Department of Primary Industries
and Regional Development

# Buffalo Fly

## Results Report

Climate Vulnerability Assessment

NSW GOVERNMENT

*Authors*

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

*Funding*

The Climate Vulnerability Assessment has been completed as part of the NSW Primary Industries Climate Change Research Strategy funded by the NSW Climate Change Fund.

*Suggested citation*

Department of Primary Industries and Regional Development (2025) Climate Vulnerability Assessment Buffalo Fly Results Report. https://www.dpi.nsw.gov.au/dpi/climate/climate-vulnerability-assessment/publications-and-reports/Climate-Vulnerability-Assessment-Buffalo-Fly-Results-Report.pdf, accessed on [insert access date].

*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.

TITLE: Buffalo Fly Results Report
ISBN: 978-1-76058-887-8



## Table of Contents



## 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 buffalo fly model from the Climate Vulnerability Assessment. The report introduces the buffalo fly 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 buffalo fly.

# 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.

Buffalo fly significantly impact livestock production. The suitability of land for livestock is determined by climate, topography and water availability. Due to the variety of climate needs of the beef and dairy industries, the majority of this production is found in the eastern half of NSW.

## A changing climate is impacting primary industries

Australia has one of the most variable climates in the world, and primary producers have always managed climate variability. Now, they are planning for and adapting to future climate change. Climate change refers to human-induced changes in long-term climate patterns at global and regional scales, and it adds a new dimension to the challenge of producing food and fibre within Australia's variable climate. Its effects include increasing temperatures, changes in rainfall patterns and the intensification of extreme weather events such as heatwaves and heavy rain 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 will likely worsen their impact in NSW by altering their range, distribution, and 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 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 we reviewed have 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 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 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.

# Buffalo fly in NSW

Buffalo fly (*Haematobia irritans exigua*) is an introduced small livestock parasite that primarily affects cattle and buffalo. It is found mainly in northern Australia, including north-eastern NSW and costs the Australian beef cattle industry an estimated $99 million annually[6].

Adult flies lay their eggs in fresh dung, and live on cattle, biting them and feeding on their blood up to 40 times a day. This causes irritation, allergies and sores that can reduce the productivity of heavily infested cattle.

Buffalo fly occurs in both endemic and seasonal regions in NSW (Figure 1). In endemic areas, the flies are an ever-present pest, especially from November to April when their numbers increase greatly due to warmer weather. Flies overwinter (see call-out box below) in low numbers in sheltered, moist and hilly areas that are less likely to be affected by frost. The population increases and spreads from endemic regions into seasonal regions during spring and summer. During the wet years of 2010–11, buffalo fly was detected as far south as Maitland and as far west as Bourke.

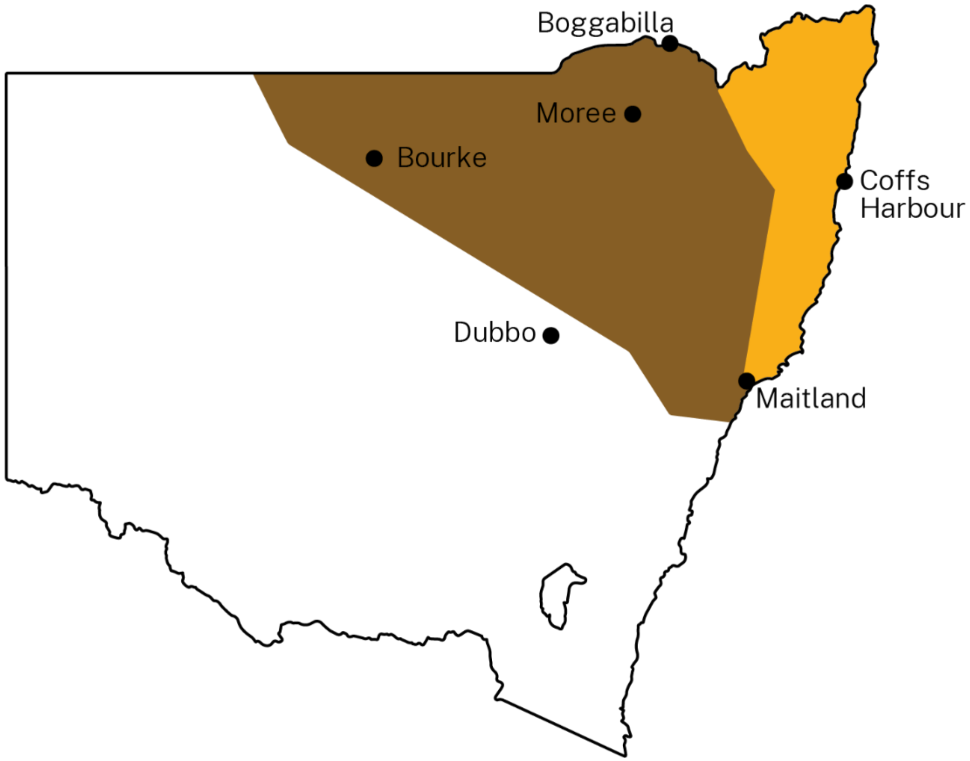



*Figure 1: Endemic (yellow) and seasonal (brown) distribution of buffalo flies across NSW. Bourke, Dubbo and Maitland represent the edges of the seasonal distribution.*

## What is overwintering?

'Over-wintering' refers to the survival of relatively small populations of a pest through the cold winter months. They survive by sheltering in small pockets where conditions are favourable and provide protection from the cold. These types of areas provide a way for organisms which would not survive low temperatures to persist throughout the year. For insect pests, such as fruit flies, this can allow the establishment of endemic populations. Organisms can use this type of sheltering to survive other hostile climatic conditions such as drought, high rainfall, cold, heat or even bushfire, if appropriate habitat features are available.

[6] Lane J, Jubb T, Shephard R, Webb-Ware J and Fordyce G. (2015) Priority list of endemic diseases for the red meat industries. Project Report. Meat & Livestock Australia Limited.

# Climate Vulnerability Assessment framework

The Climate Vulnerability Assessment was intended 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. These models were developed 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 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[7], reflecting the consensus reached by the focus group experts.

[7] 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 plant or animal growth in the absence of other limiting factors[8].

