Department of Primary Industries
and Regional Development

Fusarium oxysporum f.sp. *vasinfectum*

Results Report

Climate Vulnerability Assessment

NSW GOVERNMENT

Authors

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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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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, as well as for 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 for the *Fusarium oxysporum* f.sp. *vasinfectum* model, referred to hereafter as *Fusarium,* from the Climate Vulnerability Assessment. The report introduces the pathogen 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 the *Fusarium* pathogen.

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.

Fusarium significantly impacts cotton production by causing Fusarium wilt disease which results in reduced yields. *Fusarium* infects all stages of crop growth in cotton plants which can lead to reductions in yields, threatening the profitability and sustainability of the cotton industry.

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.

This NSW $23.1 billion sector supports economic growth and development, contributes to food security at the state and national levels, and plays a vital role in biosecurity management. Biosecurity risks threaten primary industries. Climate change is likely to worsen their impact in NSW by altering their range, distribution, and ability to spread. Industries with permanent plantings or geographic constraints are particularly vulnerable.

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 the differences in methodology, assumptions and projection data used[1]. A literature review of research on climate change impacts for primary industries revealed 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 reviewed as part of the present project revealed significant collective impacts of climate change. As temperatures increase, we can expect species to experience southward range shifts[2,3] and to see those currently restricted by cool temperatures in lower altitudes moving into higher altitude areas[3,4.] Climate change is likely to expand the range of some biosecurity risks while further constraining others. The literature on this topic has largely overlooked how these changes will 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 examined 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, thus, most in need of adaptation strategies, as well as those 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. Ecology 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.*

Fusarium in NSW

The specific pathogen studied in this report is *Fusarium oxysporum* f.sp. *vasinfectum*, first detected in Australia in the Darling Downs region of Queensland in 1993. In this region, during the 2009/10 season, Fusarium wilt caused losses of $57 million. In the late 1990s, the disease spread to northern NSW, in particular into the Gwydir Valley (Moree) and subsequently in the other cotton-growing river valleys of NSW (Figure 1).

Cotton is grown in the Gwydir Valley (Mungindi and Moree), the Namoi Valley (Narrabri, Wee Waa, Bourke, Boggabri and Gunnedah), the Macquarie Valley (Warren, Trangie and Narromine), the Lachlan Valley (Condobolin, Forbes and Hillston) and the Murrumbidgee Valley (Griffith, Hay, Balranald, Narrandera and Jerilderie). *Fusarium* has predominantly been found in the Gwydir and Namoi Valleys, but detections have been made in all of these valleys.

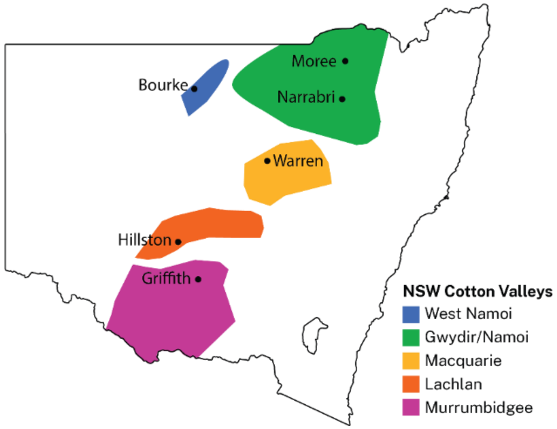


Figure 1: Map showing the cotton growing regions within NSW and key towns within each region.

Fusarium infects all stages of crop growth in cotton plants, with the mortality rate of seedlings frequently greater than 50%. Reduced yields result, threatening the profitability and sustainability of the cotton industry. The incidence of *Fusarium* wilt in cotton has been reported as high as 44.5% in the early season and 98.5% in the late cotton season[6].

Fusarium persists in the soil as chlamydospores or mycelium, capable of surviving for years, infecting cotton seedlings through their roots. Once inside the plant, it spreads through the vascular system (xylem), clogging the xylem vessels and restricting water and nutrient flow, leading to wilting and sometimes death. Under conducive climatic conditions, the majority of infection occurs early in the season and progresses upwards in the plant through the remaining growing season (Figure 2).

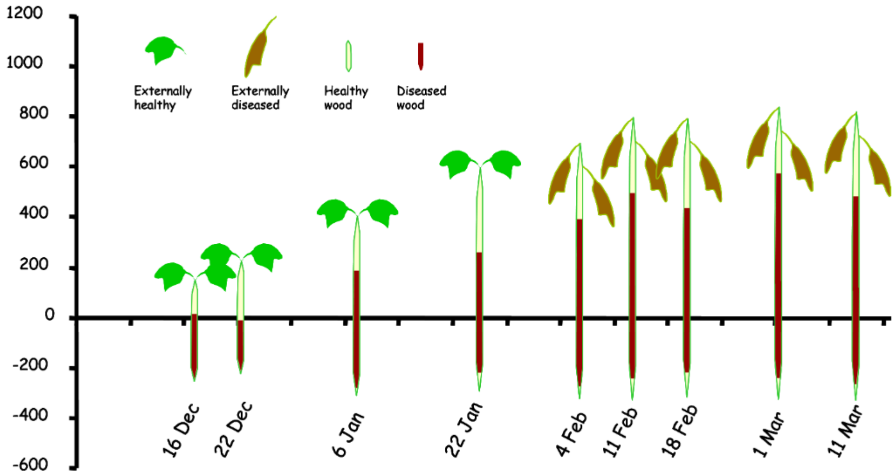


Figure 2: The movement of vascular discolouration and appearance of external symptoms in cotton crop at Moree in 2003/03 season[7].

[6] Le, D. P., Nguyen, C. P., Kafle, D., Scheikowski, L., Montgomery, J., Lambeth, E., Thomas, A., Shakeshaft, B., Young, A., Mckay, A., Twine, A., Hudson, E., Jackson, R., & Smith, L. J. (2022). Surveillance, Diversity and Vegetative Compatibility Groups of Fusarium oxysporum f. Sp. Vasinfectum Collected in Cotton Fields in Australia (2017 to 2022). *Pathogens*, *11*(12), 1537.

[7] Inside Cotton (2006) Severity factors in Fusarium wilt of cotton, https://www.insidecotton.com/severity-factors-fusarium-wilt-cotton, retrieved 21 February 2025.

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 comparable way.

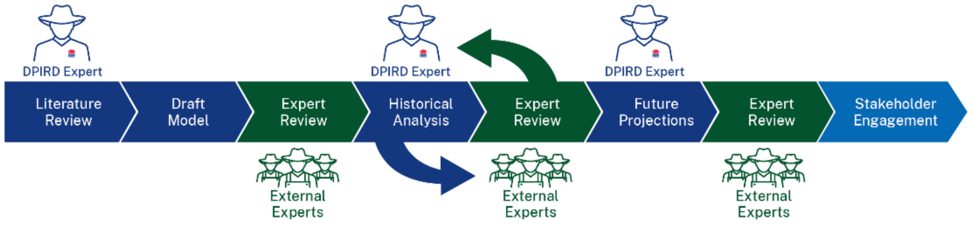


Figure 3: Outline of expert engagement for framework developed by the Climate Vulnerability Assessment. Internal and external experts were involved throughout the process, helping to develop and refine the models of primary industry commodities and biosecurity risks in their area of expertise.

The assessment framework, outlined in Figure 3, 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 commodity and biosecurity risk, and these models were developed using a combination of published data, empirical evidence and expert judgment. In the hierarchical structure of an MCA model, the commodity or biosecurity risk sits at the top level, with the key lifecycle stages forming the level below. The next level of the model then associates one or more climate variables with each of these 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[8], reflecting the consensus reached by the focus group experts.

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

The MCA model is 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 an organism's growth in the absence of other limiting factors[9].

Using the model, an assessment of climate suitability (ranging from 'unsuitable' to 'very high') was 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 conditions in order to understand how the climate suitability for the biosecurity risk may be altered 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 *Fusarium* and give the key results which show important changes to future climate suitability for *Fusarium*.

For further details on the Climate Vulnerability Assessment Project framework, MCA modelling and the climate data used in this work (historical observations and future projections), please refer to the [Climate Vulnerability Assessment Methodology Report.]

Project limitations

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

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

These factors should be considered alongside the project's findings when examining the current or future impacts on production 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.

[9] 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 *Fusarium* model

For more information, refer to the Climate Vulnerability Assessment Methodology Report[10].

Climate variables

The climate variables used in this model were mean temperature (Tmean, °C) and rainfall (Rain, mm).

Categorising climate variables

The hierarchical structure of the MCA model (Figure 4) categorises climate variables to assess their impact on *Fusarium*. Each category (for example, a temperature between 25C and 30°C) is assigned a rating, R, between 0 (unsuitable) and 1 (optimal) that indicates how well it suits *Fusarium*. This is repeated for each life stage.

Modules used in the *Fusarium* MCA model

The project's MCA models used the standardised techniques, referred to as 'modules', to produce ratings from the climate variables. The *Fusarium* model used only one module:

Matrix module: this module capture the interaction between two climate variables. In the *Fusarium* model, these were monthly mean temperature and monthly cumulative rainfall. This module was used for life stages that are particularly sensitive to the interplay between two climate variables. The matrix categories define bivariate combinations of climate conditions, for example, temperature between 15C and 25°C with cumulative rainfall of between 183mm and 300mm.

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 *Fusarium*.

Fusarium model assumptions

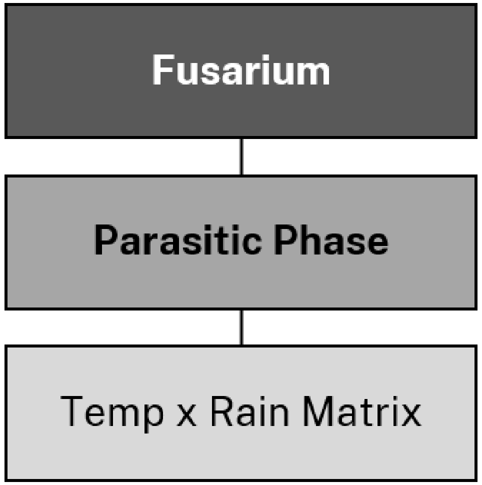
A model represents a simplified version of reality. Assumptions and exclusions simplify complex systems by reducing the number of influencing factors, enabling model development. In addition to the project assumptions and exclusions, the assumptions for the *Fusarium* model were:

- a specific organism is described,
- the parasitic phase of *Fusarium* is modelled,
- a susceptible host is available,
- no treatment or control for *Fusarium* is undertaken, and
- host crops are rain-fed (not irrigated).

Final *Fusarium* model

The MCA model structure for *Fusarium* is shown in Figure 4. This model examines only the parasitic phase, and so only climate variables that affect the parasitic phase are included in the model.

