while winter may take weeks, depending on environmental conditions.

The number of highly suitable months for the adult life stage (Appendix Figure A1) in the cattle tick region and along the east coast is likely to increase by 1 to 2 months per year under both emissions scenarios (*moderate to high confidence*). The rest of the state is likely to see negligible change in the number of highly suitable months (*moderate to high confidence*).

The climate suitability calendar for the adult life stage, Figure 15, shows the monthly climate suitability and expected changes throughout the year around representative sites of importance for cattle tick. Key results include:

- **Minimal to moderate increases** in climate suitability across the winter months in Murwillumbah, Kyogle, Boorook, Casino and Grafton (*high confidence*), in the autumn months for Kyogle and Boorook and in November for Boorook (*high confidence*).
- **Historical climate suitability is likely to be maintained** during all remaining months across all the sites under both emissions scenarios (*moderate to high confidence*).

Egg

Eggs are laid in the grass of the pasture by adult ticks. The egg stage is highly sensitive to temperature and relative humidity, as these environmental conditions significantly impact their viability and the timing of hatching. In cold or dry conditions, only a small proportion of eggs hatch, due to desiccation of the eggs.

The number of highly suitable months for the egg life stage (Appendix Figure A2) is likely to increase by up to one month across the alpine region and parts of the north coast *(moderate to high confidence*). A small area of the southern Great Dividing Range is likely to experience a decrease of up to one month under the high emission scenario (*moderate confidence).* Negligible change is likely across the rest of state (*moderate to high confidence*).

The climate suitability calendar for the egg life stage, Figure 16, shows the monthly climate suitability and expected change throughout the year around representative sites of importance for cattle tick. Key results include:

- **Minimal increases** in climate suitability are likely at Murwillumbah during June under the high emissions scenario (*high confidence*).
- **Minimal decrease** in climate suitability is likely at Casino during the summer months under the high emissions scenario and at Grafton during December under the intermediate emissions scenario (*moderate to high confidence*).
- **Historical climate suitability is likely to be maintained** during the remaining months across all the sites, under both emissions scenarios (*moderate to high confidence*).

Larvae

Larvae can live for four to six months in warm, moist conditions but are sensitive to drying out in winter due to cold or dry conditions. After they hatch, they climb grass blades to find a host, waiting for animals to pass by so they can climb on.

The number of highly suitable months for the larval life stage (Appendix Figure A3) is likely to increase by up to two months along most of the Great Dividing Range and south coast *(moderate to high confidence*). A small area in the northern central region of the state is likely to experience a decrease of up to one month under both emissions scenarios (*moderate confidence*). The remainder of the state is likely to experience negligible change in climate suitability for cattle tick, under both emissions scenarios (*low to high confidence*).

The climate suitability calendar for the larval life stage, Figure 17, shows the monthly climate suitability and expected change throughout the year around representative sites of importance for cattle tick. Key results include:

- **Minimal increases** in climate suitability are likely at Murwillumbah, Kyogle, Casino and Grafton during September and at Boorook during November. Minimal increases are also likely during the winter months at Murwillumbah, Kyogle and Grafton under the high emissions scenario (*high confidence*).
- **Minimal to moderate decreases** in climate suitability are likely to occur in the summer months at Kyogle, Casino and Grafton under both emissions scenarios (*moderate to high confidence*).
- **Historical climate suitability is likely to be maintained** during the remaining months around all sites, under both emissions scenarios (*moderate to high confidence*).

Cattle tick – climate suitability calendar for adult life stage

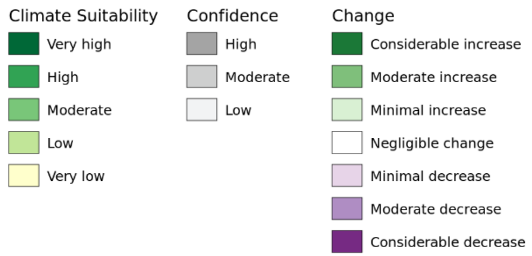


Figure 15: Climate suitability calendar for the cattle tick adult life stage. The climate suitability calendar displays the historical and future climate suitability, change in suitability and confidence in change for each site of interest. It shows two emissions scenarios, the intermediate emissions scenario, RCP4.5, on the left and the high emissions scenario, RCP8.5, on the right. The climate suitability categories represent median values within a 10km radius of each location.

Findings: Climate suitability for adult ticks is expected to increase during most winter months at all sites, some autumn months at Kyogle and Boorook, and in November at Boorook. This suggests that future climate conditions will be more suitable for adult ticks during these months, leading to changes in tick populations and activity.

At all locations except Boorook, the period of high to very high suitability for ticks is projected to extend from October to June or July in the future. This situation presents challenges for the region's livestock industries and tick control efforts.

Historically, adult ticks have not experienced climatic restrictions from spring to autumn, and this is likely to be maintained into the future. High to very high suitability for adult ticks is expected at all sites during these months. Consequently, livestock industries in these regions are likely to face similar challenges from ticks in the coming months as they have in the past.

Cattle tick – climate suitability calendar for egg life stage

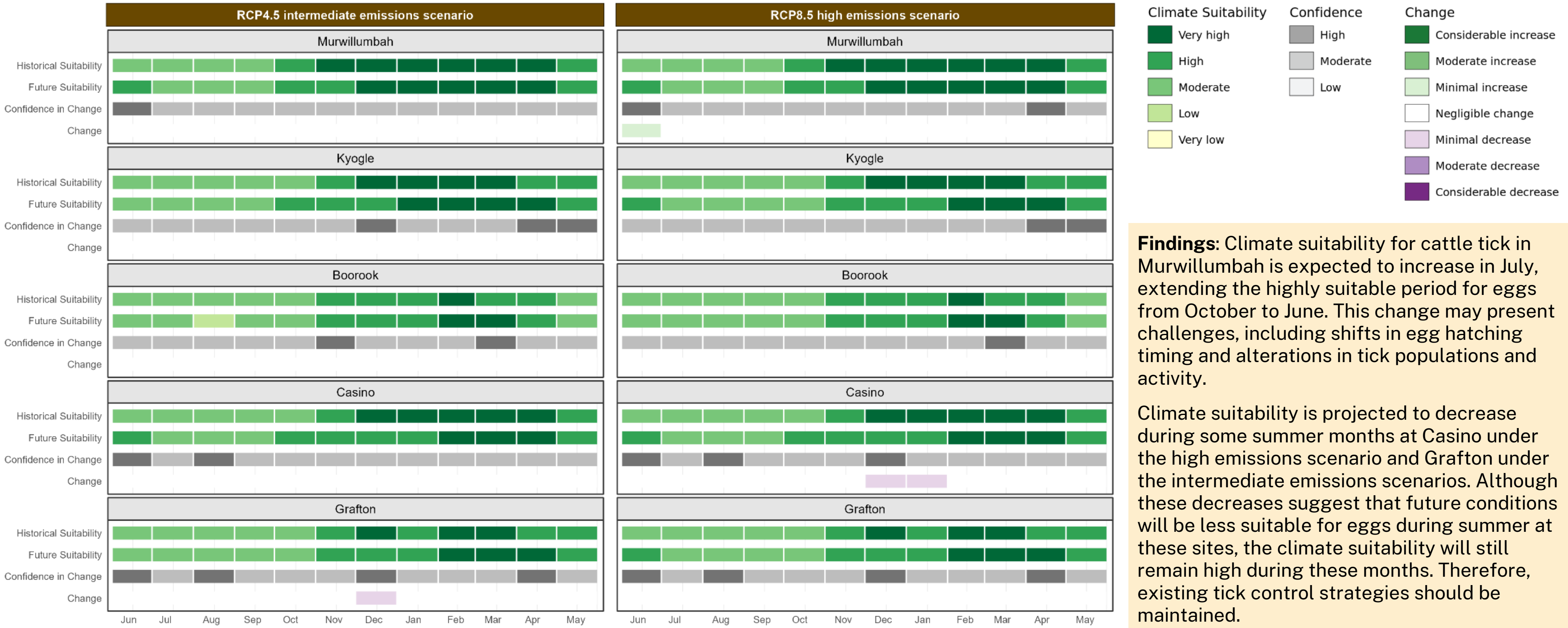


Figure 16: Climate suitability calendar for the cattle tick egg life stage. The climate suitability calendar displays the historical and future climate suitability, change in suitability and confidence in change for each site of interest. It shows two emissions scenarios, the intermediate emissions scenario, RCP4.5, on the left and the high emissions scenario, RCP8.5, on the right. The climate suitability categories represent median values within a 10km radius of each location.

Findings: Climate suitability for cattle tick in Murwillumbah is expected to increase in July, extending the highly suitable period for eggs from October to June. This change may present challenges, including shifts in egg hatching timing and alterations in tick populations and activity.

Climate suitability is projected to decrease during some summer months at Casino under the high emissions scenario and Grafton under the intermediate emissions scenarios. Although these decreases suggest that future conditions will be less suitable for eggs during summer at these sites, the climate suitability will still remain high during these months. Therefore, existing tick control strategies should be maintained.

Historically, eggs have faced few climatic restrictions from October to May, and this is likely to continue, with all sites experiencing high to very high suitability. Suitability will remain moderate from June to October. As a result, livestock industries in these regions are likely to face similar impacts from egg survival during these months as they have in the past.