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 buffalo fly and key results showing important changes to future climate suitability for buffalo fly, 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 buffalo fly 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 buffalo fly 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 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.

[8] 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 buffalo fly model

For more information about the MCA modelling used in this project, 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 4Error! Reference source not found.) categorises climate variables to assess their impact on buffalo fly. Each category (for example, a temperature between 15 and 30°C) is assigned a rating, R, between 0 and 1 that indicates how well it suits buffalo fly, from unfavourable (R=0) to optimal (R=1). This is repeated for each life stage.

## Modules used in buffalo fly MCA

The buffalo fly MCA model uses the following standardised techniques, referred to as 'modules', to produce ratings from the climate variables. Four modules were used in this model:

- **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**: Define extreme climate conditions that are fatal to the life stage. If these limits are reached, then the life stage dies (indicated by an R = -2 in Figure 4). 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 adult fly, these were monthly mean temperature and cumulative rainfall. This module was used for 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 12 and 25°C with cumulative rainfall of between 48 and 170 mm. 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 buffalo fly.

## Buffalo fly 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 buffalo fly model were:

- a specific organism is described,
- egg, larvae, pupae lifecycle stages, adults excluded due to the microclimate of the host,
- breeding adults always present,
- susceptible host available,
- constant fresh dung (solid consistency as preferred by the fly), and
- no treatment or control for buffalo fly is applied.

The exclusions for the buffalo fly model were:

- microclimates (dung/soil/grass),
- differences in male/female tolerances,
- dung moisture (relative humidity as a proxy),
- dung beetles, and
- impact of overwintering on population dynamics.

# Buffalo fly life stages

The buffalo fly model has been divided into key life cycle stages, and the model has been repeated each month, as the flies' life cycle is short and multiple cycles can occur within a month (Figure 3). Using model monthly outputs allows us to assess the influence of climate during any given month on the buffalo fly 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 buffalo fly hosts, informing planning for future education and management. The life stages used in this modelling are egg, larvae and pupae. The adult stage was excluded due to the impact of the host microclimate on the flies as they reside on the host. Climate conditions were considered for each month and each life stage.

*Table 1: The life stages of the buffalo fly life cycle assessed in the model.*

| Life stage | Description |
|---|---|
| Egg | Females lay eggs on fresh dung. The eggs hatch within 24 hours. |
| Larvae | Larvae live in the dung for 4-5 days before they pupate. |
| Pupae | Pupae live in dung or soil for 5-7 days before an adult emerges. |