[10] Department of Primary Industries (2023) Climate Vulnerability Assessment Summary Report. https://www.dpi.nsw.gov.au/dpi/climate/climate-vulnerability-assessment/publications-and-reports/Climate-Vulnerability-Assessment-Methodology-Report.pdf, accessed on 21 February 2025.



		Mean Temperature (°C)				
		< 15	**15 to 25**	**25 to 30**	**30 to 34**	**> 34**
Cumulative Rain (mm) (for three months)	**> 300**	R = 0.20	R = 1	R = 0.60	R = 0.40	R = 0.10
	183 to 300	R = 0.16	R = 0.80	R = 0.48	R = 0.32	R = 0.08
	90 to 183	R = 0.08	R = 0.40	R = 0.24	R = 0.16	R = 0.04
	< 90	R = 0.02	R = 0.10	R = 0.06	R = 0.04	R = 0.01

Figure 4: MCA model hierarchical structure and model components for Fusarium. *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: an intermediate emissions scenario, RCP4.5, and a high emissions scenario, RCP8.5. 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[11], and the median of these models was used to produce ensemble future projection climate suitability maps.

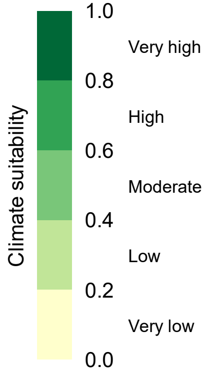


Figure 5: Colour scheme for the climate suitability maps

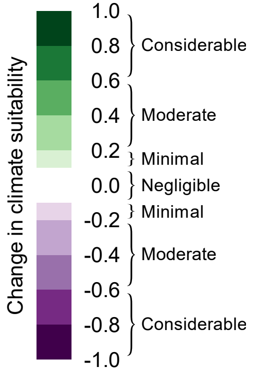


Figure 6: Colour scheme for the change in climate suitability maps

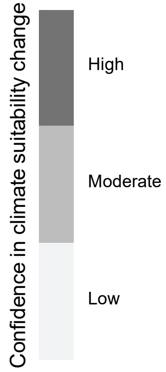


Figure 7: Colour scheme for the confidence in the change in climate suitability maps

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.

[11] 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.

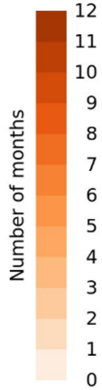


Figure 8: Colour scheme for the number of highly suitable months maps

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 from 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 overall years and thus may be any value between 0 and 12.

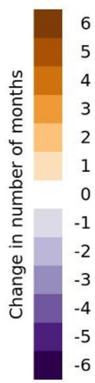


Figure 9: Colour scheme for the change in the number of highly suitable months maps

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.

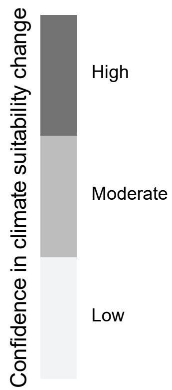


Figure 10: Colour scheme for confidence in the change in the number of highly suitable months maps

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 calendar plots

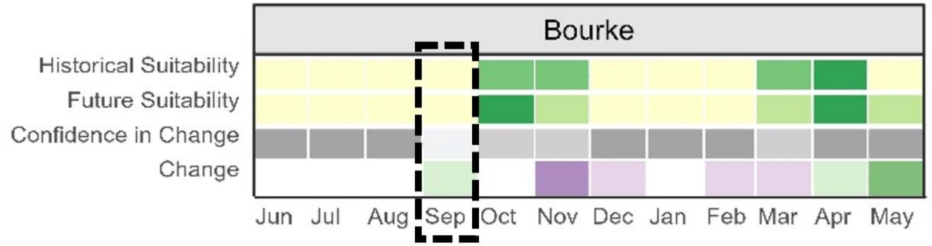
Calendar plots for biosecurity risks were made for individual sites of interest. These plots provide a visual comparison of the change in climate suitability over the year, comparing the mean historical climate suitability with the median future climate suitability for each emissions scenario (RCP4.5 and RCP8.5). Calendar plots are included for the biosecurity risk overall and each life stage.

Calendar plots 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.

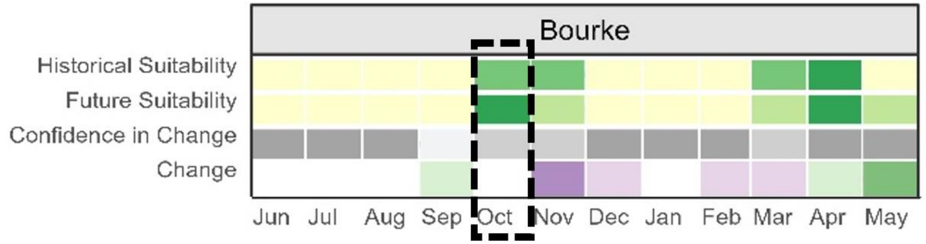
There are two important points to note when interpreting calendar plots: one occurs when the historical and future climate suitability categories are the same, but the 'change in suitability' is non-negligible (green or purple). This situation is shown in **Example 1** and has arisen from a historical 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 calendar plot 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 plot 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 *Fusarium*

A warmer climate is likely to increase climate suitability for Fusarium*. Without strict hygiene management strategies, the distribution of* Fusarium *may spread and thrive in some areas of NSW. This poses a threat to the state's billion-dollar cotton industry.*

This section provides a selection of key results for the *Fusarium* climate vulnerability assessment. It begins with an overview of the overall climate impacts and a breakdown of the climate impacts on the parasitic life stage, followed by the relevant maps and calendar plots. 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 calendar plot panels. 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, presented as calendar plots which show climate suitability on a monthly basis. Each map includes the key cotton growing valleys in NSW.

The locations of the major cotton-producing valleys in NSW shown in Figure 8 are used to highlight the region of interest in the spatial distribution of *Fusarium.* These sites represent where *Fusarium* can have an impact on cotton production.

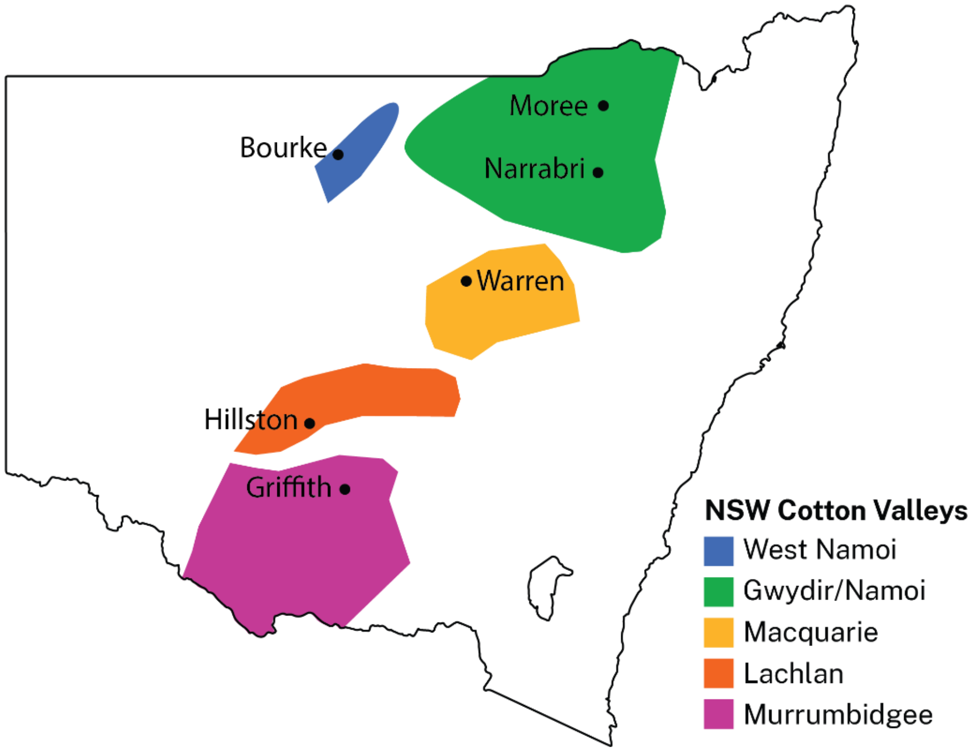


Figure 11: The major cotton growing valleys of NSW, including key towns in each region.

Overall climate impacts

Annual climate suitability trends: impacts on different regions in NSW

Within NSW, the river valleys where cotton is grown have varied climate conditions for *Fusarium*. 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 *Fusarium*. The number of highly suitable months varies between different locations of the state, as shown in Figure *12*.

By 2050, the number of highly suitable months in the Gwydir and Namoi valleys is expected to decrease by 0.5 to 1 month per year under the high emissions scenarios (*low to moderate confidence*). In the intermediate emissions scenario, similar decreases are likely in those valleys in isolated areas (*low to moderate confidence*).

Conversely, in the other cotton growing valleys, the number of highly suitable months are likely to remain similar to historical levels under both emissions scenarios (*low to moderate confidence*).

Changes in seasonal climate suitability

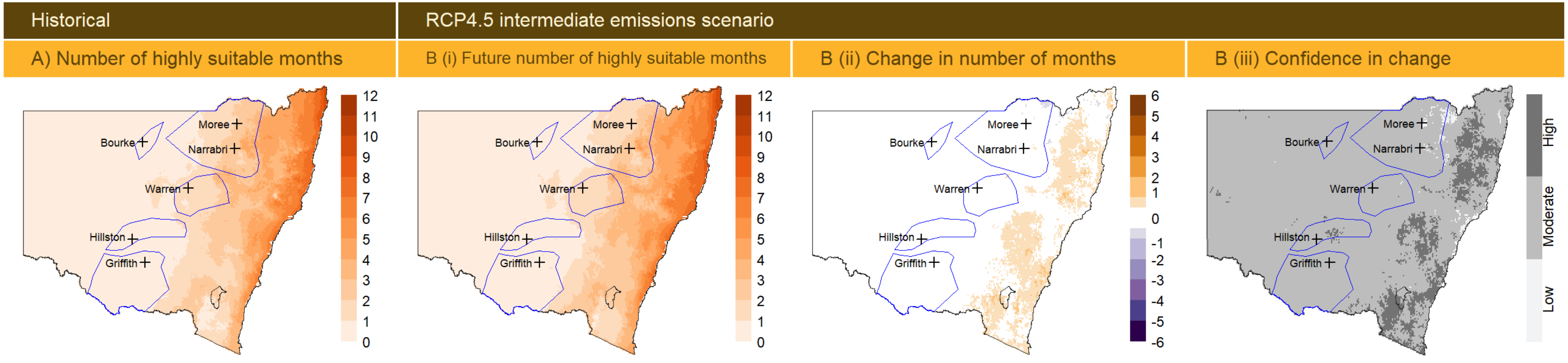
Spatial trends: how climate change will alter *Fusarium* distribution across NSW

In this section, the spatial distribution of *Fusarium,* based on climate suitability for the parasitic phase of the organism's lifecycle, is examined for key months of the cotton growing season. Planting begins in September/October and harvest is generally around April.