Cattle tick – climate suitability calendar for larval life stage

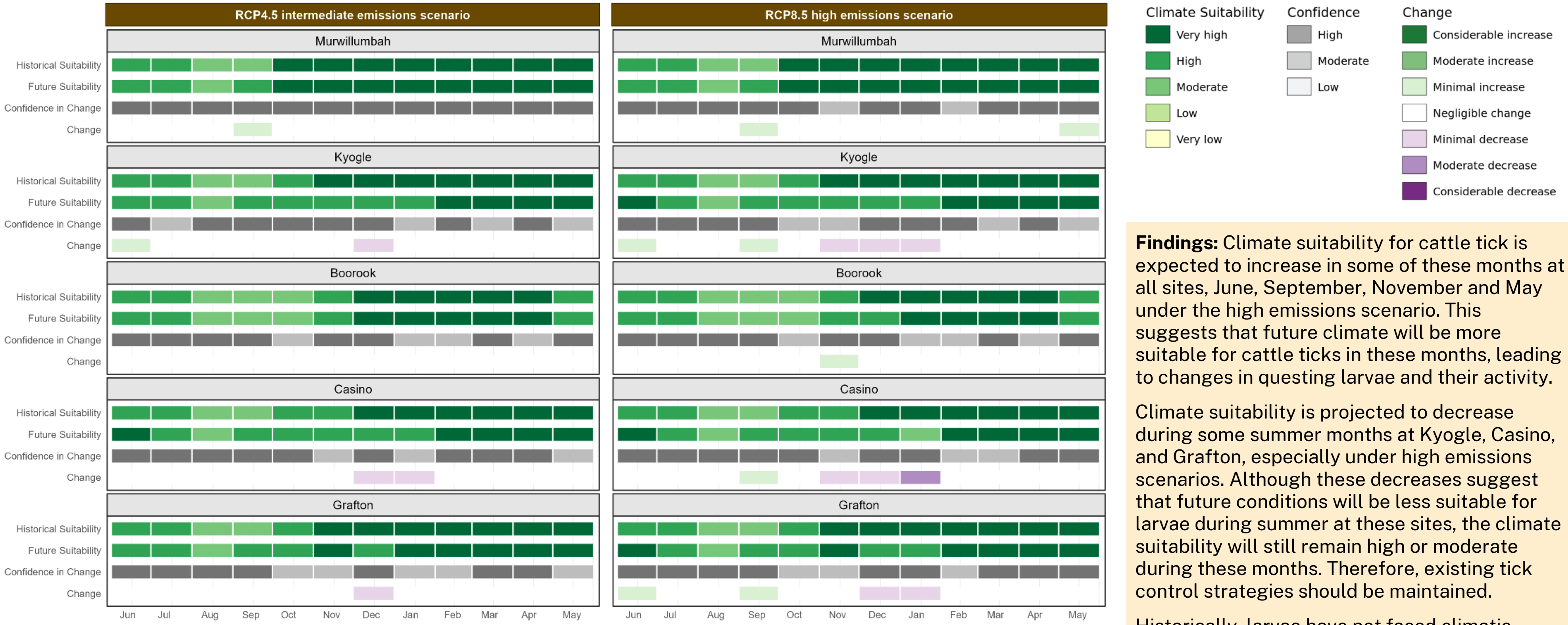


Figure 17: Climate suitability calendar for the cattle tick larval life stage. The climate suitability calendar displays the historical and future climate suitability, change in suitability and confidence in change for each site of interest. It shows two emissions scenarios, the intermediate emissions scenario, RCP4.5, on the left and the high emissions scenario, RCP8.5, on the right. The climate suitability categories represent median values within a 10km radius of each location.

Findings: Climate suitability for cattle tick is expected to increase in some of these months at all sites, June, September, November and May under the high emissions scenario. This suggests that future climate will be more suitable for cattle ticks in these months, leading to changes in questing larvae and their activity.

Climate suitability is projected to decrease during some summer months at Kyogle, Casino, and Grafton, especially under high emissions scenarios. Although these decreases suggest that future conditions will be less suitable for larvae during summer at these sites, the climate suitability will still remain high or moderate during these months. Therefore, existing tick control strategies should be maintained.

Historically, larvae have not faced climatic restrictions from September to July, and this is likely to remain the case in the future, with most sites having high to very high climate suitability during these months. Livestock industries in these regions are likely to experience a similar impact from these larval survival during these months as they have had in the past.

Key findings and insights from a changing climate

The results of this study provide valuable insights into the historical and potential future climate suitability for cattle tick in NSW.

Key insights for the cattle tick region

Cattle tick infestations have historically only been found in the far northeast of NSW. A key observation is that this region consistently has a high number of months that are highly suitable for cattle ticks. By 2050, this number is expected to increase by an additional 1 to 2 months (Figure 11). This increase is attributed to changes in average temperatures and relative humidity, resulting in more suitable climate conditions for both adult and larval stages of the ticks in the coming years. In this region, cattle ticks currently do not face severe climatic restrictions from spring through autumn, and this trend is expected to continue. Future projections indicate that increased climate suitability may extend this favourable period, resulting in an increase in the number of highly suitable months during winter and autumn for most life stages of cattle tick.

Key findings beyond the cattle tick region

A key observation in areas outside the current cattle tick region is that the number of months with highly suitable conditions is likely to increase by 2050, as shown in Grafton in Figure 11. These increases in climate suitability are likely to occur along the Great Dividing Range and in coastal NSW. The patterns of climate suitability observed within the cattle tick region are also seen at Grafton and other regions, suggesting that the climate conditions in certain areas of NSWs would support cattle ticks and most of their life stages. This situation could pose challenges, as it may lead to the expansion of the cattle tick range beyond its current limits in NSW.

Key findings across life stages

Climate change will affect all life stages of cattle ticks. Increases in climate suitability due to changes in mean temperatures and relative humidity for all life stages, will lead to more suitable conditions in the future, especially during winter and autumn months. The climate suitability in most parts of the cattle tick region is expected to be high to very high from spring through autumn, meaning that tick life stages will not face severe climatic restrictions during this time. Although there may be some decreases in climate suitability during the summer months for the egg and larval stages, these reductions are unlikely to significantly impact these stages, as their suitability remains high throughout the summer.

Expected challenges for primary industries

The effects of cattle tick on the beef and dairy industries in NSW will depend on many factors, including:

- the future distribution of those industries,
- potential changes in production timings, and
- the overlap between susceptible cattle and dairy production stages and the life stages of cattle tick.

Increased suitability under a future climate is likely to lead to a greater impact of cattle ticks on beef and dairy industries within the cattle tick region in NSW.

An increase in climate suitability to the south of the current cattle tick region could lead to significant new impacts on the beef and dairy industries in NSW. Those industries may need education on the increasing risk of cattle ticks and advice on management strategies if a warmer future facilitates a southward spread.

Cattle tick: where to from here?

Future priorities

Assessing future climate suitability for cattle tick is a prerequisite for making effective planning decisions and developing management strategies to address future climate change impacts.

The results presented in this report have identified changes in climate suitability for cattle tick that are likely to have a moderate impact on the beef and dairy industries in NSW. The NSW North Coast beef and dairy industry is likely to need higher levels of investment in the near future to ensure that education, including new management techniques and adaption options, and control methods for cattle tick, is undertaken efficiently and effectively while conditions for ticks continue to improve. Implementing broad-reaching cattle tick education programs are required to raise awareness of the increased risk and convey the management strategies for regions to the south that have not previously been affected but are likely to become suitable under climate change.

Additional work is also needed to understand the financial and market access impacts of increased pressure from potential cattle tick infestation.

New management approaches for cattle tick must be carefully planned, evaluated, and deployed to minimise disruptions and costs. Producers may face challenges from market pressures that require reassessment of business plans in response to chosen options.

Addressing the gaps, barriers and challenges

The information generated by this project has helped to identify future changes in climate suitability for cattle tick. 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 cattle tick model used here. The following areas are deemed key knowledge gaps in need of further research:

- Low minimum and high maximum temperatures, combined with relative humidity, significantly impact ticks. While the effects of optimal temperatures and humidity are well documented, the limits of ticks' tolerance to extreme conditions are not fully understood.
- Impact of rain and heavy rainfall on all life stages.

Many studies have been conducted under lab conditions, which may differ from those in the field. Some studies also lack clarity on whether stated temperatures were minimum, mean or maximum.

This report aims to highlight such gaps to assist in directing future research and project development. It was not possible to cover all biosecurity risks that are important to NSW. Consideration should be given to modelling other significant biosecurity risks, like those listed in the National Priority List of Exotic Environmental Pests, Weeds and Diseases[10]. Expanding the range of the current modelling to Australia-wide would provide valuable information for future industry planning and assist with inter-jurisdictional engagement if climate change is likely to shift biosecurity risks into new geographic regions.

[10] The National Priority List of Exotic Environmental Pests, Weeds and Diseases, https://www.agriculture.gov.au/biosecurity-trade/policy/environmental/priority-list

Conclusion

The Climate Vulnerability Assessment provides important baseline information to support state, regional and strategic industry-level planning for climate change, highlighting where management and investment should be prioritised to sustain eradication and containment efforts and to limit the impacts on the beef and dairy industries of changing climate suitability for cattle tick in NSW. Future efforts are essential to support these communities and improve biosecurity measures to prevent ticks from establishing in NSW.

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

DPIRD will use these findings to work 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 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 on the website.

Other Climate Vulnerability Assessments that may be of particular interest to cattle tick are the impacted hosts:

- Beef Cattle
- Dairy Cow

An accompanying report on NSW Drought in a Changing Climate provides a comprehensive understanding of how drought frequency and duration may change as a result of climate change.

Contact us

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

Acknowledgements

We thank the four experts who participated in the cattle tick 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 DPIRD staff who participated in the DPIRD Biosecurity Team: Andrew Eliot, Andrew Sanger, Anil Raghavendra, Fiona Lidbetter, Jim Rothwell, Jane Bennett, Karen Kirkby, Kurt Lindbeck, Polychronis Rempoulakis, Samantha Currie, Scott Charlton, Shannon Mulholland, Stephen Johnson and Will Cuddy.

We thank the Climate Vulnerability Assessment team for driving this project from inception to completion over the last five years, individually acknowledging each team member: Jane Kelley, Bethany Ellis, Samantha Currie, David Allingham, Joanna Pardoe, Rebecca Darbyshire, Gary Allan, Mary Timms, James Lawson, Lachlan Philips, Rachael Young, Paris Capell and Chris Nunn.

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NSW GOVERNMENT

Appendix

Figure A1. Number of Highly Suitable Months for cattle tick adult stage

The number of highly suitable months counts the months in which climate suitability is greater than or equal to 0.6. The panel is comprised of 7 maps: A) shows the historic 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 projected 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). Sites representing the cattle tick region are marked by black crosses, and the blue polygon shows the cattle tick region. The sites are Boorook (Boo), Kyogle (Kyo), Murwillumbah (Mur), Casino (Cas) and Grafton (Gra).