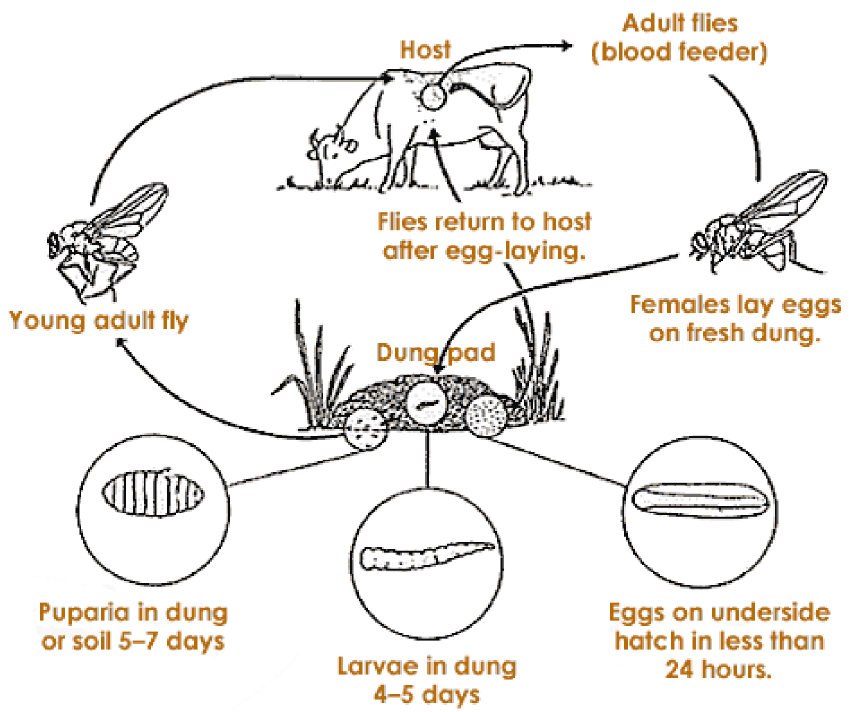



*Figure 3: The lifecycle of buffalo fly.[9]*

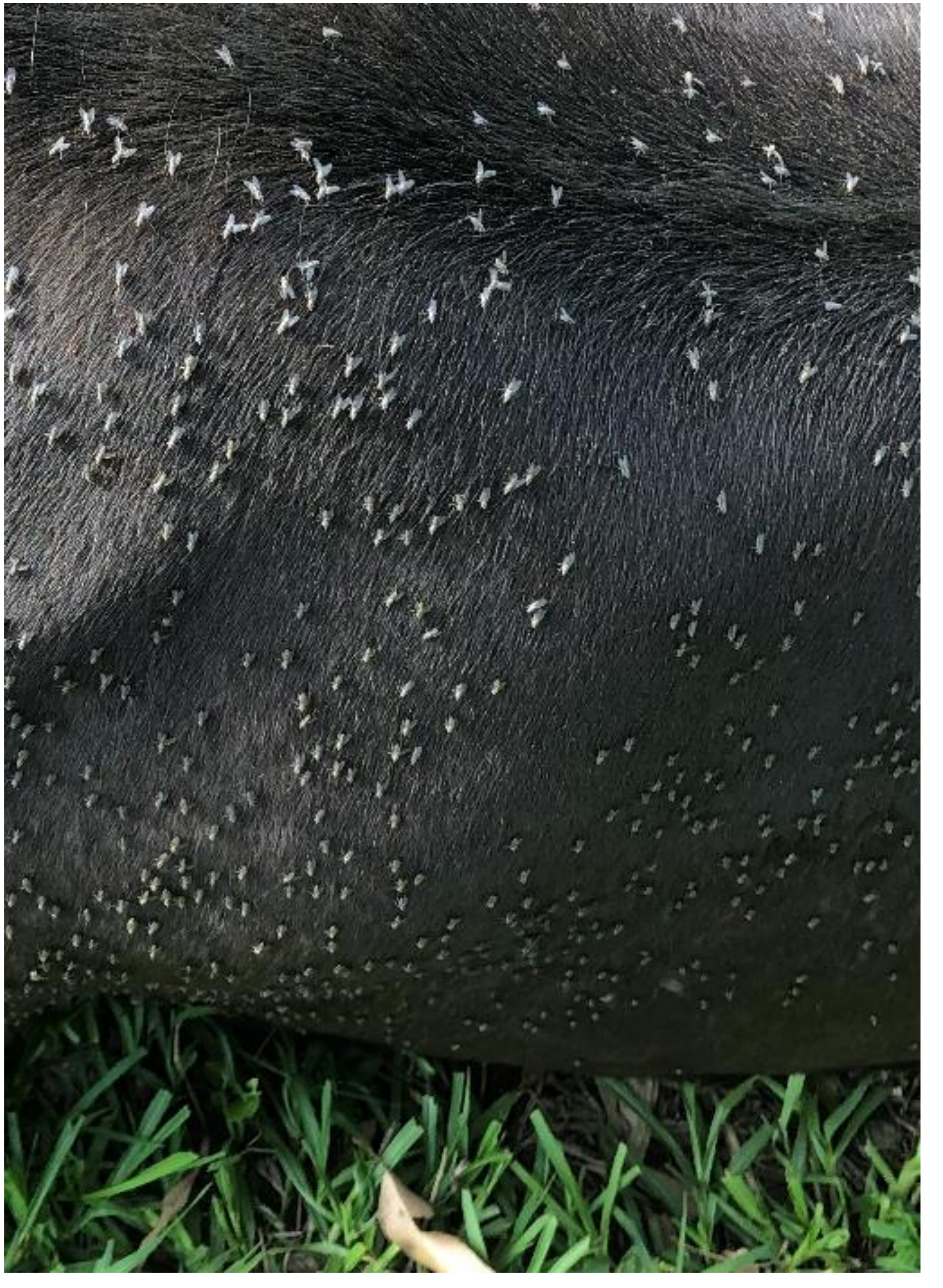
[9] Spence, S. (2007) Buffalo flies and their control. Primefacts, NSW DPI.

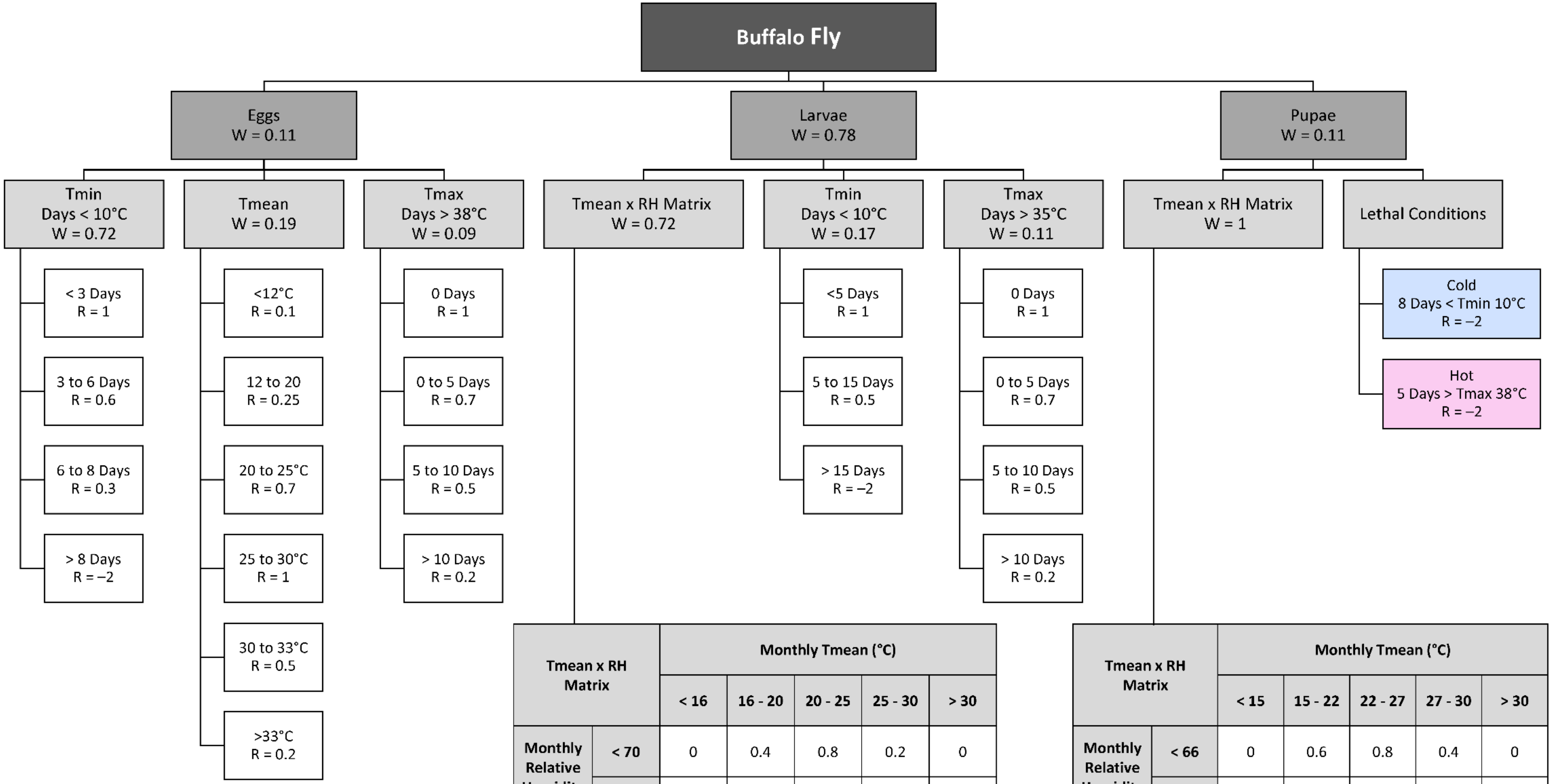
## Final buffalo fly model

The main MCA model structure with weightings for buffalo fly is shown on the following page (Figure 4). The model has been divided into the key life stages for buffalo fly: egg, larvae and pupae. Each life stage has a number of climate variables that impact climate suitability. Climate variables are categorised into ideal conditions and further categorised to capture conditions less than or greater than the ideal.