The results indicated likely changes in the following months:

- **September:** most cotton-growing regions are expected to experience minimal to moderate increases in climate suitability for *Fusarium*, except for the West Namoi and Murrumbidgee regions, under both emissions scenarios (see Figure *13*). The increases are likely to be greatest under the high emissions scenario (*low to high confidence*).
- **December, January, February, and March**: there are likely to be minimal to moderate decreases in climate suitability for Fusarium in the Gwydir/Namoi and Macquarie regions, extending to the Lachlan region in December (see Figure *14*,Figure *15*Figure 16 and Figure *17*). The decreases are likely to be greatest under the high emissions scenario (*low to high confidence.*
- **May**: there are likely to be minimal to moderate increases in climate suitability for *Fusarium* in all cotton-growing regions except for the West Namoi region, under both emissions scenarios (see Figure *18*). The increases are likely to be greatest under the high emissions scenario, with changes extending to the Lachlan region (*low to high confidence*).
- **April & November:** climate suitability for Fusarium is expected to remain similar to what has been historically experienced under both emissions scenarios in most cotton-growing regions (*low to high confidence*) (see Appendix Figure A1 and Figure A6). There are scattered areas of minimal changes in climate suitability in the Gwydir/Namoi cotton region in these months (*low to high confidence).*
- **June, July, August and October**– climate suitability for *Fusarium* is expected to remain similar to what has been historically experienced under both emissions scenarios (*moderate to high confidence*) (see Appendix Figure A2,Figure A3, Figure A4 and Figure A5). There are scattered areas of minimal positive changes in climate suitability in the Gwydir/Namoi cotton region in most of these months (*moderate to high confidence*).

Fusarium: number of highly suitable months



Findings: The number of highly suitable months in a year varies across the state. In the cotton regions, there are likely to be negligible changes in the number of highly suitable months under both emissions scenarios. However, some minimal decreases in the number of highly suitable months are anticipated in the Gwydir/Namoi regions represented by the sites of Moree and Narrabri under the high emissions scenario. This could be beneficial for growers in this area by reducing the risk of mid- to late-season *Fusarium* infection.

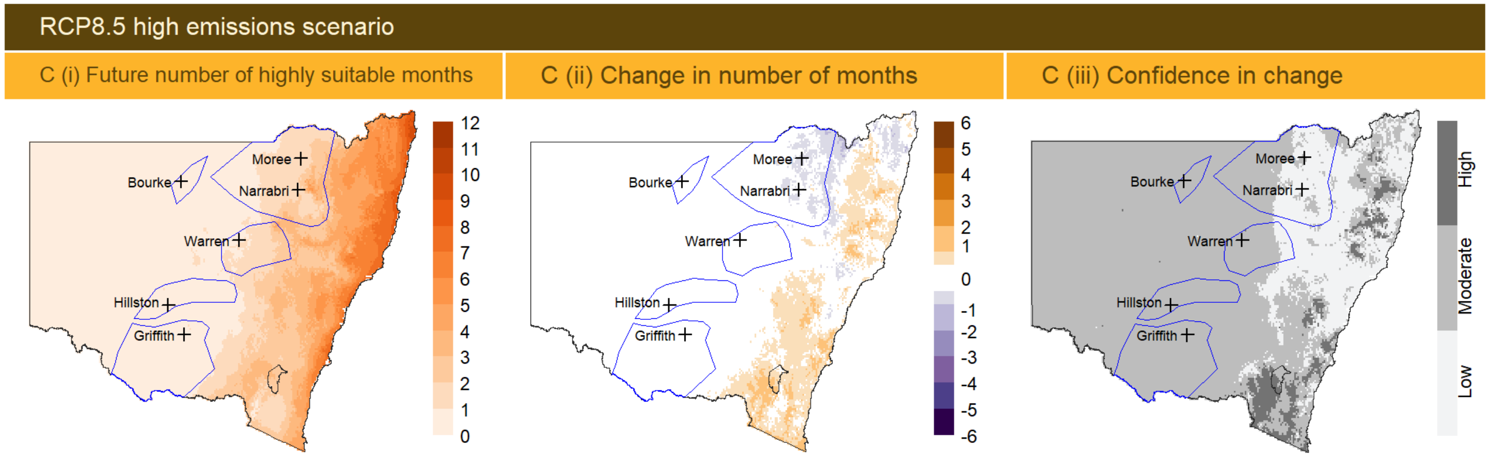
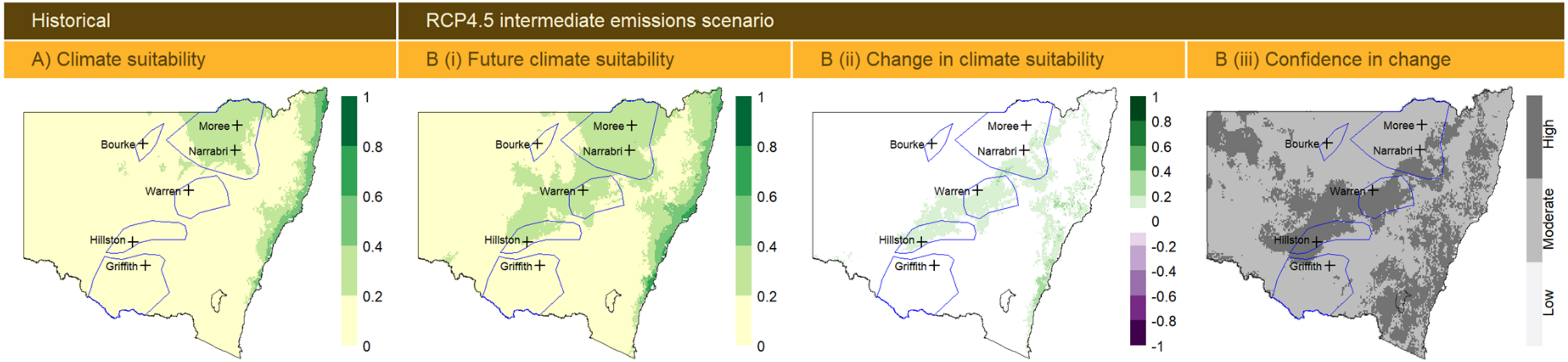


Figure 12: the number of months highly suitable for *Fusarium* in NSW. The number of highly suitable months measures the months in which climate suitability is greater than or equal to 0.6. The panel is comprised of 7 maps: A) shows the historic number of highly suitable months; B) and C) show the future number of highly suitable months for the intermediate and high emissions scenarios, respectively; (i) shows number of suitable months under intermediate and high emissions scenario future number of highly suitable months, (ii) shows the projected change in the number of highly suitable months as negligible (white), increasing (orange) or decreasing (purple) change and (iii) shows the level of confidence in this change (low, moderate or high). Key cotton growing regions are marked by blue polygons and key towns in these regions are marked by black crosses.

Fusarium: overall climate suitability for September



Findings: Climate suitability for *Fusarium* in September is expected to increase in some of the NSW cotton-growing regions (outlined in blue on the maps) under both emissions scenarios. Changes in temperature and rainfall lead to this increase, and these changes in September are likely to lead to increased early-season infection of cotton seedlings.

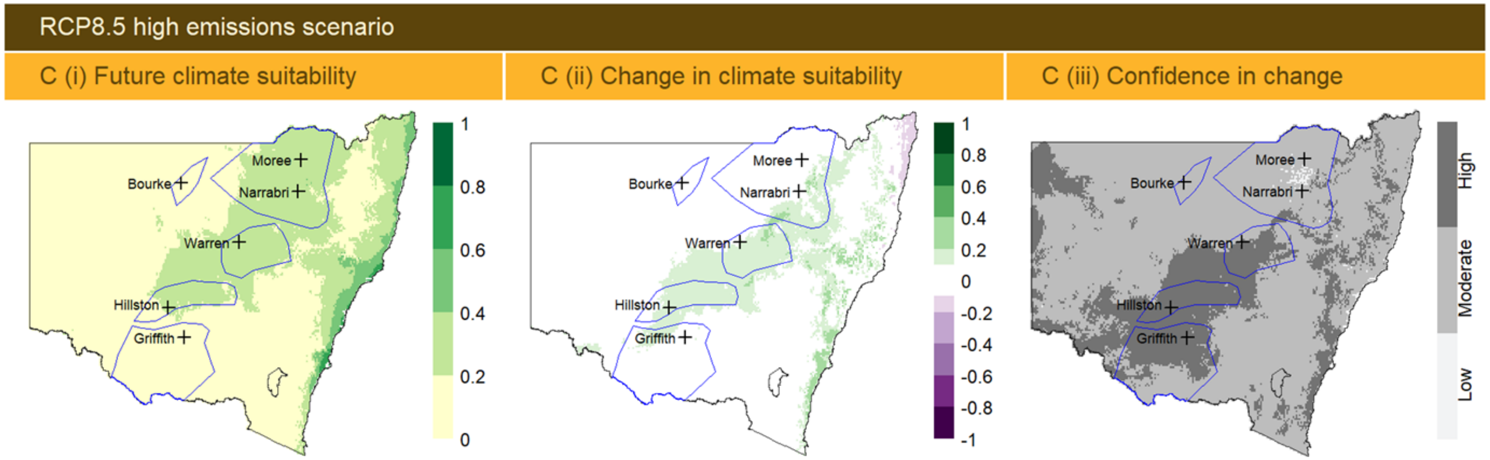
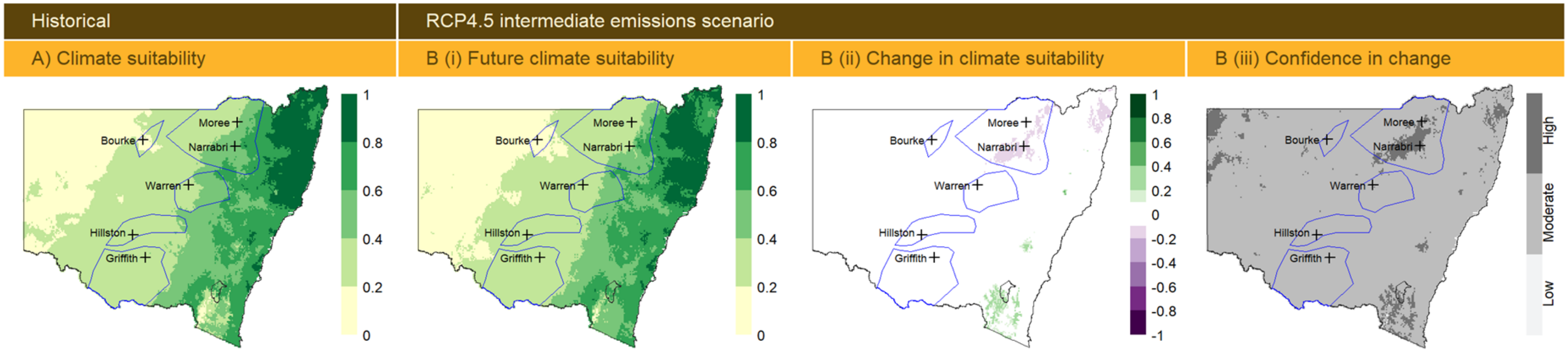


Figure 13: Overall climate suitability for *Fusarium* in NSW for September. The panel is comprised of 7 maps: A) shows the historic climate suitability; B) and C) show future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability, (ii) 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). Key cotton growing regions are marked by blue polygons and key towns in these regions are marked by black crosses.