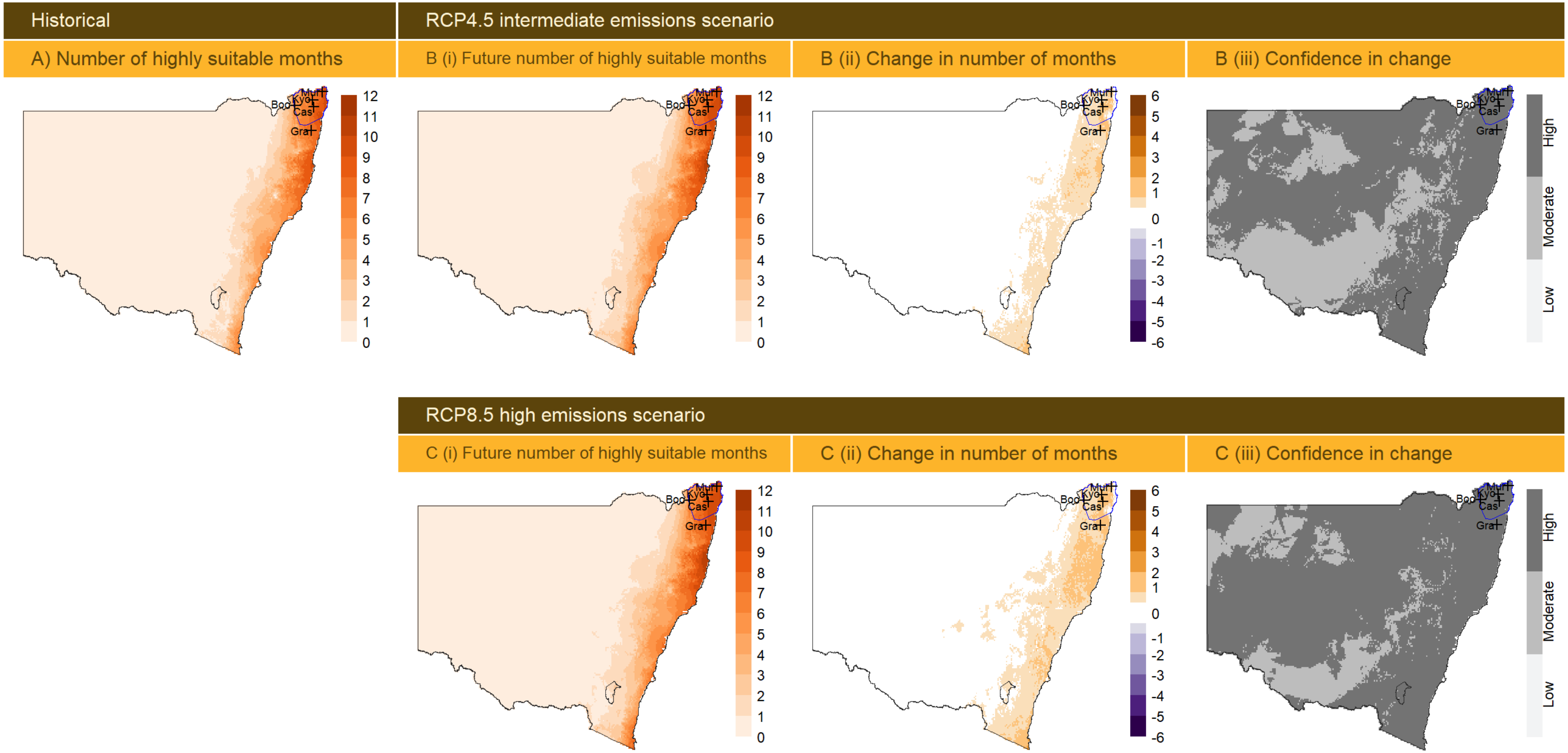


Figure A2. Number of Highly Suitable Months for cattle tick egg stage

The number of highly suitable months counts the months in which climate suitability is greater than or equal to 0.6. The panel is comprised of 7 maps: A) shows the historic 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 projected 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). Sites representing the cattle tick region are marked by black crosses, and the blue polygon shows the cattle tick region. The sites are Boorook (Boo), Kyogle (Kyo), Murwillumbah (Mur), Casino (Cas) and Grafton (Gra).

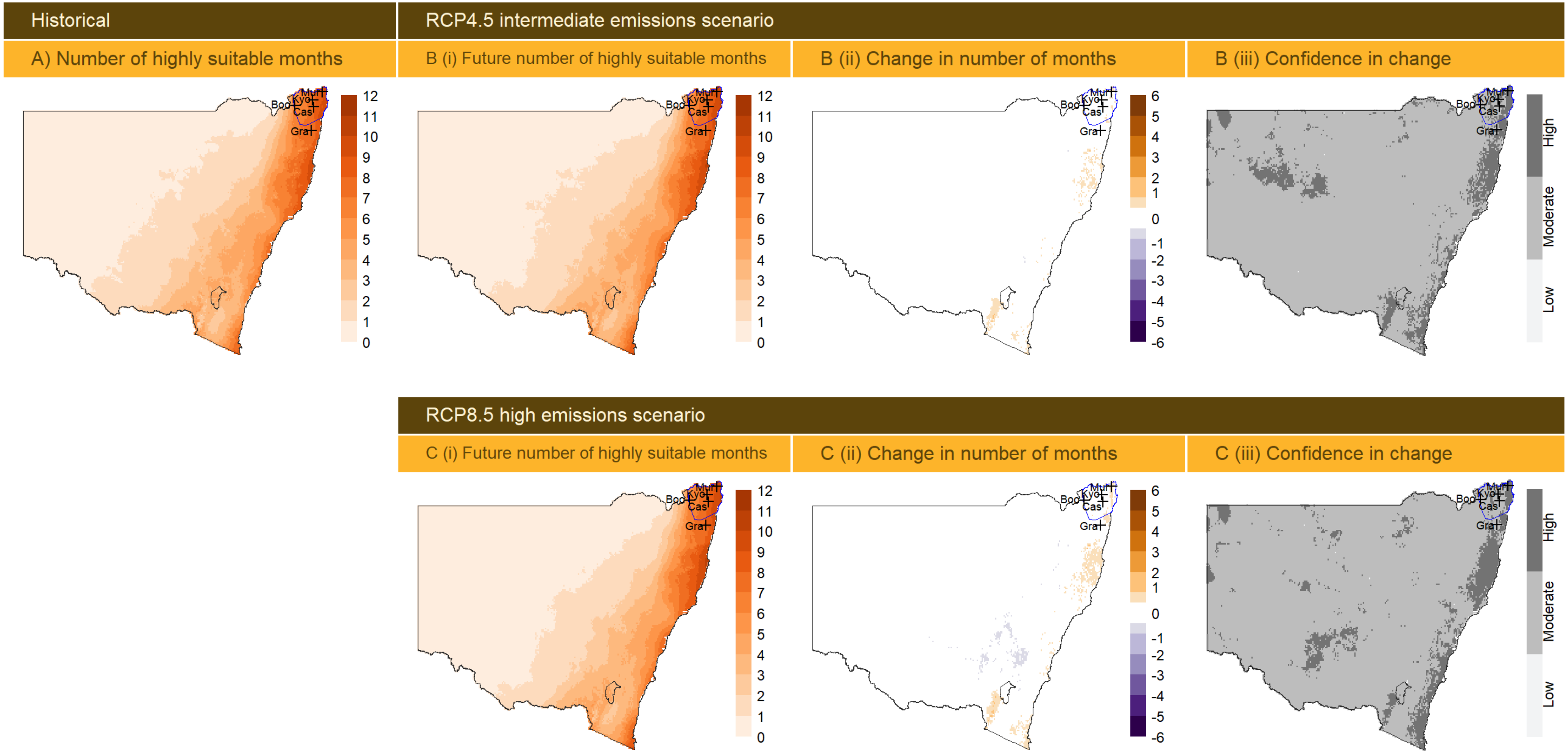


Figure A3: Number of highly suitable months for cattle tick larvae life stage

The number of highly suitable months counts the months in which climate suitability is greater than or equal to 0.6. The panel is comprised of 7 maps: A) shows the historic 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 projected 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). Sites representing the cattle tick region are marked by black crosses, and the blue polygon shows the cattle tick region. The sites are Boorook (Boo), Kyogle (Kyo), Murwillumbah (Mur), Casino (Cas) and Grafton (Gra).