Some climate variables are presented as matrices, whereby the interaction of two climate variables is captured. Mean temperature and relative humidity are key variables for the larvae and pupae 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 buffalo fly. The assigned rating for each temperature and relative humidity combination reflects how the different combinations impact the larvae and pupae stages, considering their sensitivity to climate and exposure. For more information, please refer to the Climate Vulnerability Assessment Methodology Report.






| Tmean x RH Matrix | | Monthly Tmean (°C) | | | | |
|---|---|---|---|---|---|---|
| | | < 16 | 16 - 20 | 20 - 25 | 25 - 30 | > 30 |
| Monthly Relative Humidity (%) | < 70 | 0 | 0.4 | 0.8 | 0.2 | 0 |
| | > 70 | 0.1 | 0.8 | 1 | 0.6 | 0 |

| Tmean x RH Matrix | | Monthly Tmean (°C) | | | | |
|---|---|---|---|---|---|---|
| | | < 15 | 15 - 22 | 22 - 27 | 27 - 30 | > 30 |
| Monthly Relative Humidity (%) | < 66 | 0 | 0.6 | 0.8 | 0.4 | 0 |
| | > 66 | 0.1 | 0.85 | 1 | 0.7 | 0.1 |

*Figure 4: MCA model hierarchical structure and model components for buffalo fly. 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[10], and the median of these models was used to produce ensemble future projection climate suitability maps.

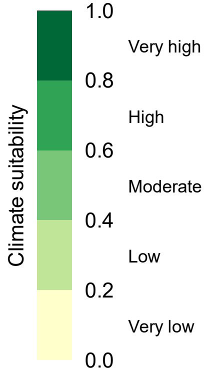



*Figure 5: Colour scheme for the climate suitability maps*

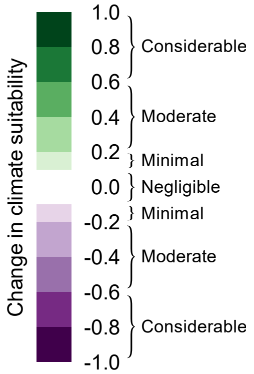



Figure 6: Colour scheme for the change in climate suitability maps

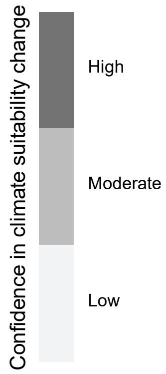



*Figure 7: Colour scheme for the confidence in the change in climate suitability maps*

### *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.

[10]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 9) and confidence (see colour scheme in Figure 10) 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.

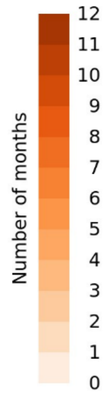



*Figure 8: Colour scheme for the number of highly suitable months maps*

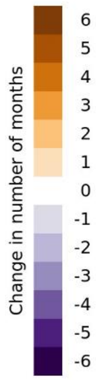



*Figure 9: Colour scheme for the change in the number of highly suitable months maps*

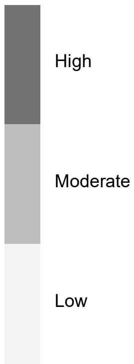



*Figure 10: Colour scheme for confidence in the change in the number of highly suitable months maps*

### *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 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.

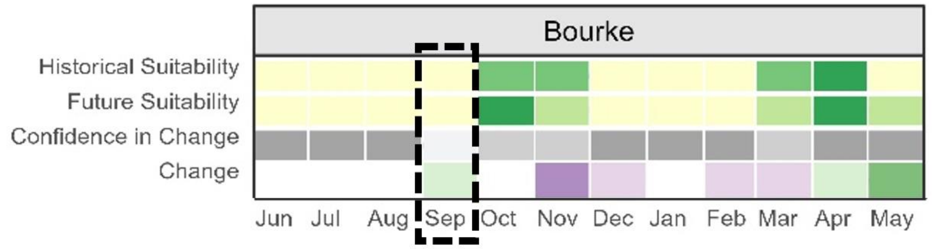
Calendar plots use the same colour categorisation as the climate suitability panels (see page 10, 'Interpreting climate suitability colour schemes'), except that the 'change' scale uses 7 colours instead of 11, condensing them into the following categories: negligible, minimal, moderate and considerable.

There are two important points to note when interpreting calendar plots:

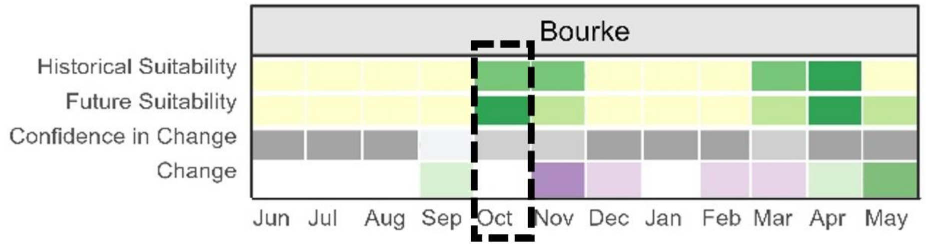
One occurs when the historical and future climate suitability categories are the same, but the 'change in suitability' is non-negligible (green or purple). This situation is shown in **Example 1** and has arisen from a historical September climate suitability of 0.000 and a future climate suitability 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 buffalo fly

*Changes in buffalo fly climate suitability are likely to create challenges for the beef and dairy industries in NSW.*

This section provides a selection of key results for the buffalo fly 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 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 (on a monthly basis), presented as calendar plots. Each map includes the outline (in blue) of key buffalo fly-related regions in NSW. These regions are shown in Figure 11, and will be referred to as the 'endemic' and 'seasonal' regions in the results section of this report.

The locations shown in Figure 11 are used to study the annual changes for buffalo fly. These sites were selected because they align with surveillance locations for buffalo fly in NSW, and they represent some of the key areas where Buffalo fly has an impact.