Fusarium: overall climate suitability for December



Findings: Climate suitability for *Fusarium* during December is expected to see a minimal decrease in northern cotton-growing regions under both emissions scenarios. This decrease is more widespread under the high emissions scenario in the north and reaching the central parts of the state. This change is driven by changes in temperature and rainfall and is likely to lead to a decreased risk of mid- to late-season infection.

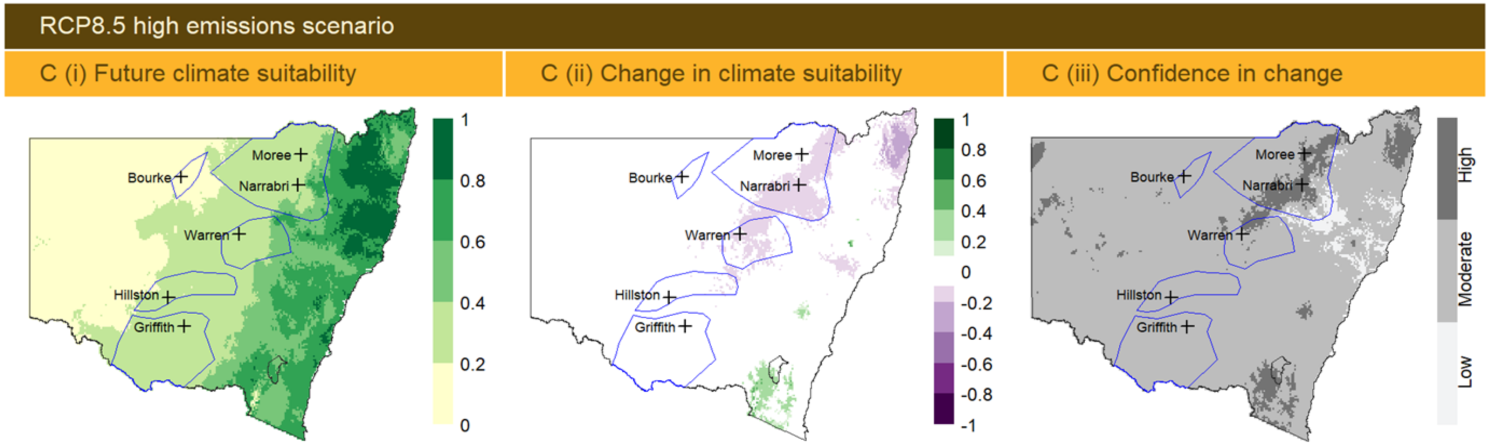
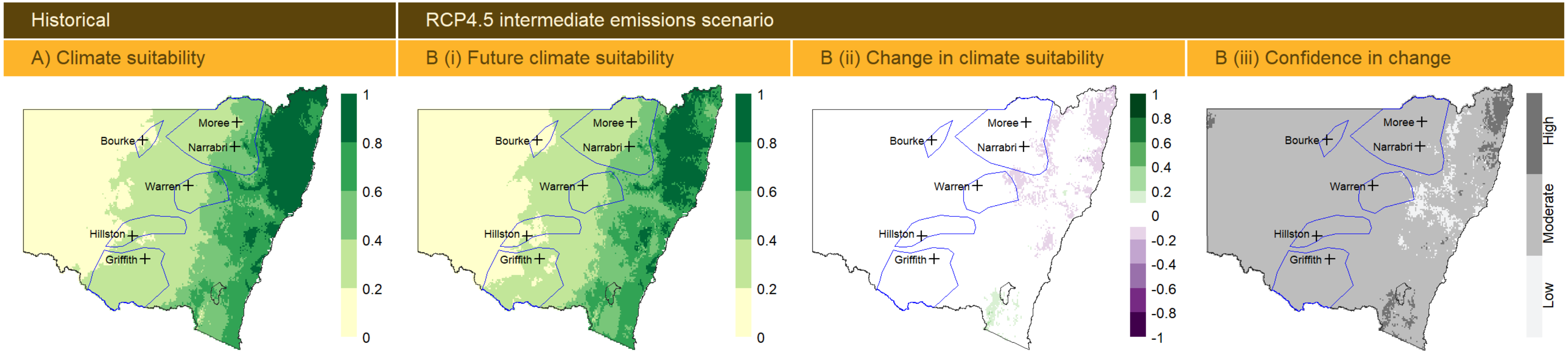


Figure 14: Overall climate suitability for *Fusarium* in NSW for December. The panel is comprised of 7 maps: A) shows the historic climate suitability; B) and C) show future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability, (ii) 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). Key cotton growing regions are marked by blue polygons and key towns in these regions are marked by black crosses.

Fusarium: overall climate suitability for January



Findings: Climate suitability for *Fusarium* in January is expected to decrease on the edges of northern cotton-growing regions (outlined in blue on the maps) under both emissions scenarios. This minimal decrease is driven by changes in temperature and rainfall lead, and its timing is likely to lead to a decreased risk of mid- to late-season infection.

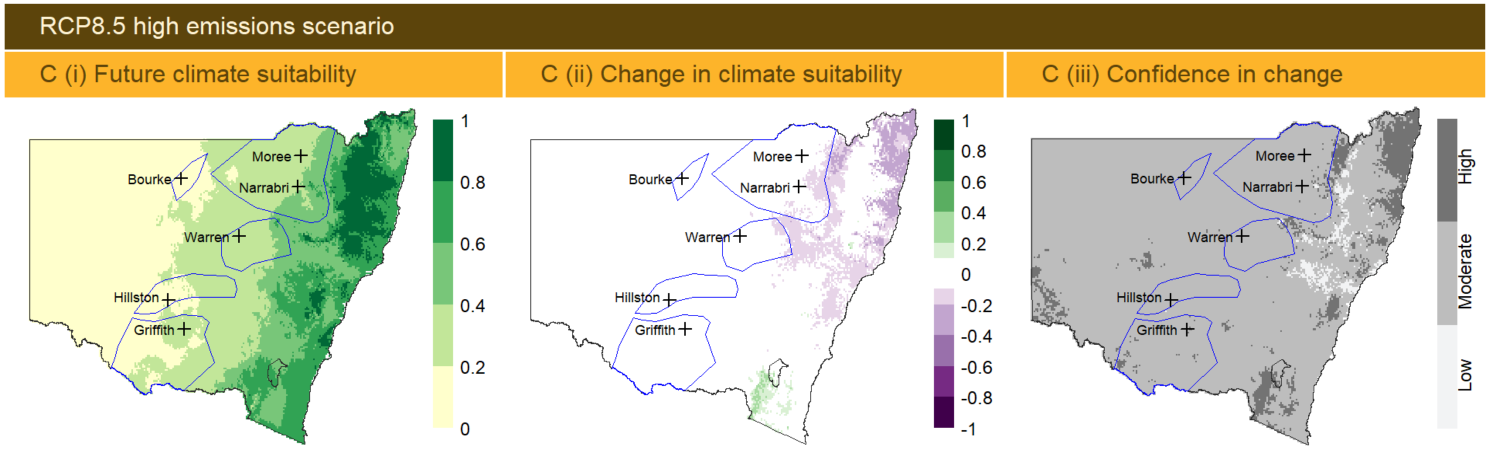
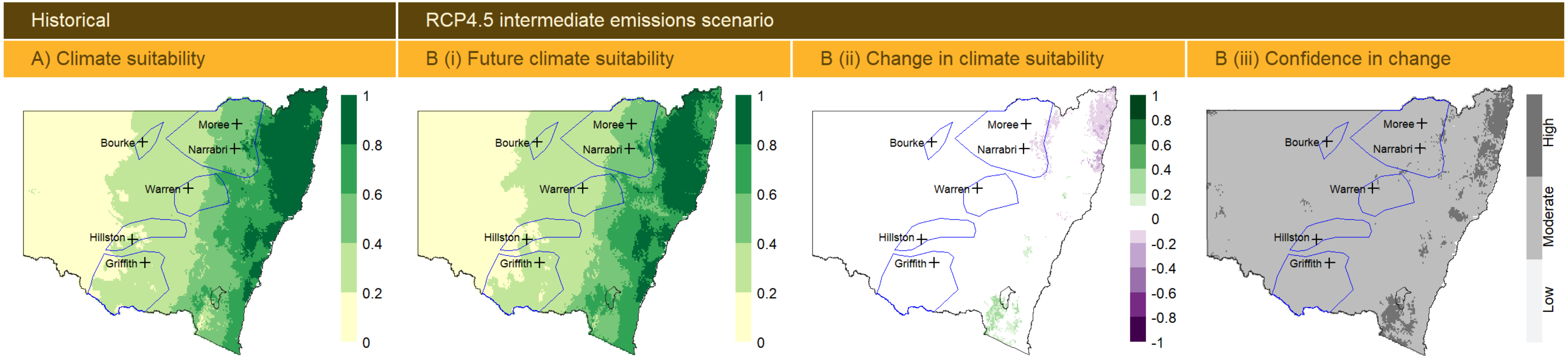


Figure 15: Overall climate suitability for *Fusarium* in NSW for January. The panel is comprised of 7 maps: A) shows the historic climate suitability; B) and C) show future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability, (ii) 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). Key cotton growing regions are marked by blue polygons and key towns in these regions are marked by black crosses.

Fusarium: overall climate suitability for February



Findings: Climate suitability for *Fusarium* in February is expected to decrease on the fringe of the Gwydir/Namoi cotton growing valley under both emissions scenarios. The minimal decrease is more pronounced under the high emissions scenario near Moree, Narrabri and Warren. Changes in temperature and rainfall lead to this decrease, and these changes in February are likely to lead to decreased risk of mid- to late-season infection.