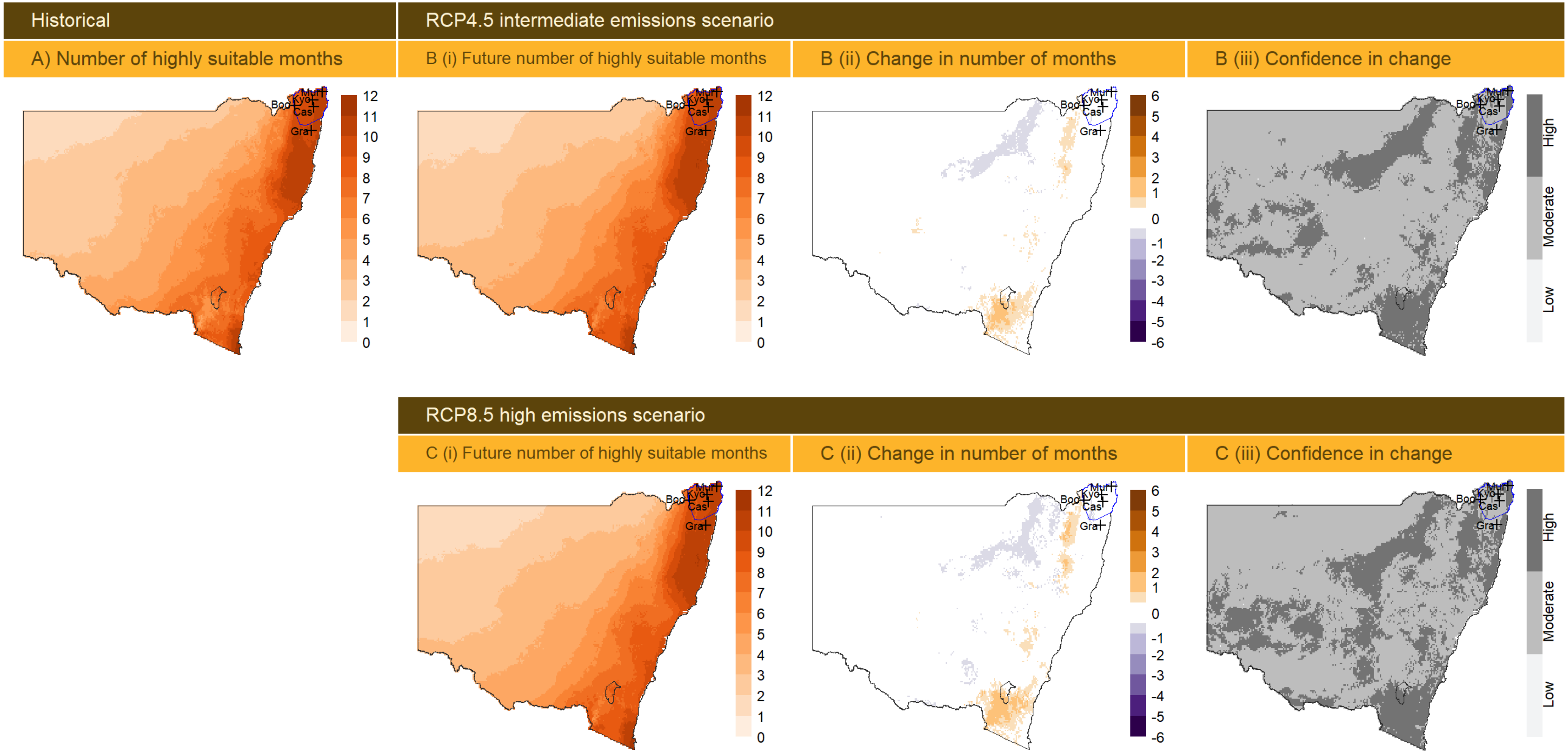


Figure A4. January climate suitability for cattle tick

The panel is comprised of 7 maps: A) shows the historic climate suitability; B) and C) shows 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). Sites representing the cattle tick region are marked by black crosses, and the blue polygon shows the cattle tick region. The sites are Boorook (Boo), Kyogle (Kyo), Murwillumbah (Mur), Casino (Cas) and Grafton (Gra).

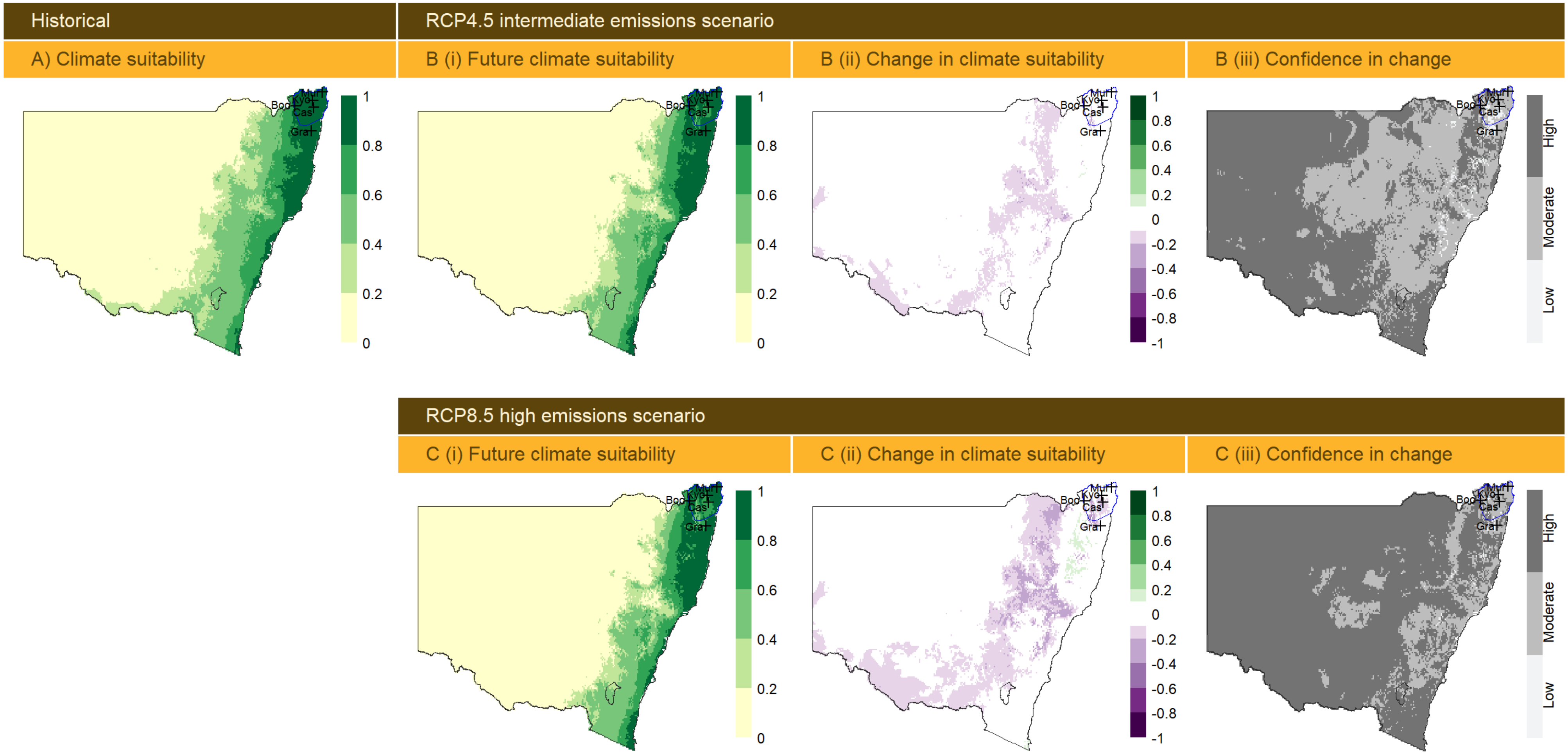


Figure A5. February climate suitability for cattle tick

The panel is comprised of 7 maps: A) shows the historic climate suitability; B) and C) shows 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). Sites representing the cattle tick region are marked by black crosses, and the blue polygon shows the cattle tick region. The sites are Boorook (Boo), Kyogle (Kyo), Murwillumbah (Mur), Casino (Cas) and Grafton (Gra).

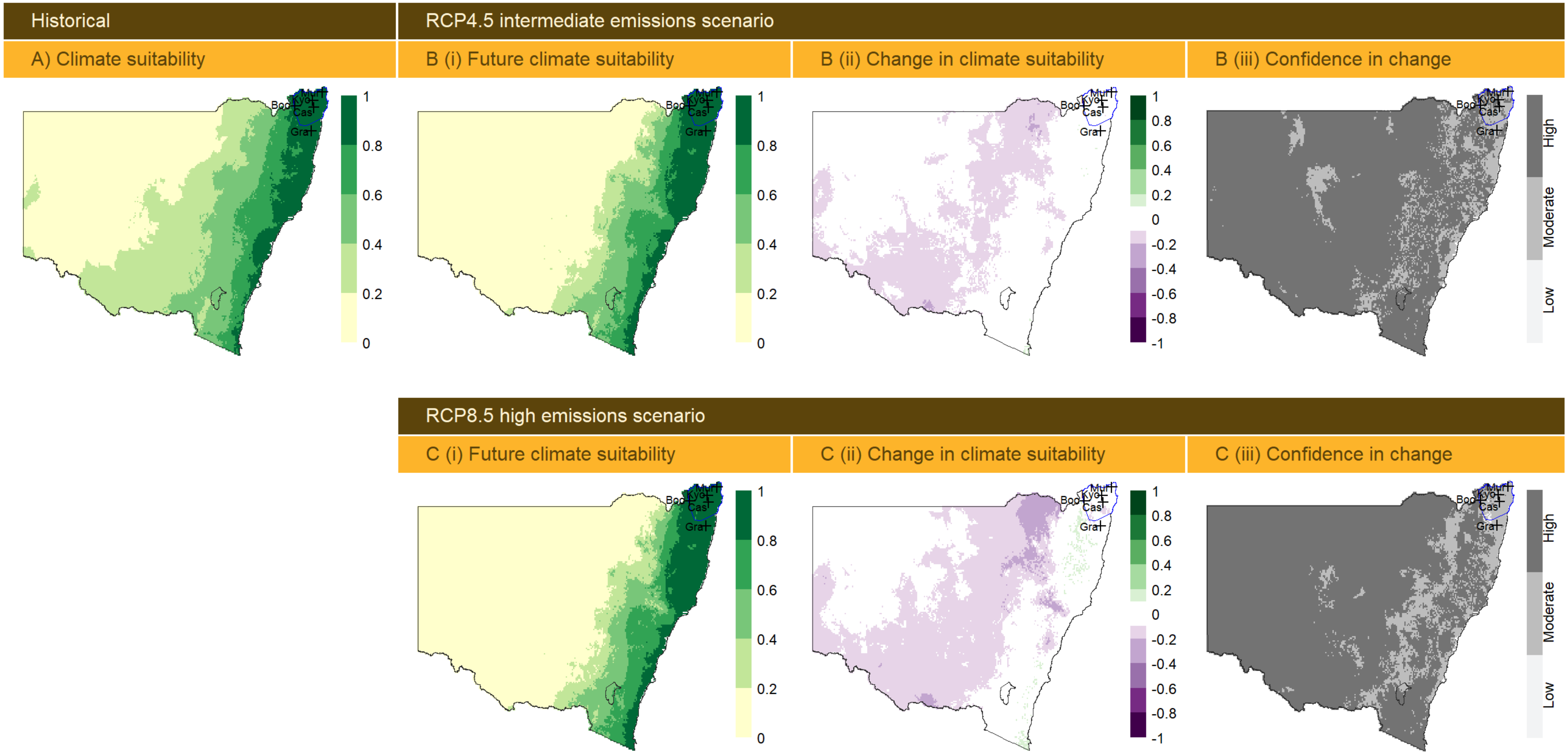


Figure A6. March climate suitability for cattle tick

The panel is comprised of 7 maps: A) shows the historic climate suitability; B) and C) shows 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). Sites representing the cattle tick region are marked by black crosses, and the blue polygon shows the cattle tick region. The sites are Boorook (Boo), Kyogle (Kyo), Murwillumbah (Mur), Casino (Cas) and Grafton (Gra).