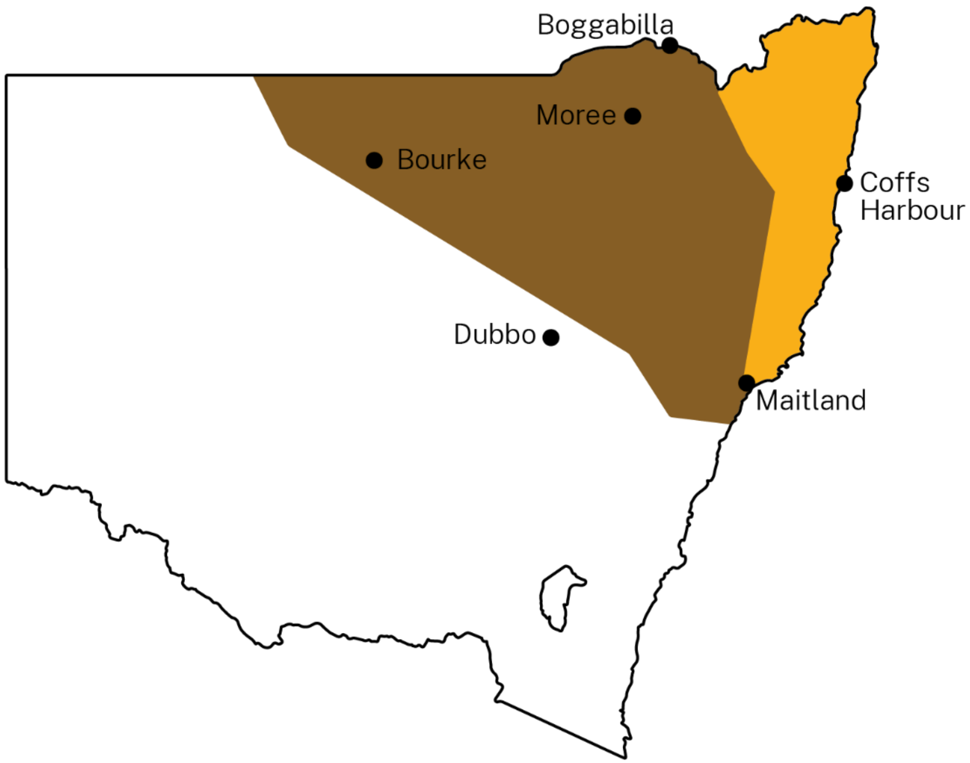



*Figure 11: Endemic (yellow) and seasonal (brown) distribution of buffalo flies across NSW. Bourke, Dubbo and Maitland represent the edges of the seasonal distribution.*

## Overall climate impacts

### Annual climate suitability trends: impacts on different regions in NSW

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 buffalo fly.

Figure 12 shows that by 2050, the number of highly suitable months in the endemic region and areas of the seasonal region are likely to increase by 1 to 2 months per year under both emissions scenarios (*moderate to high confidence*).

Beyond the endemic and seasonal regions, a similar increase in suitability of 1 to 2 months is also expected along the coast, extending to the border with Victoria (*high confidence*).

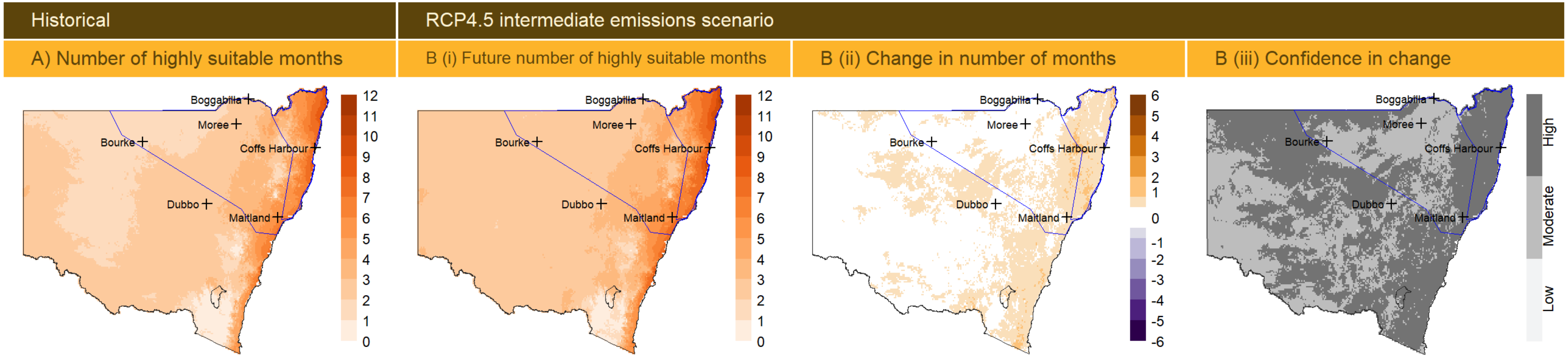
## Changes in monthly climate suitability

### Spatial trends: How climate change will alter buffalo fly distribution across NSW

Climate change is likely to impact the spatial distribution of buffalo fly across NSW due to changes in climate suitability. These changes vary across the year. In this section, the spatial distribution of buffalo fly based on climate suitability is examined for key months of the year. Potential changes in the endemic and seasonal buffalo fly regions (Figure 11) include:

- **February to May and September to November** – there are likely to be minimal to moderate increases in climate suitability in endemic *(moderate to high confidence)* and seasonal regions *(low to high confidence)*. The increases are likely to be greatest under the high emissions scenario. For April and October, see Figures 13 and 14, respectively; for other months see Appendix Figures A5, A6, A8, A12 and A14.
- **June to August** –there are likely to be minimal to moderate increases in climate suitability in the endemic region. The increase is likely to be greatest under the high emissions scenario (*moderate to high confidence*) (see Appendix Figures A9, A10 and A11).
- **November to March** – there are likely to be minimal to moderate decreases in climate suitability in the seasonal region. The decrease is likely to be greatest under the high emissions scenario (*low to high confidence*) (see Appendix Figures A14, A15, A4, A5 and A6).