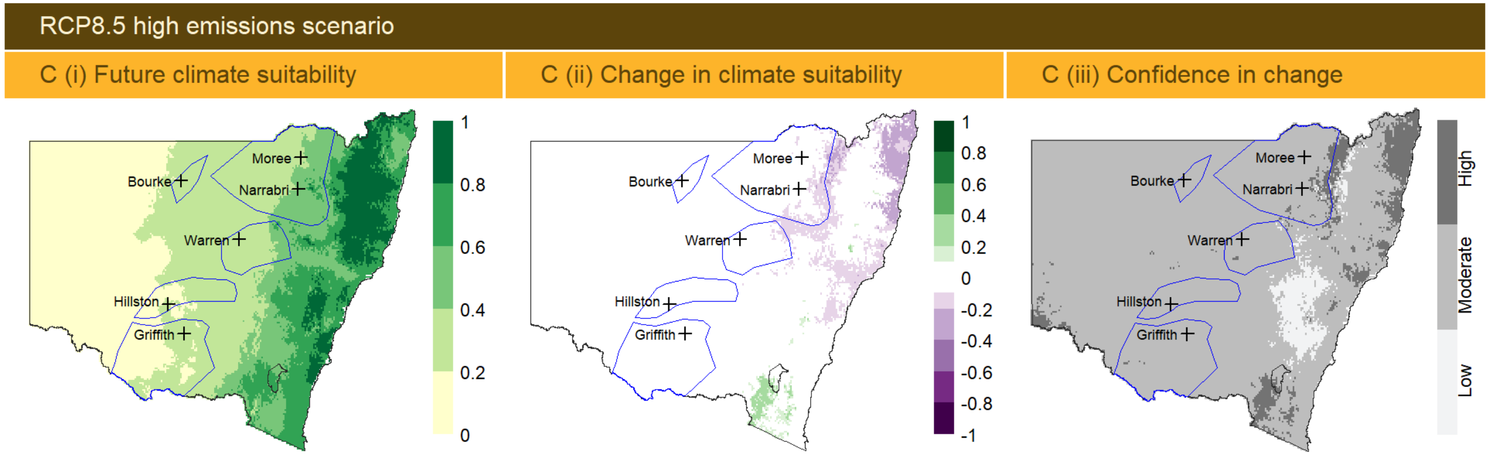
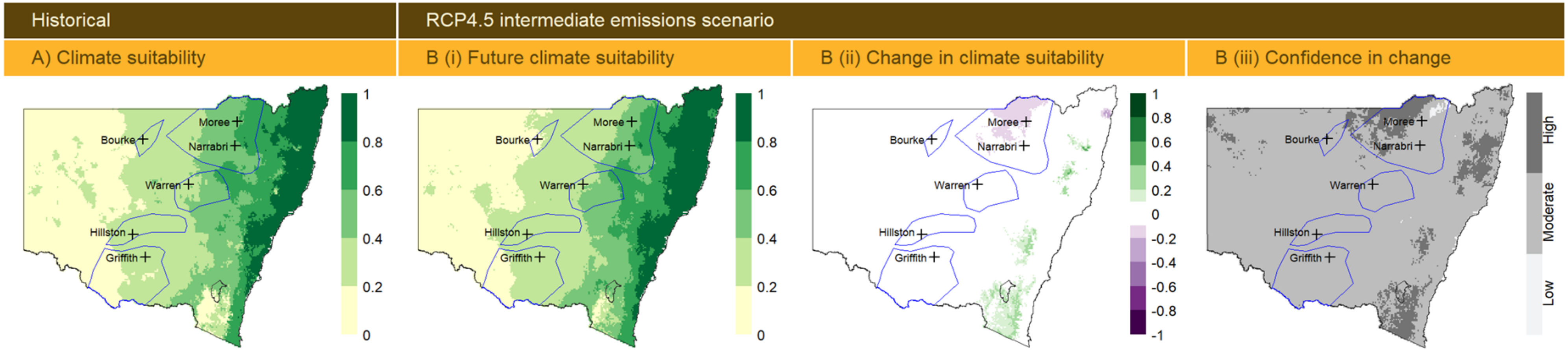


Figure 16: Overall climate suitability for *Fusarium* in NSW for February. The panel is comprised of 7 maps: A) shows the historic climate suitability; B) and C) show future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability, (ii) 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). Key cotton growing regions are marked by blue polygons and key towns in these regions are marked by black crosses.

Fusarium: overall climate suitability for March



Findings: Climate suitability for *Fusarium* in March is expected to decrease in the Gwydir/Namoi valley. Changes are expected to be minimal under the intermediate emissions scenario and up to moderate under the high emissions scenario in the far north of the region. Changes in temperature and rainfall lead to this decrease, and these changes are likely to lead to decreased late-season infection.

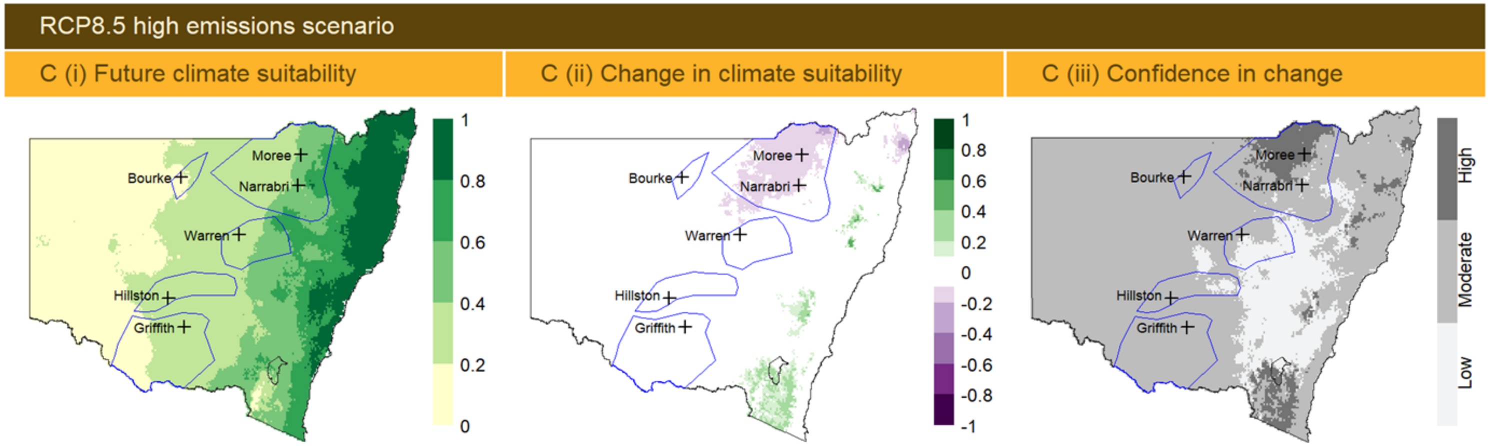
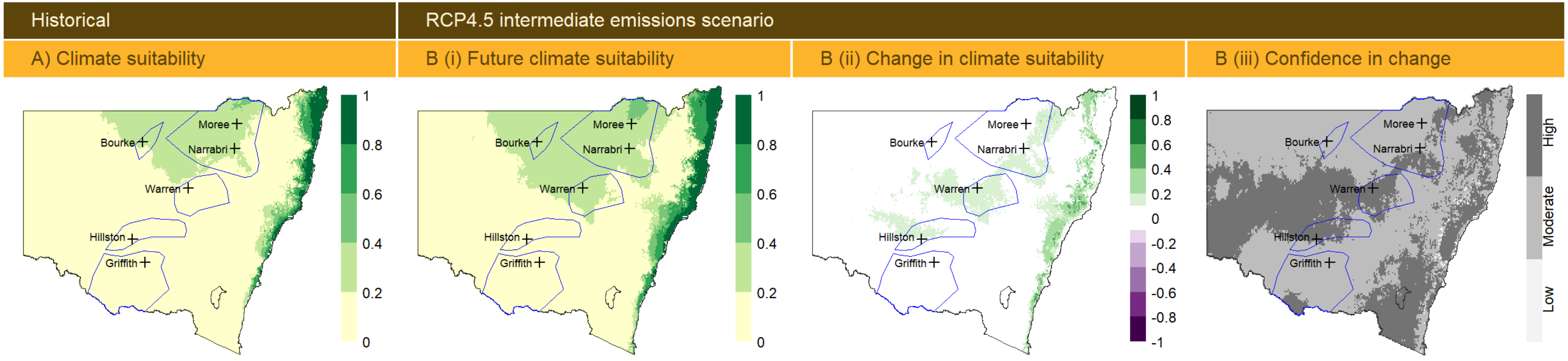


Figure 17*:* Overall climate suitability for *Fusarium* in NSW for March. The panel is comprised of 7 maps: A) shows the historic climate suitability; B) and C) show future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability, (ii) 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). Key cotton growing regions are marked by blue polygons and key towns in these regions are marked by black crosses.

Fusarium: overall climate suitability for May



Findings: Climate suitability for *Fusarium* in May is expected to increase across most of the NSW cotton-growing areas. Under the intermediate emissions scenario, changes are likely to be minimal, but this increases to moderate change across the Gwydir/Namoi valley in the high emissions scenario. Changes in temperature and rainfall lead to this increase which is likely to lead to increased survival of the pathogen following harvest and stubble incorporation.

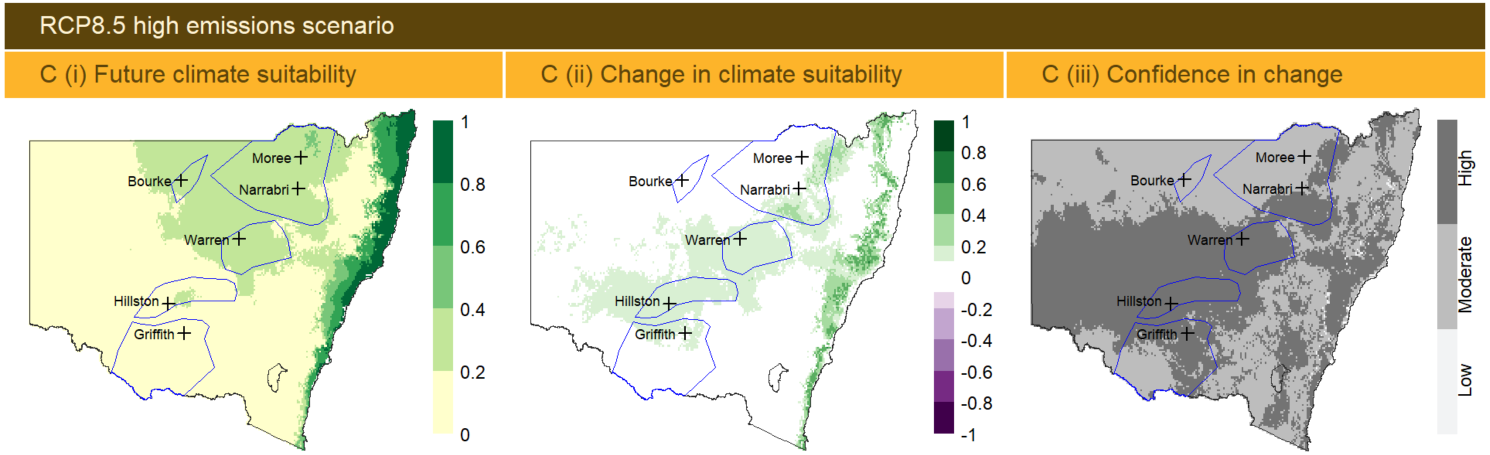


Figure 18: Overall climate suitability for *Fusarium* in NSW for May. The panel is comprised of 7 maps: A) shows the historic climate suitability; B) and C) show future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability, (ii) shows 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). Key cotton growing regions are marked by blue polygons and key towns in these regions are marked by black crosses.