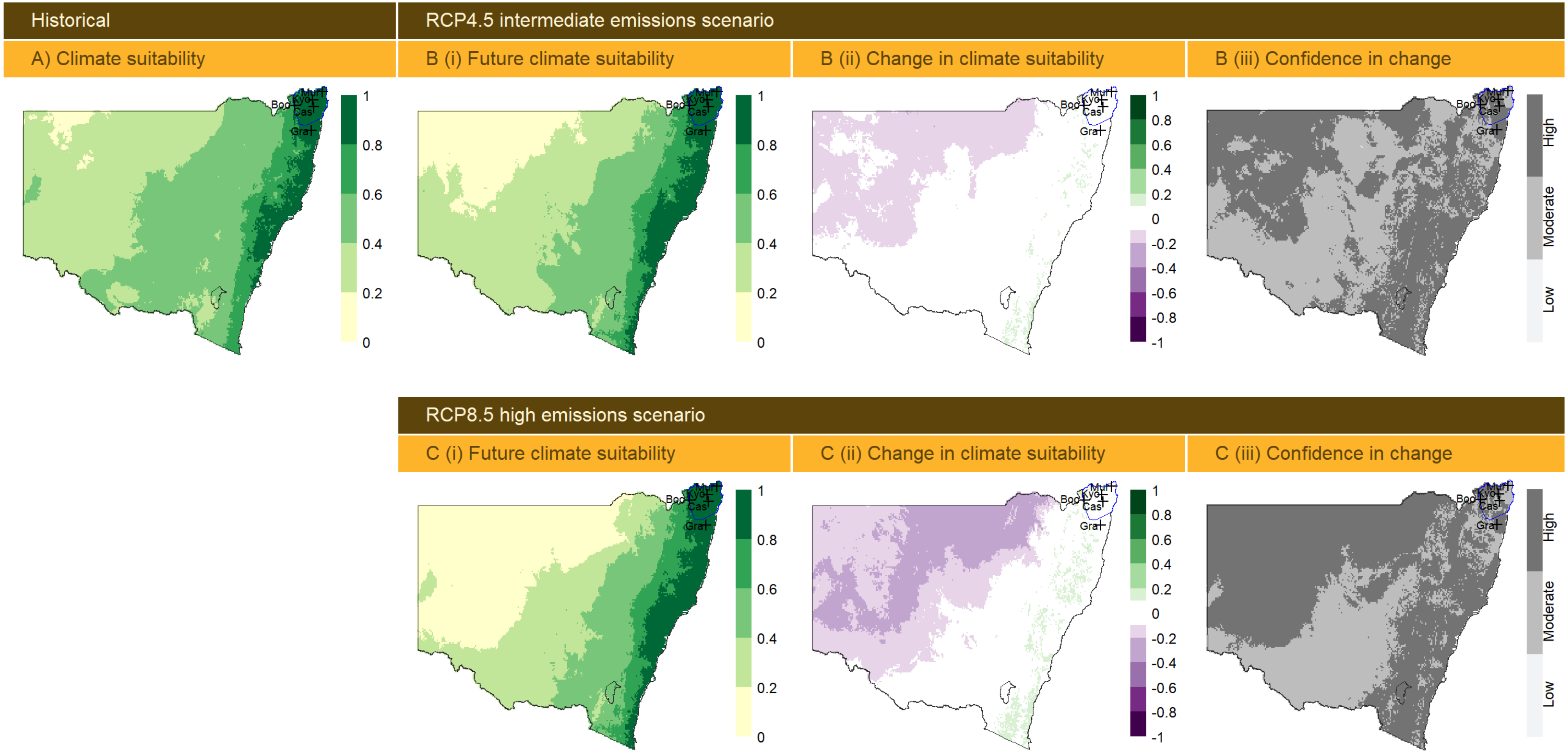


Figure A7. April climate suitability for cattle tick

The panel is comprised of 7 maps: A) shows the historic climate suitability; B) and C) shows 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). Sites representing the cattle tick region are marked by black crosses, and the blue polygon shows the cattle tick region. The sites are Boorook (Boo), Kyogle (Kyo), Murwillumbah (Mur), Casino (Cas) and Grafton (Gra).

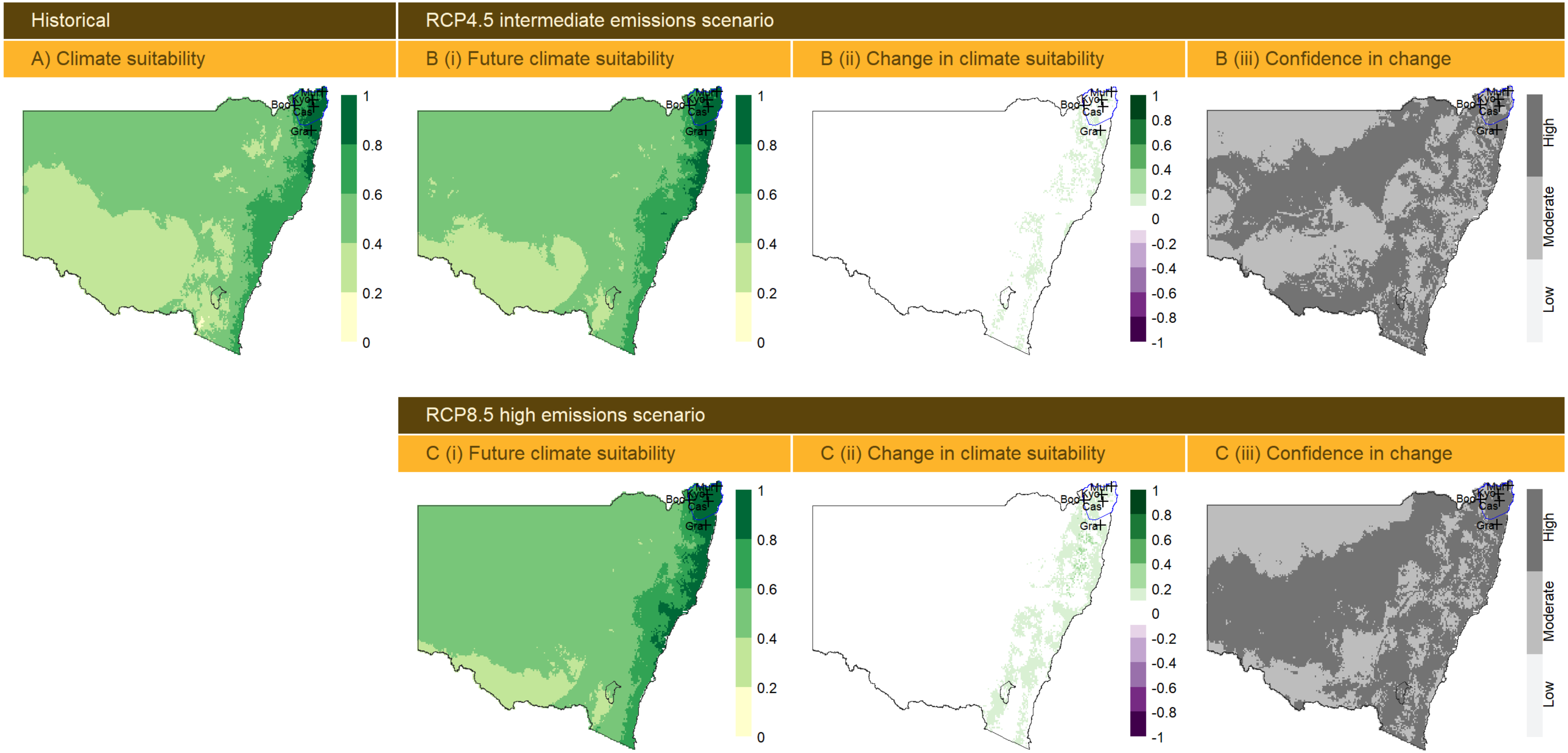


Figure A8. May climate suitability for cattle tick

The panel is comprised of 7 maps: A) shows the historic climate suitability; B) and C) shows 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). Sites representing the cattle tick region are marked by black crosses, and the blue polygon shows the cattle tick region. The sites are Boorook (Boo), Kyogle (Kyo), Murwillumbah (Mur), Casino (Cas) and Grafton (Gra).