# Buffalo fly: number of highly suitable months




**Findings:** The number of highly suitable months in a year varies across the state. In coastal NSW, most months of the year have historically been highly suitable for Buffalo Fly, with the number of highly suitable months expected to increase in the future. Inland, where the number of highly suitable months is likely to increase, Buffalo Fly is expected be active in months during which they have not been, historically, due to less favourable climate suitability in the past.

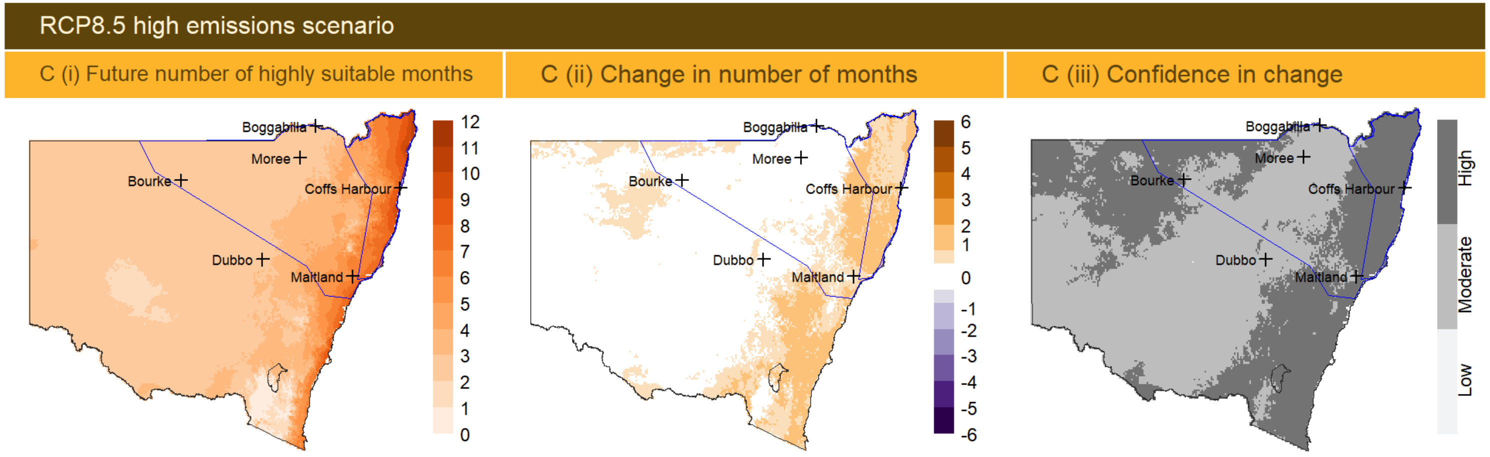
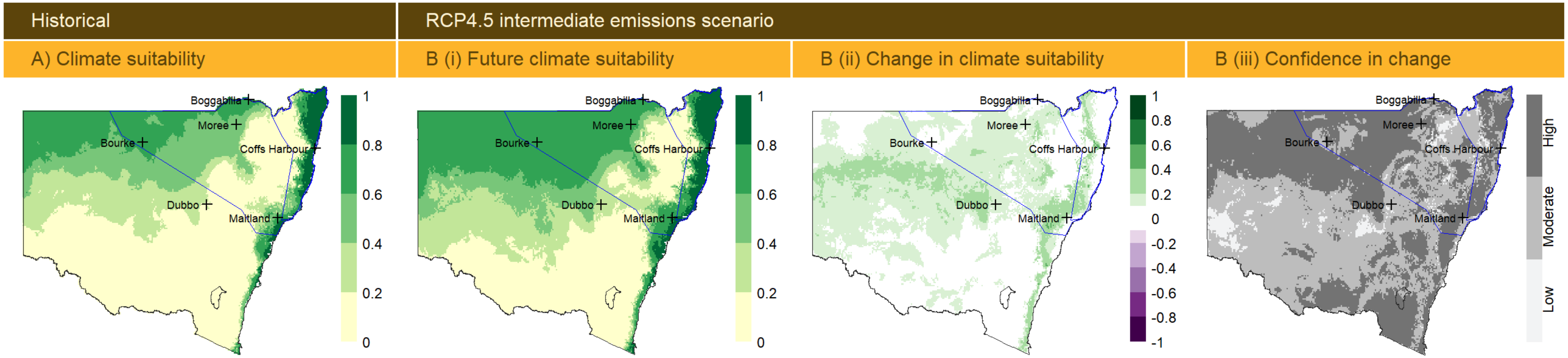



*Figure 12: Number of highly suitable months for buffalo fly. The number of highly suitable months measures the months in which climate suitability is greater than or equal to 0.6. The panel is comprised of 7 maps: A) shows the historic number of highly suitable months; B) and C) show the future number of highly suitable months for the intermediate and high emissions scenarios, respectively; i) shows 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 of importance where buffalo fly are currently found are marked by black crosses, and the blue polygons show the endemic (northeast) and seasonal (north) buffalo fly regions.*

# Buffalo fly: overall climate suitability for April




**Findings:** Climate suitability is expected to minimally to moderately increase along most of the coast and inland regions within the seasonally Buffalo fly areas. Warmer temperatures in all life stages lead to this increase, and these changes in April are likely to lead to higher populations impacting the coastal dairy industries throughout the year in NSW.