Monthly trends at *Fusarium* sites: how climate change will alter climate suitability throughout the year.

The overall calendar plot (Figure 19) shows the expected temporal change in climate suitability for *Fusarium* for each month near locations where *Fusarium* is a relevant biosecurity risk to crop production. An analysis of future climate suitability around these sites for the two emissions scenarios provides insights into potential future monthly trends in 2050. As the cotton season generally runs from September to April, the calendar plot shows the months in order starting from September. Key findings are:

- Under the high emissions scenarios, climate suitability for *Fusarium* is expected to **decrease** during some warmer months for the around Moree, Narrabri, and Warren (*moderate to high confidence*).
- Under both emissions scenarios, climate suitability for *Fusarium* is expected to **increase** during September and May around Warren and Hillston (*moderate to high confidence*).
- The climate suitability during late autumn, winter and mid-summer is likely to remain similar to the historical suitability under both emissions scenarios (*moderate to high confidence*)

Fusarium – climate suitability calendar

Figure 19: Fusarium *overall climate suitability calendar. The calendar plot 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 *Fusarium* is expected to decrease during warmer months around Moree, Narrabri, and Warren. These changes are more prominent under the high emissions scenario. Changing temperatures and rainfall decrease climate suitability, which could benefit growers by reducing the risk of mid-to-late infections from *Fusarium*.

Near Warren and Hillston, climate suitability for *Fusarium* is expected to increase from very low to low in September and May. This increase may extend the *Fusarium* infection period, necessitating earlier surveillance in these areas.

All sites, except around Bourke, are expected to maintain historical levels of low or moderate climate suitability during the spring, summer and autumn months. During winter months, all sites are likely to have very low climate suitability, with the Bourke area maintaining very low climate suitability from June to January. Consequently, these months are likely to experience similar impacts from *Fusarium* as they have 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 of *Fusarium* in the major cotton-producing valleys of NSW.

Key insights for the Macquarie and Lachlan Valleys

In September, climate suitability for *Fusarium* in the Macquarie and Lachlan valleys is expected to increase under both emissions scenarios. As a result of these changes, there is likely to be a higher risk of infection for cotton crops planted early in the season by 2050, specifically during September and October. To adapt, the cotton industry in these valleys may need to adjust their management strategies. This may involve planting earlier, as soon as soil temperatures rise, which is crucial to plant development. The opposite strategy, delaying planting until late October, is not an option due to the shorter growing season in these regions. Early planting will be essential for maximising crop health and yield amid the changing climate.

A key effect of climate change is an increase in climate suitability for *Fusarium* during May, under both emissions scenarios. This shift could enhance the survival rates of *Fusarium* in crop stubble and on host weeds, posing a risk to the health and yield of crops in subsequent years. By 2050, it may be necessary to adopt management strategies which minimise this risk, such as leaving stubble from the crop in the field for a minimum of two months before incorporating it into the soil, and prioritising control of host weeds. Implementing these practices may decrease *Fusarium* survival and reduce the infection risk during future growing seasons.

Key insights for the Murrumbidgee Valley

A key effect of climate change in the Murrumbidgee Valley is an expected increase in climate suitability for *Fusarium* during May, under both emissions scenarios. As in the Macquarie and Lachlan valleys, this shift could enhance the survival rates of *Fusarium* in crop stubble and on host weeds, posing a risk to the health and yield of subsequent crops. By 2050, it may be necessary to adopt management strategies which minimise this risk, such as leaving stubble from the crop in the field for a minimum of two months before incorporating it into the soil, and prioritising control of host weeds. Implementing these practices may decrease *Fusarium* survival and reduce the infection risk during future growing seasons.

Key insights for the Gwydir and Namoi Valleys

A key effect of climate change for this region is an expected decrease in climate suitability for *Fusarium* in December, January, February and March under both emissions scenarios. These projected changes could reduce the risk of mid- to late-season infections, lowering the risk of yield loss, and offering a chance for regional cotton industries to adopt management strategies which boost mid- to late-season growth to take advantage of the reduced risk of *Fusarium* infection. Strategic irrigation can promote early growth and minimise water stress, and it would play an important role in that ensuring plants have access to nutrients essential for growth during this time. The adoption of such strategies could improve plant health and yield in the future.

Expected challenges for the cotton industry

The effects of *Fusarium* on future cotton production in NSW will depend on several factors:

- the future growth of the cotton industry into new regions,
- changes in planting timings, and
- the overlap between susceptible life stages of cotton and the lifecycle of *Fusarium*.

Increased climate suitability for *Fusarium* in a warmer future climate is likely to lead to a greater impact of *Fusarium* on cotton production in all NSW cotton-producing regions by 2050. Climate suitability is likely to increase in the Macquarie and Lachlan valleys during September and October due to higher mean temperatures in spring and autumn. This could result in increased infection earlier in the season, at planting in September or October, and an increase in *Fusarium* survival in plant stubble after harvest in May. Decreased climate suitability for *Fusarium* in a warmer, drier future climate during the summer months could result in a reduced late-season infection risk, with potential future benefits for currently impacted cotton-producing regions.

Current strategies for managing *Fusarium* are likely to remain effective, including the selection of high F-rank cotton varieties. In addition, some modifications regarding stubble management may become necessary, leaving it on the surface for more than two months after harvest, along with a greater emphasis on controlling host weeds to minimise *Fusarium* survival and the risk of subsequent infection.

Fusarium: where to from here?

Future priorities

We have assessed the future climate suitability for *Fusarium* as a prerequisite for making effective planning decisions and developing management strategies to address future climate change impacts on the cotton industry in NSW.

The results presented in this report have identified changes in climate suitability for *Fusarium* that are likely to have a negative impact on the cotton industry in the southern regions of NSW. More research is needed to best advise impacted regions on adaptations and new management techniques for *Fusarium*, looking forward to 2050.

Addressing the gaps, barriers and challenges

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

- The published literature used to determine climate parameters for *Fusarium* were conducted in laboratory conditions, not field conditions. Many of the studies also lacked clarity on whether stated temperatures were minimums, means or maximums.
- Field trial data for minimum and maximum temperature ranges and rainfall (total or cumulative) for optimum infection of cotton by the specific genotype of *Fusarium* present in Australia have not been published.

This report aims to highlight these gaps to assist in directing future research and project development. The Climate Vulnerability Assessment Project modelled a number of biosecurity risks important to NSW, but others remain unstudied. Consideration should be given to modelling other significant biosecurity risks, as listed in the national priority list of exotic environmental pests, weeds and diseases[12].

Expanding the spatial extent of the current modelling to Australia-wide would provide valuable information for future industry planning and assist with inter-jurisdictional engagement, particularly where climate change is likely to shift biosecurity risks into new geographic regions.

[12] 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 how management and investment should be prioritised to sustain and enhance cotton production and to limit the impacts of increased climate suitability for *Fusarium*.

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 will require investment in management strategies and education to underpin future growth and sustainability for the cotton industry.

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 *Fusarium* are the impacted hosts:

- Cotton
- *Verticillium*

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.

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 *Fusarium* focus group. 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 Karen Kirkby from the Biosecurity Team of the NSW Department of Primary Industries and Regional Development, who contributed to this work.

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, James Lawson, Joanna Pardoe, Paris Capell, David Allingham, Chris Nunn, Rebecca Darbyshire, Gary Allan, Mary Timms and Lachlan Philips.

Images of *Fusarium* on cover, p. 4, 21, 25 sourced from Le, D. P., Nguyen, C. P. T., Kafle, D., Scheikowski, L., Montgomery, J., Lambeth, E., Thomas, A., O'Keeffe, K., Shakeshaft, B., Young, A., Mckay, A., Twine, A., Hudson, E., Jackson, R., & Smith, L. J. (2022). Surveillance, Diversity and Vegetative Compatibility Groups of *Fusarium oxysporum f. sp. vasinfectum* Collected in Cotton Fields in Australia (2017 to 2022). *Pathogens*, *11*(12), 1537.

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Appendix

Figure A1. April climate suitability for *Fusarium*

The panel is comprised of 7 maps: A) shows the historic 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). Cotton valleys where *Fusarium* has been observed are marked by the blue polygons.