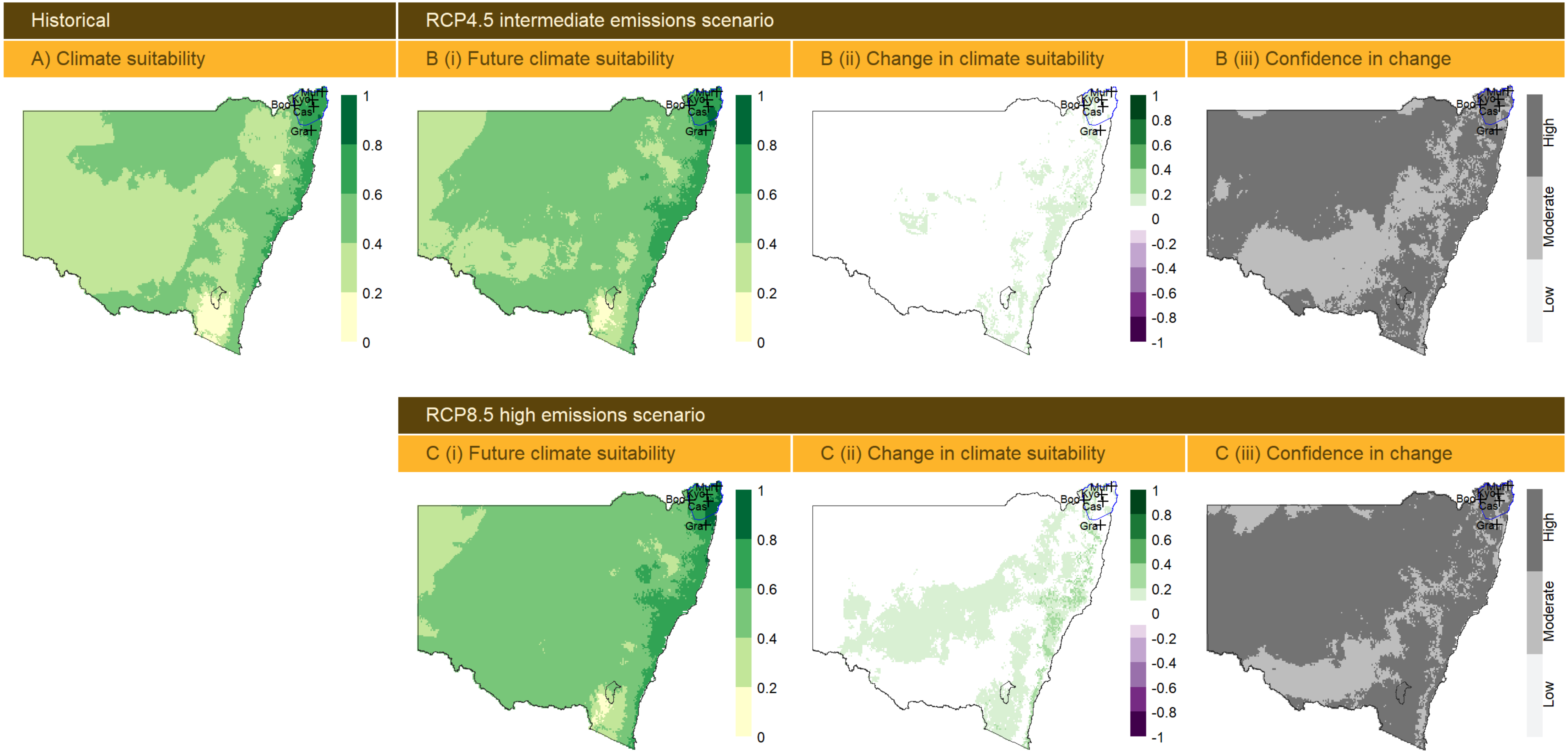


Figure A9. June climate suitability for cattle tick

The panel is comprised of 7 maps: A) shows the historic climate suitability; B) and C) shows 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). Sites representing the cattle tick region are marked by black crosses, and the blue polygon shows the cattle tick region. The sites are Boorook (Boo), Kyogle (Kyo), Murwillumbah (Mur), Casino (Cas) and Grafton (Gra).

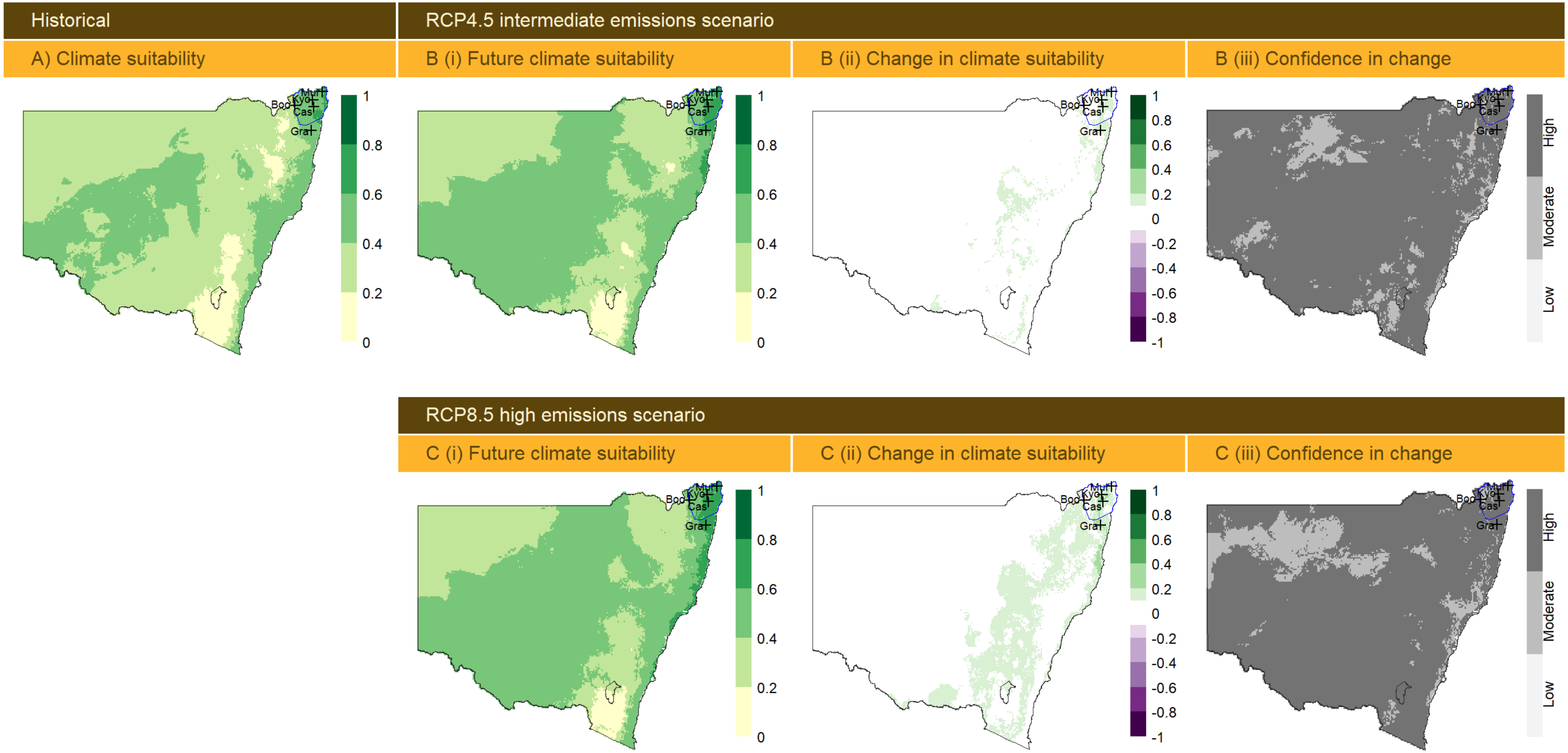


Figure A10. July climate suitability for cattle tick

The panel is comprised of 7 maps: A) shows the historic climate suitability; B) and C) shows 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). Sites representing the cattle tick region are marked by black crosses, and the blue polygon shows the cattle tick region. The sites are Boorook (Boo), Kyogle (Kyo), Murwillumbah (Mur), Casino (Cas) and Grafton (Gra).

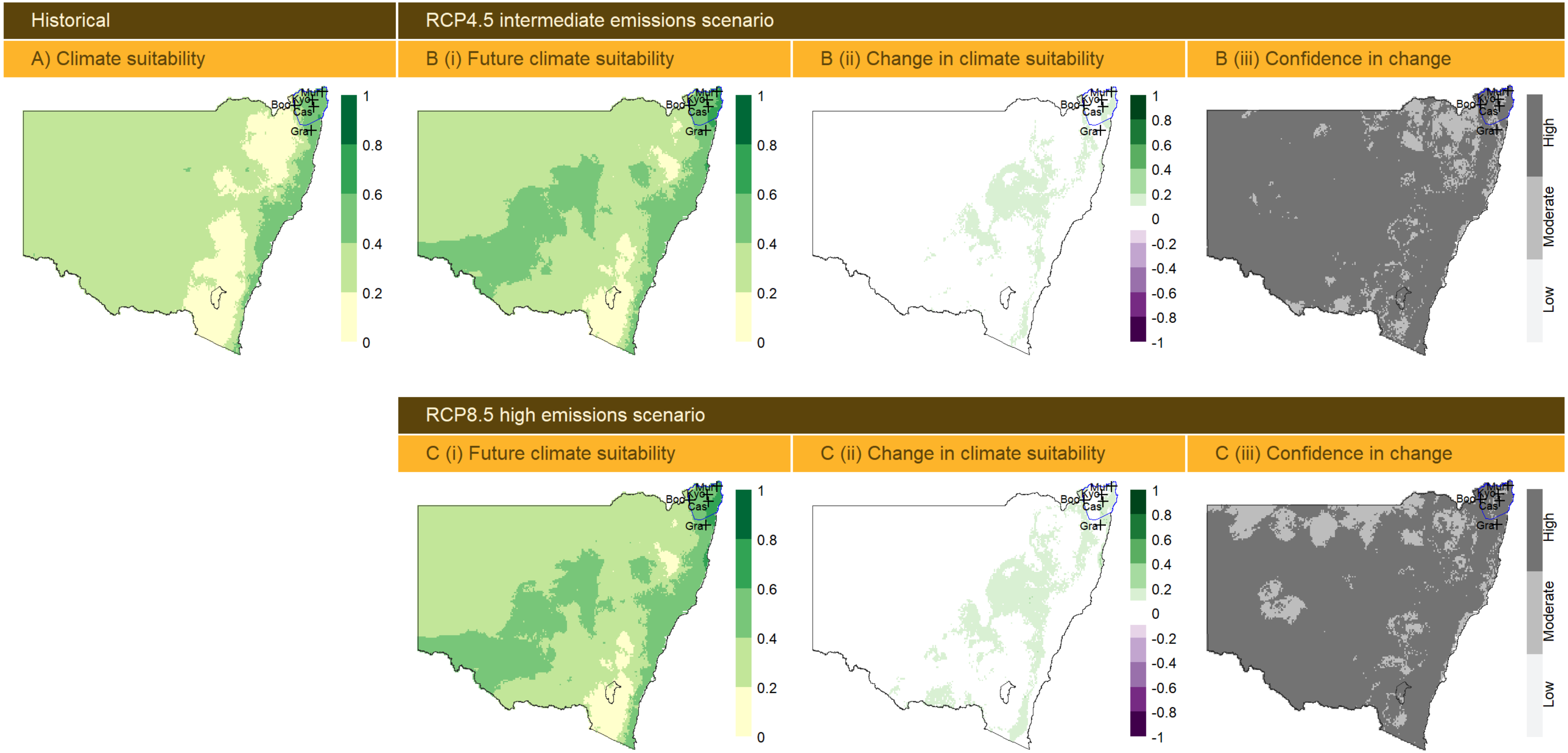


Figure A11. August climate suitability for cattle tick

The panel is comprised of 7 maps: A) shows the historic climate suitability; B) and C) shows 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). Sites representing the cattle tick region are marked by black crosses, and the blue polygon shows the cattle tick region. The sites are Boorook (Boo), Kyogle (Kyo), Murwillumbah (Mur), Casino (Cas) and Grafton (Gra).