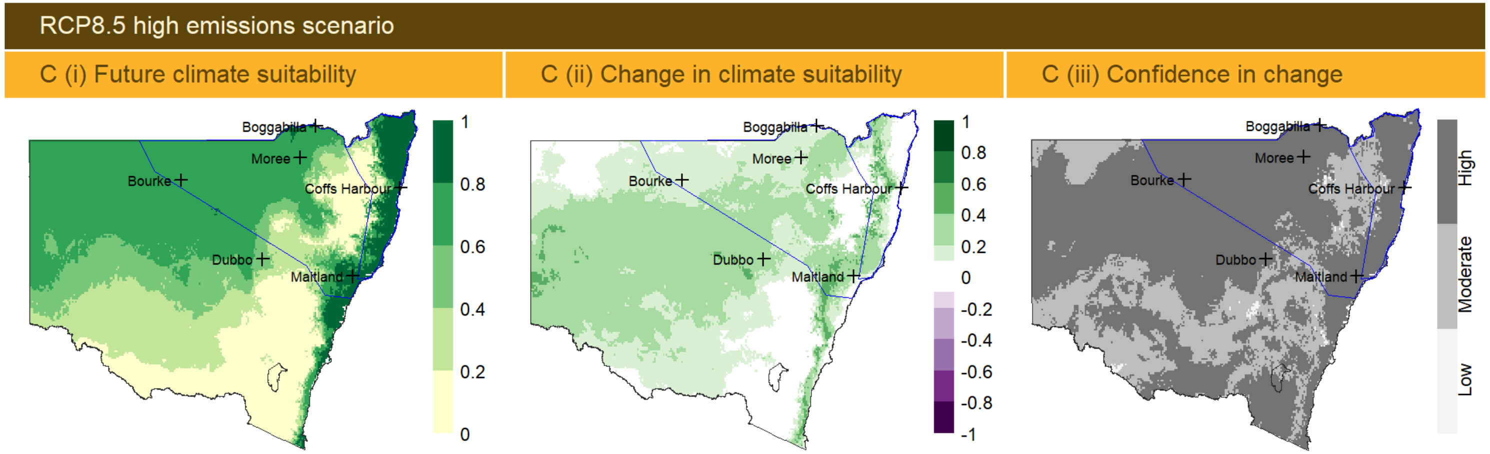
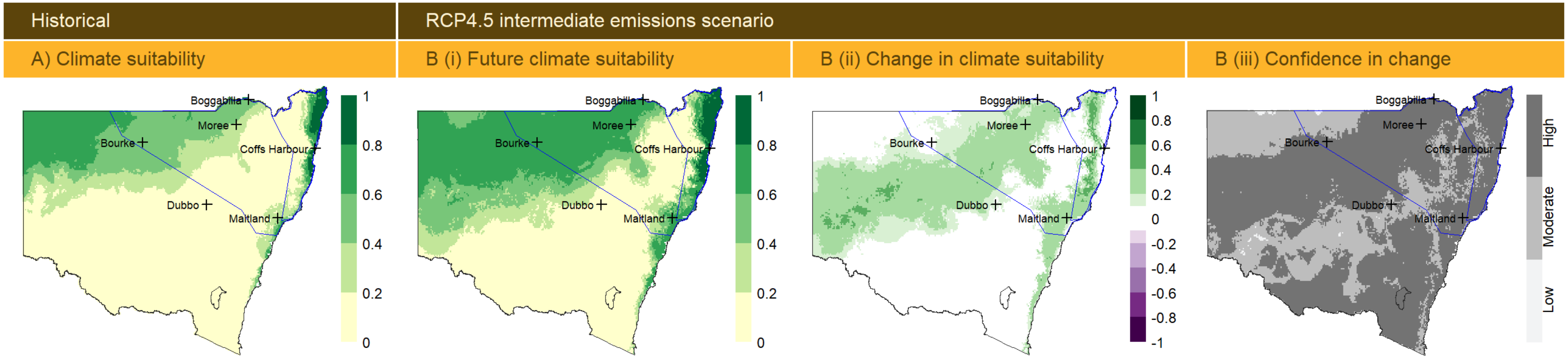



*Figure 13: Overall climate suitability for buffalo fly in NSW for April. The panel is comprised of 7 maps: A) shows the historic climate suitability; B) and C) shows future climate suitability for the intermediate and high emissions scenarios, respectively; i) shows future climate suitability, ii) shows 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 of importance where buffalo fly are currently found are marked by black crosses, and the blue polygons show the endemic (northeast) and seasonal (north) buffalo fly regions.*

# Buffalo fly: overall climate suitability for October




**Findings:** Climate suitability is expected to minimally to moderately increase along the coast to the south of Coffs Harbour and inland from Bourke to Dubbo. Warmer temperatures in all life stages lead to this increase, and these changes in October are likely to lead to higher populations impacting the coastal dairy industries throughout the year in NSW.