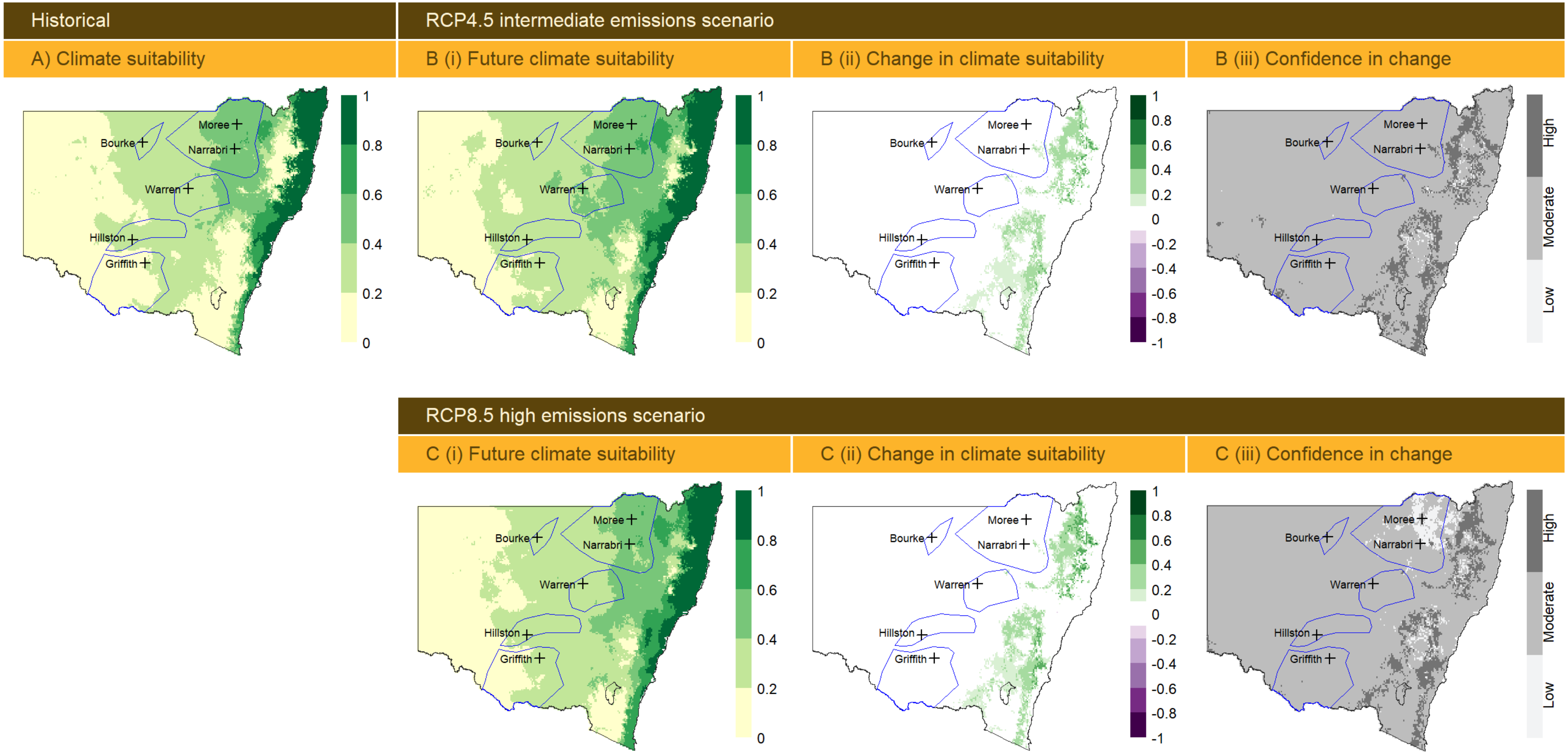


Figure A2. June climate suitability for *Fusarium*.

The panel is comprised of 7 maps: A) shows the historic 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). Cotton valleys where *Fusarium* has been observed are marked by the blue polygons.

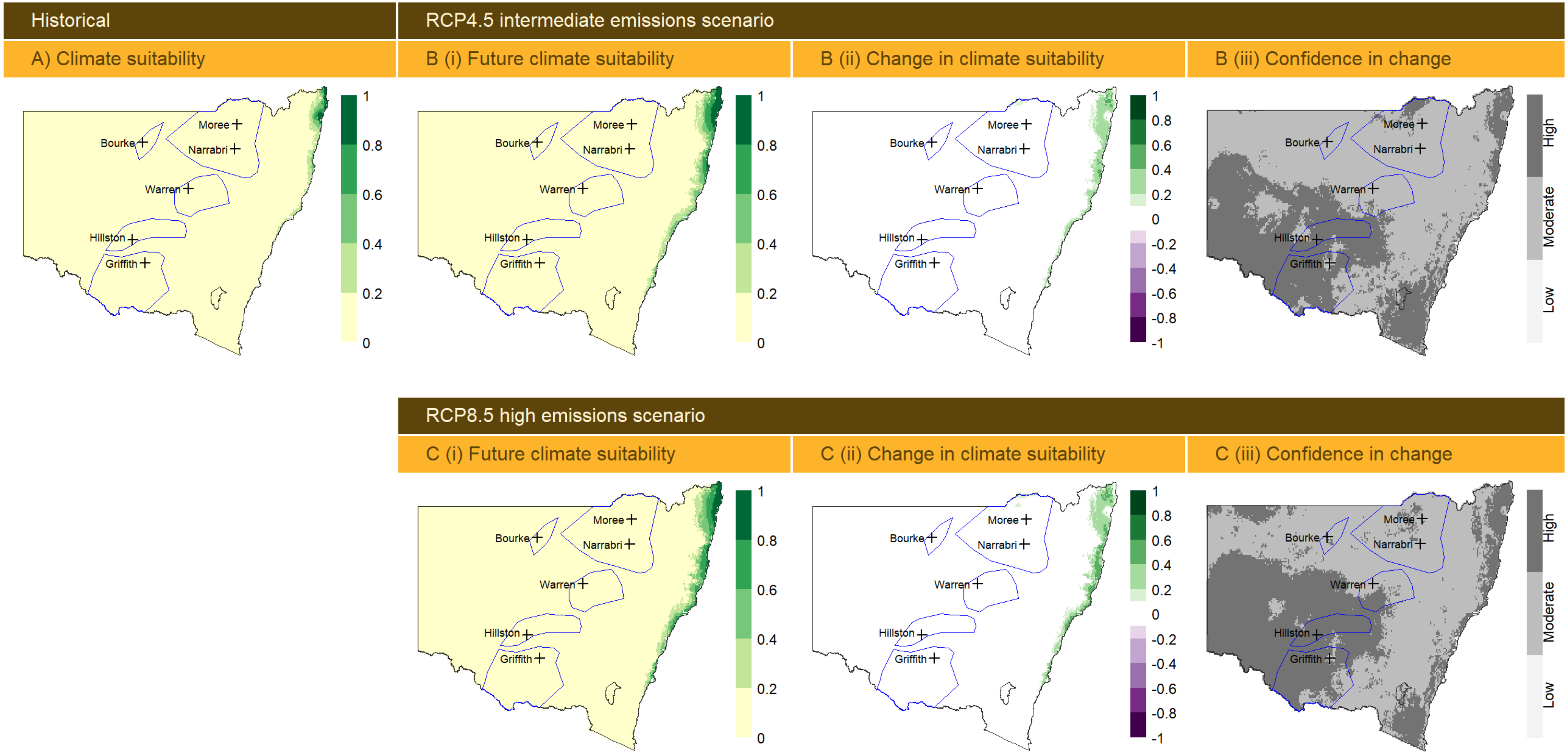


Figure A3. July climate suitability for *Fusarium*.

The panel is comprised of 7 maps: A) shows the historic 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). Cotton valleys where *Fusarium* has been observed are marked by the blue polygons.

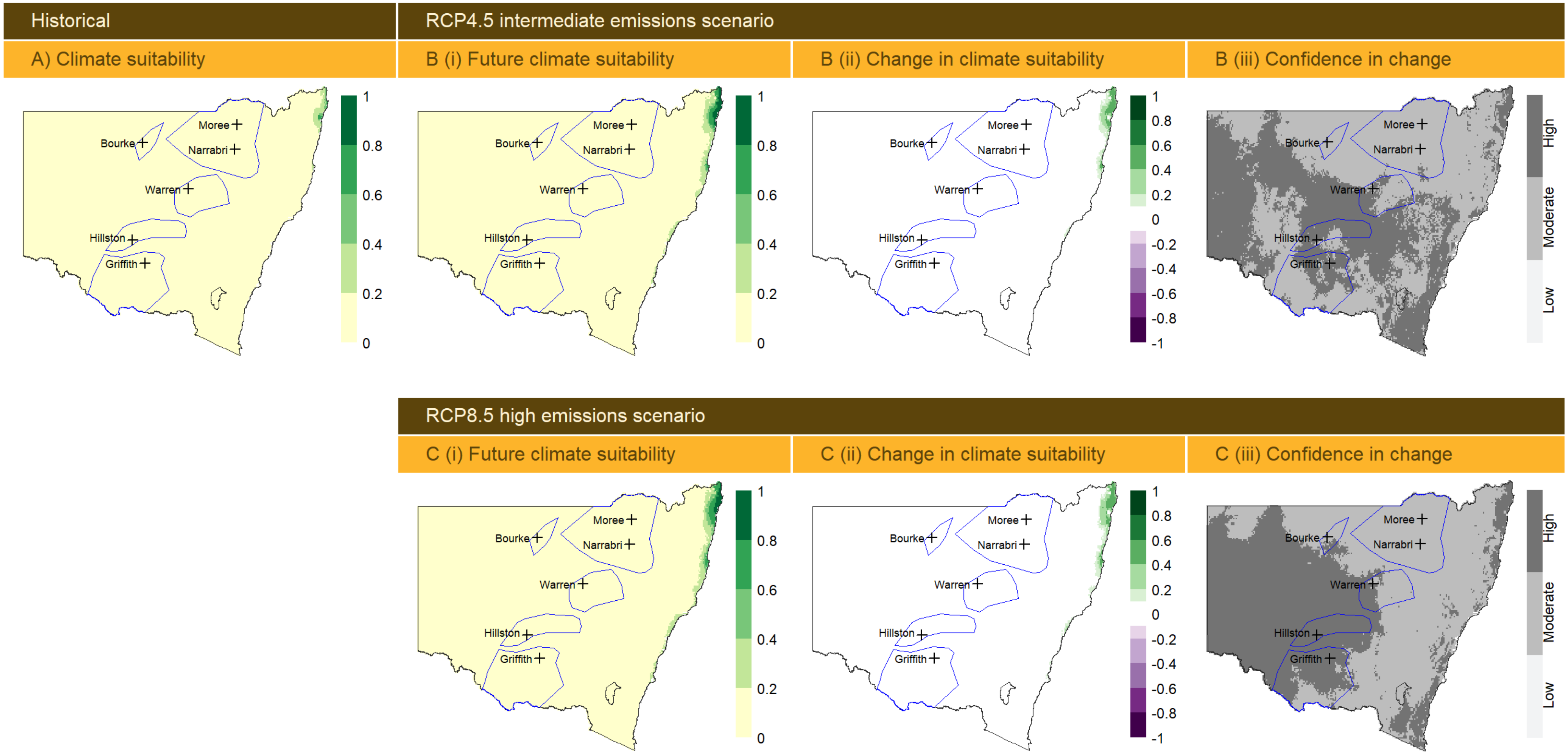


Figure A4. August climate suitability for *Fusarium*.

The panel is comprised of 7 maps: A) shows the historic 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). Cotton valleys where *Fusarium* has been observed are marked by the blue polygons.