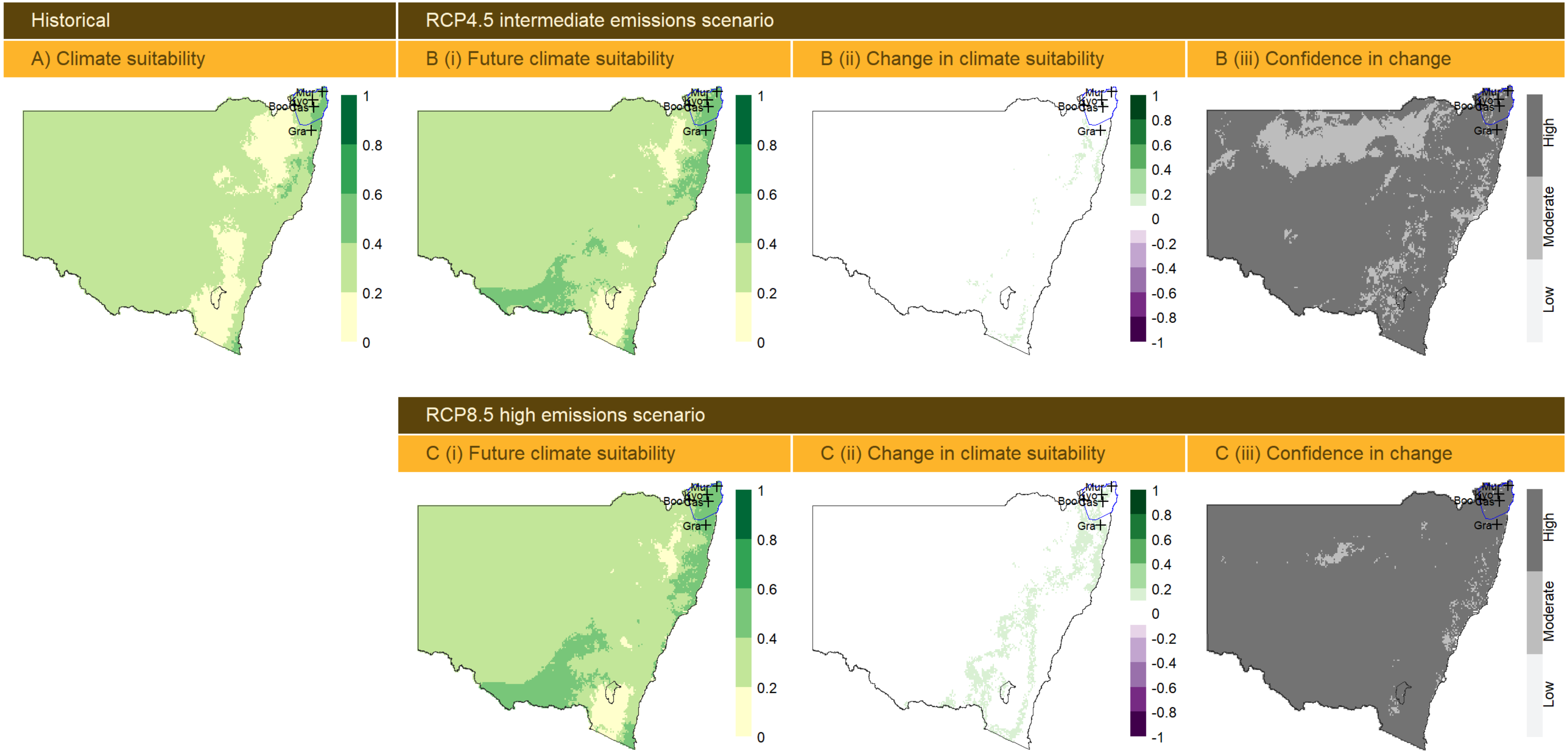


Figure A12. September climate suitability for cattle tick

The panel is comprised of 7 maps: A) shows the historic climate suitability; B) and C) shows 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). Sites representing the cattle tick region are marked by black crosses, and the blue polygon shows the cattle tick region. The sites are Boorook (Boo), Kyogle (Kyo), Murwillumbah (Mur), Casino (Cas) and Grafton (Gra).

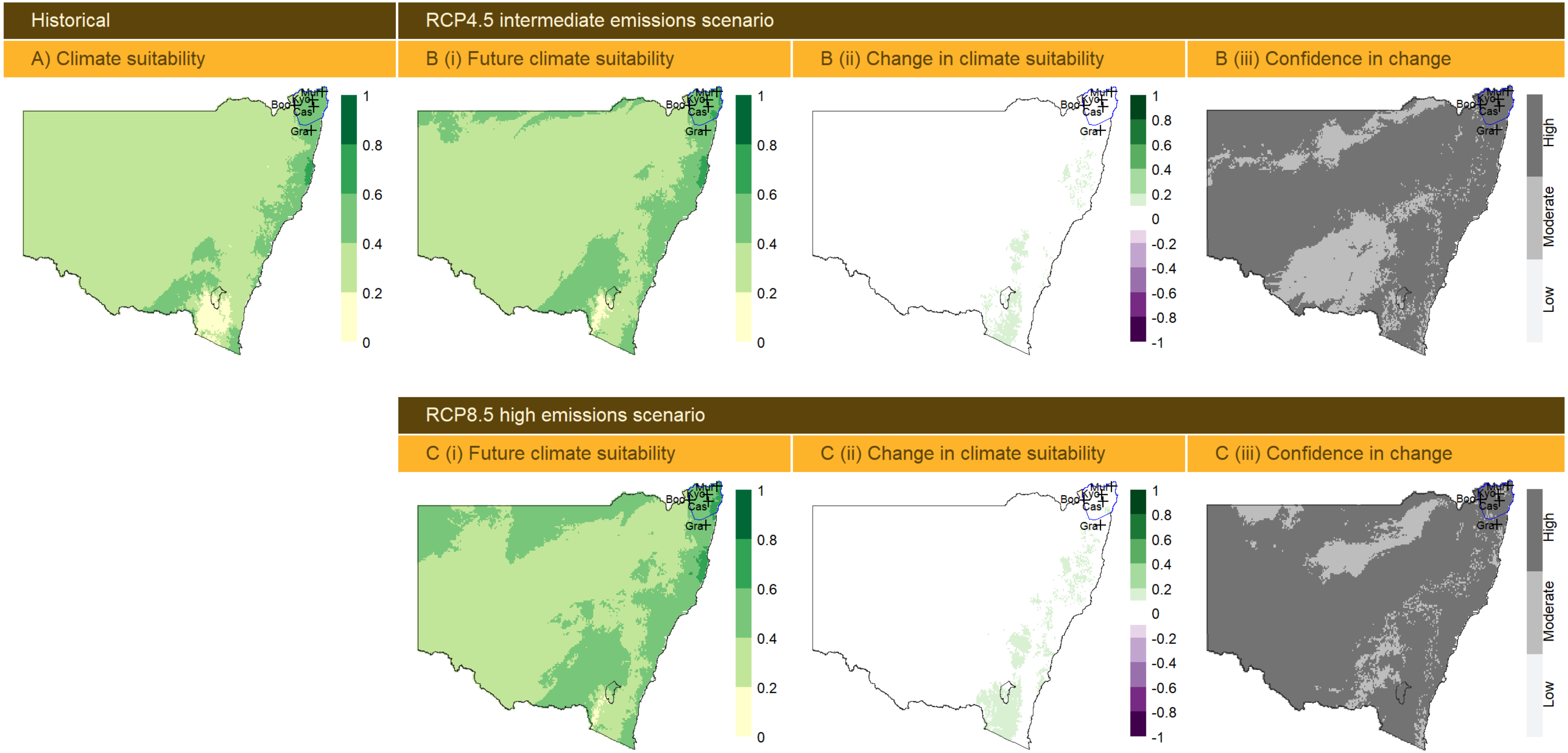


Figure A13. October climate suitability for cattle tick

The panel is comprised of 7 maps: A) shows the historic climate suitability; B) and C) shows 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). Sites representing the cattle tick region are marked by black crosses, and the blue polygon shows the cattle tick region. The sites are Boorook (Boo), Kyogle (Kyo), Murwillumbah (Mur), Casino (Cas) and Grafton (Gra).