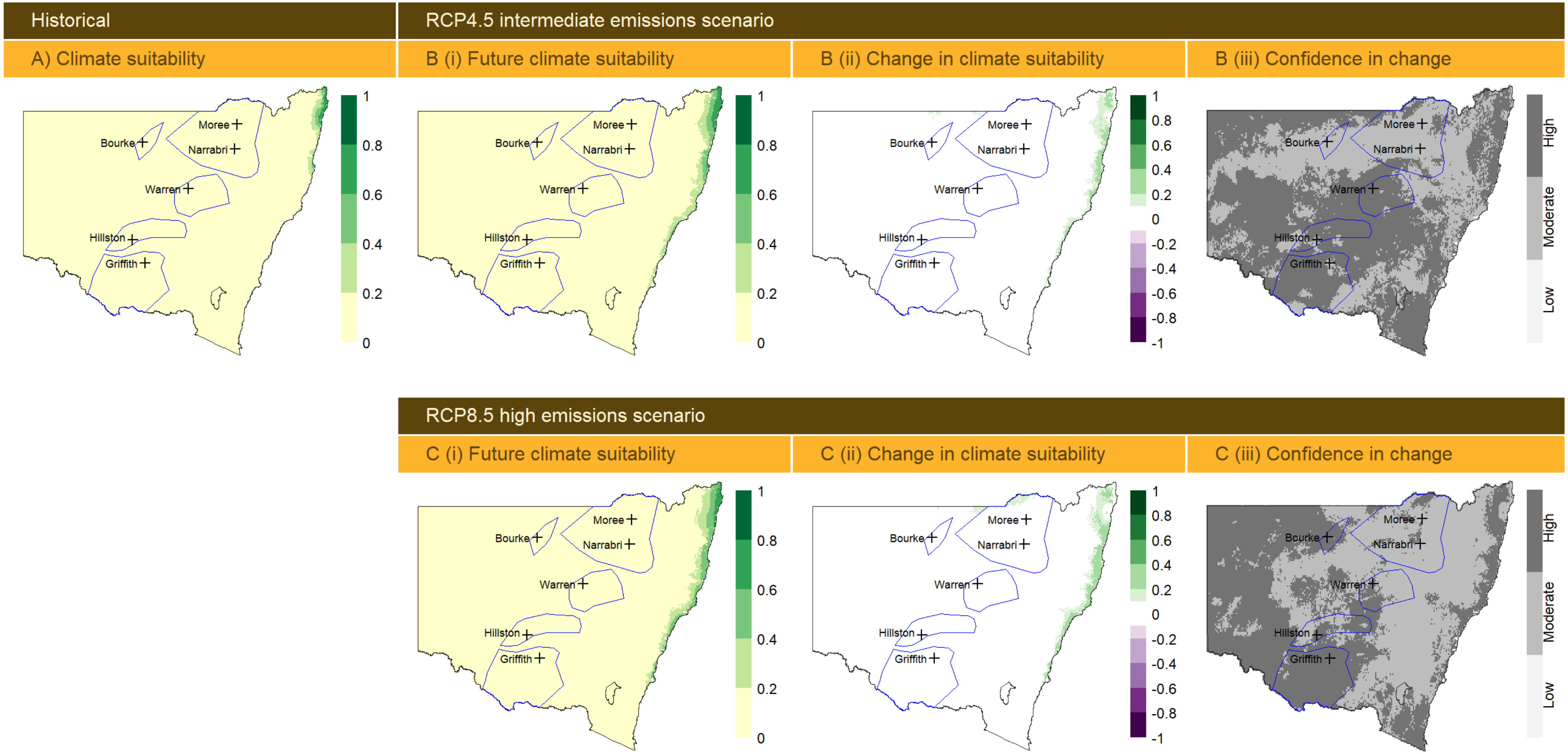


Figure A5. October climate suitability for *Fusarium*.

The panel is comprised of 7 maps: A) shows the historic 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). Cotton valleys where *Fusarium* has been observed are marked by the blue polygons.

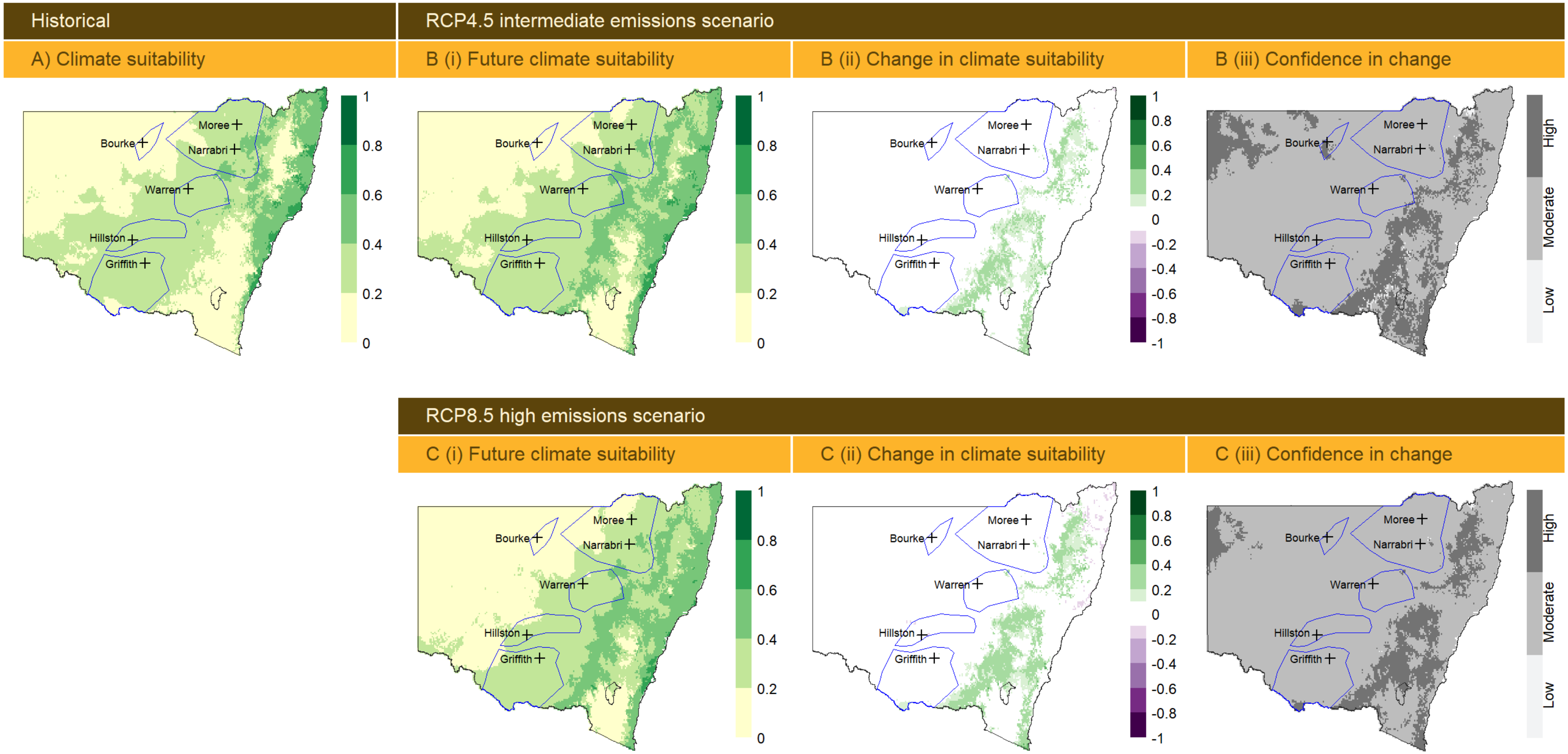
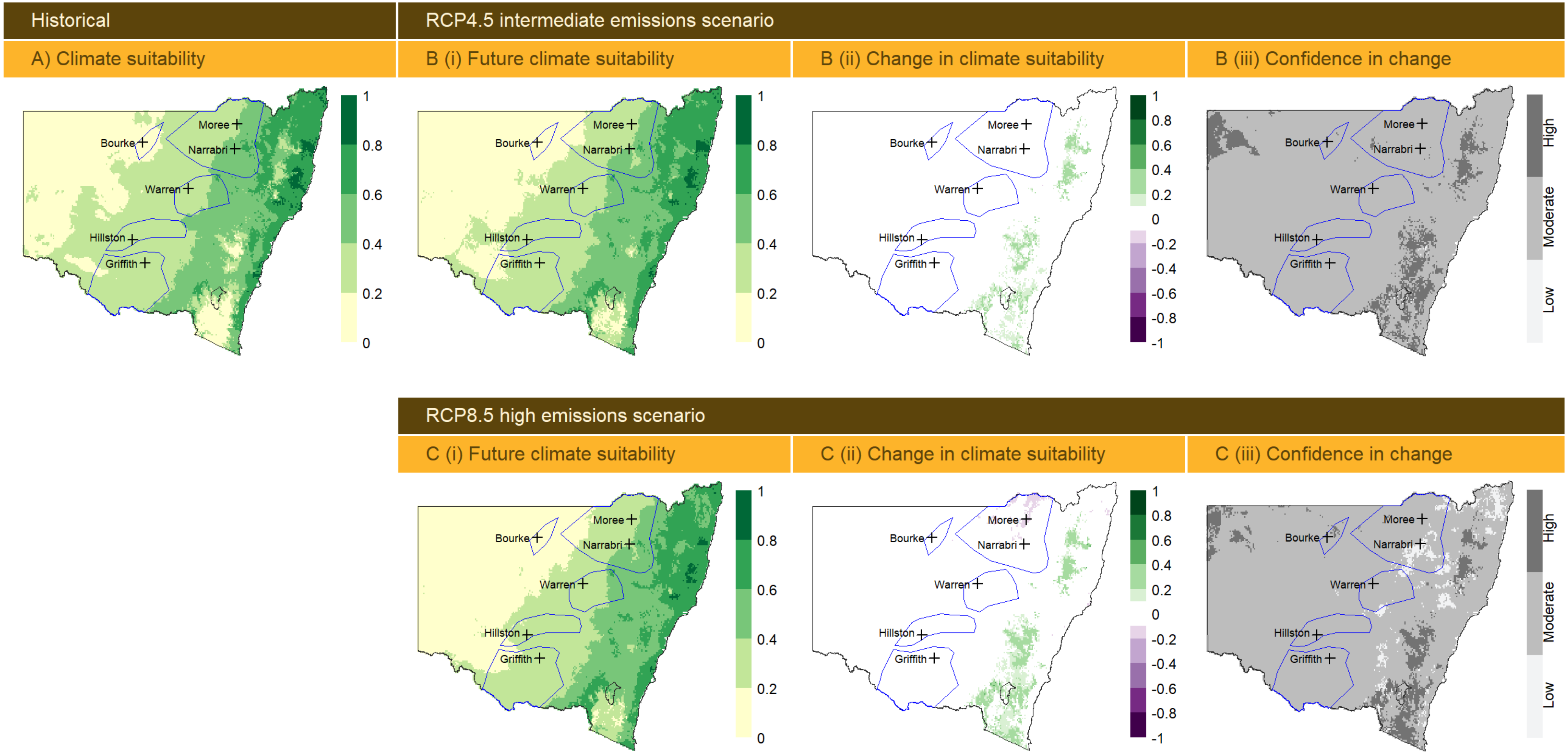


Figure A6. November climate suitability for *Fusarium*.

The panel is comprised of 7 maps: A) shows the historic 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). Cotton valleys where *Fusarium* has been observed are marked by the blue polygons.



Primary Industries Climate Change Research Strategy

Climate Vulnerability Assessment

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