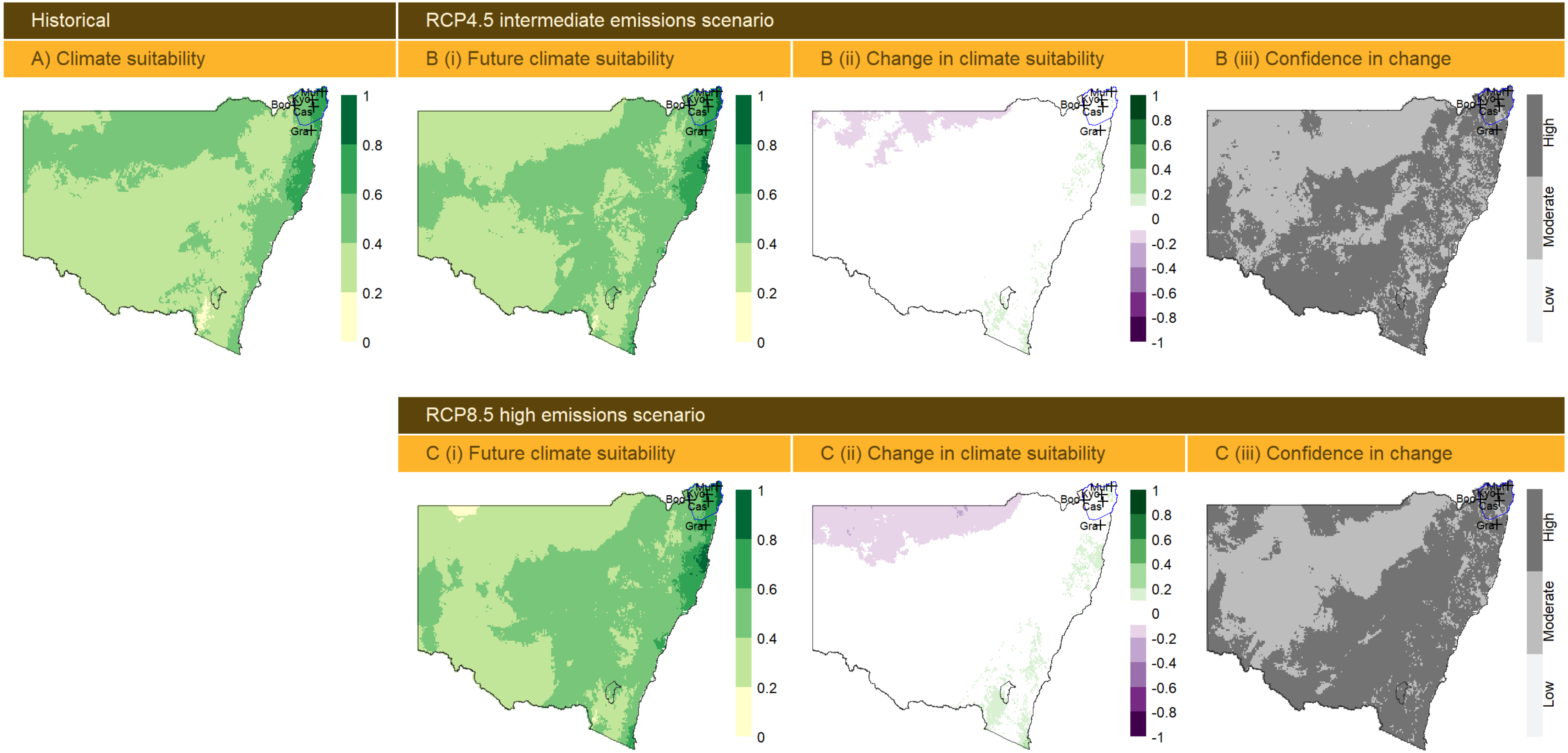


Figure A14. November climate suitability for cattle tick

The panel is comprised of 7 maps: A) shows the historic climate suitability; B) and C) shows 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). Sites representing the cattle tick region are marked by black crosses, and the blue polygon shows the cattle tick region. The sites are Boorook (Boo), Kyogle (Kyo), Murwillumbah (Mur), Casino (Cas) and Grafton (Gra).

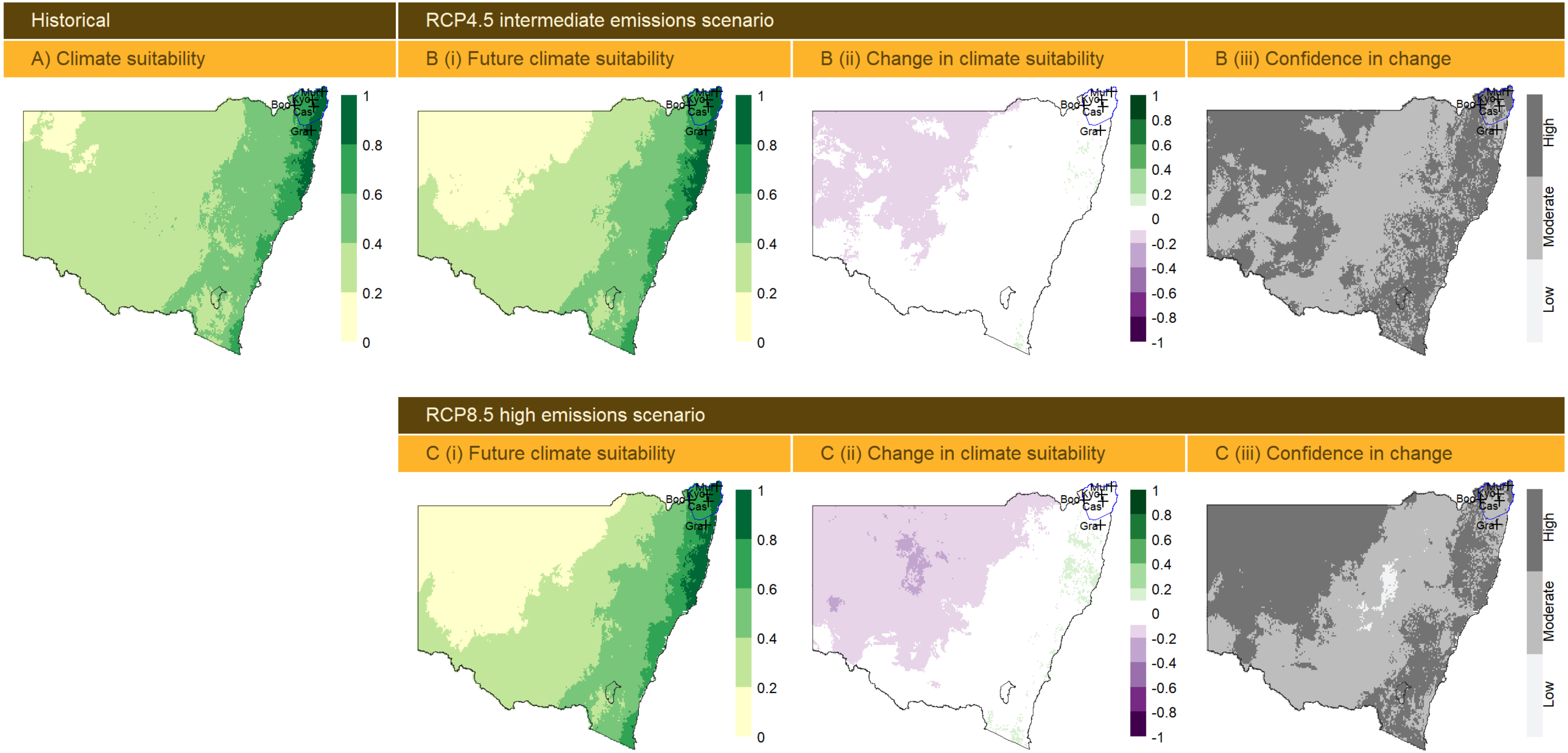
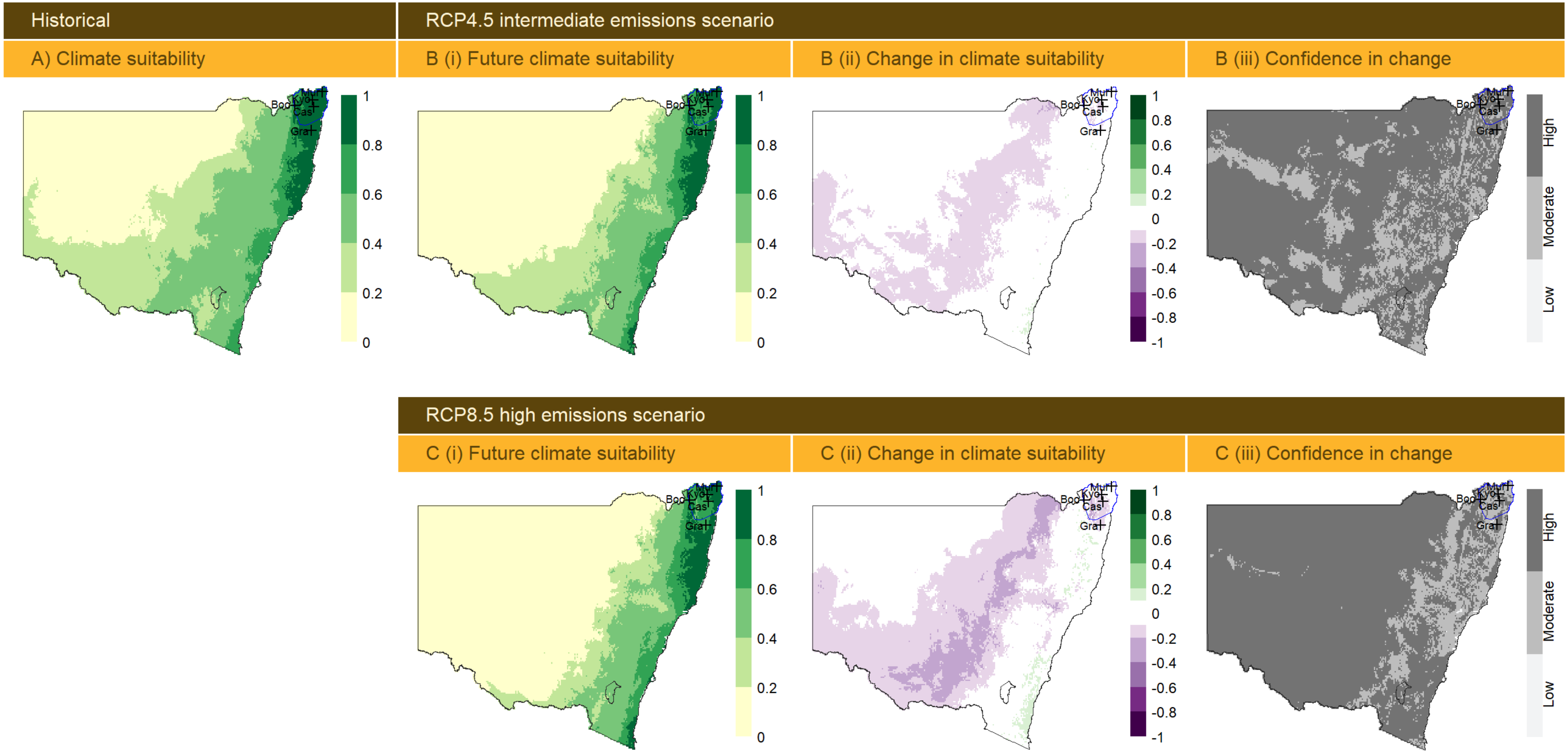


Figure A15. December climate suitability for cattle tick

The panel is comprised of 7 maps: A) shows the historic climate suitability; B) and C) shows 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). Sites representing the cattle tick region are marked by black crosses, and the blue polygon shows the cattle tick region. The sites are Boorook (Boo), Kyogle (Kyo), Murwillumbah (Mur), Casino (Cas) and Grafton (Gra).



Primary Industries Climate Change Research Strategy

Climate Vulnerability Assessment

Cattle Tick Results Report

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