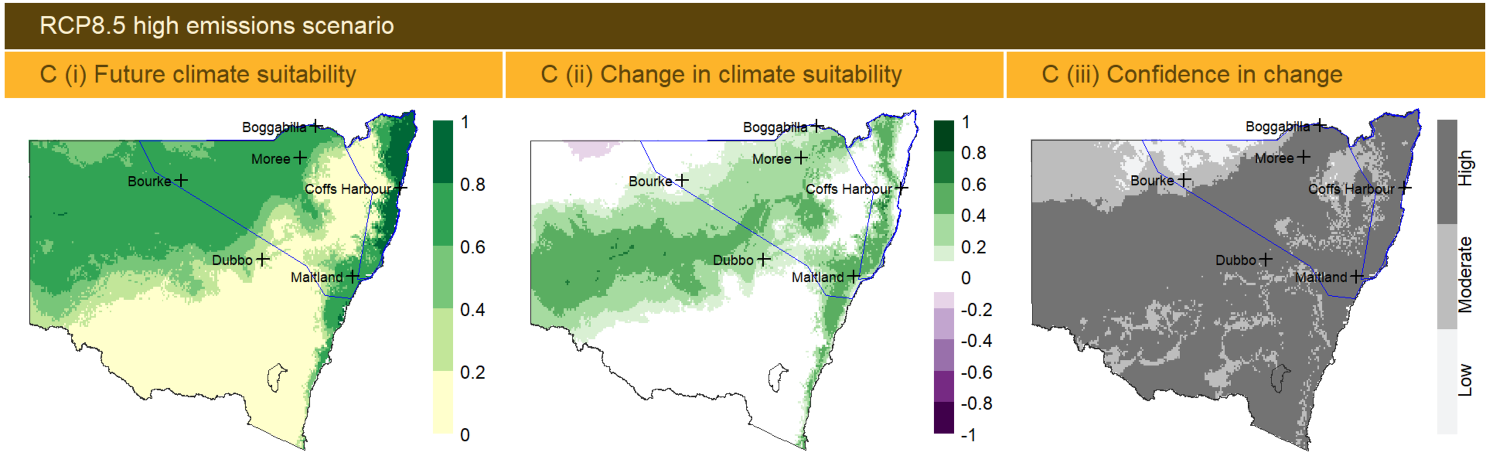


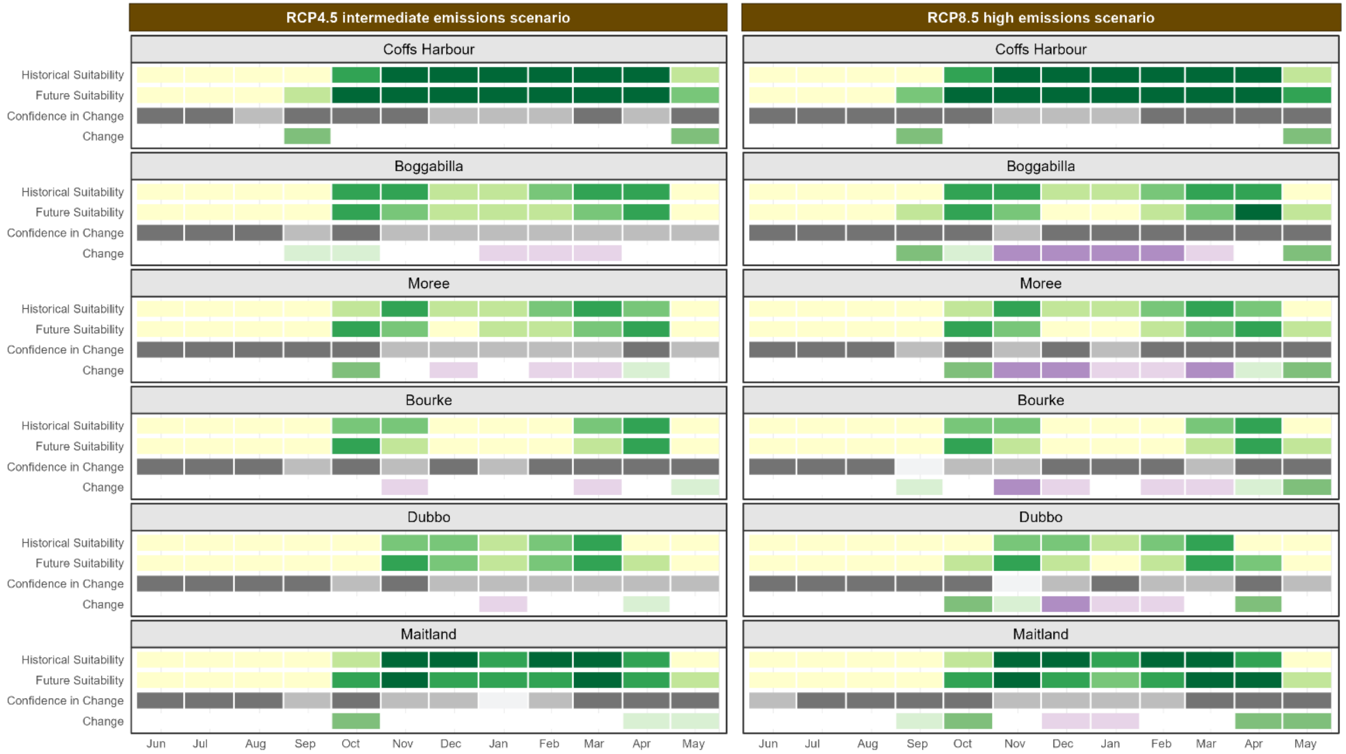

*Figure 14: Overall climate suitability for buffalo fly in NSW for October. The panel is comprised of 7 maps: A) shows the historic climate suitability; B) and C) shows future climate suitability for the intermediate and high emissions scenarios, respectively; i) shows future climate suitability, ii) 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 of importance where buffalo fly are currently found are marked by black crosses, and the blue polygons show the endemic (northeast) and seasonal (north) buffalo fly regions.*

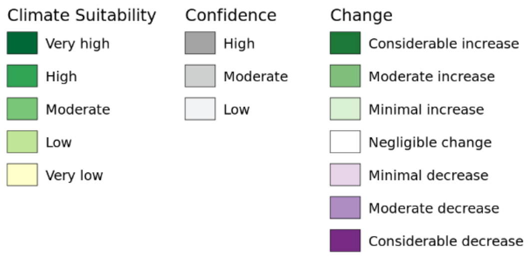
## Monthly trends at buffalo fly sites: How climate change will alter climate suitability throughout the year.

Figure 15, the overall calendar plot, shows the expected temporal change in monthly climate suitability throughout the year around sites of importance for buffalo fly. Coffs Harbour is in the endemic region, while Boggabilla, Moree, Bourke Dubbo and Maitland are within the seasonal region for buffalo fly in NSW (Figure 11). An analysis of future climate suitability around these sites provides insights into potential future monthly trends by 2050.

- Under both emissions scenarios, the climate suitability for buffalo fly is expected to increase in May and September for Coffs Harbour (*high confidence*).
- Minimal to moderate increases in climate suitability in April and May for Moree, Bourke, Dubbo, and Maitland under both emissions scenarios (*moderate to high confidence*) and Boggabilla under the high emissions scenario (*high confidence*).
- Minimal to moderate increases in climate suitability in September and October for Boggabilla, Moree, and Maitland under both emissions scenarios (*moderate to high confidence*) and Bourke and Dubbo under the high emissions scenario (*low to high confidence*).
- Minimal to moderate decreases climate suitability from November through to March for Boggabilla, Moree, Bourke and Dubbo under both emissions scenarios (*moderate to high confidence*) and Maitland under the high emissions scenario (*moderate confidence*).

# Buffalo fly: climate suitability calendar for the overall model




**Findings**: Climate suitability is expected to decrease during the warmer months for most inland locations, with the decreases more severe under the high emissions scenario.

The climate suitability is likely to increase in late autumn and early spring across all sites. For some sites this is likely to be a change from very low climate suitability to low climate suitability and may lead to seeing buffalo flies occurring in months they have not previously been seen.

*Figure 15: Climate suitability calendar for the buffalo fly overall model. 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.*

## Climate impacts on life stages

*Changes in climate suitability are likely across all key life stages of buffalo fly by 2050 under both emissions scenarios.*

### Eggs

Eggs are laid in fresh dung where they hatch into larvae within 15 to 24 hours. This stage is sensitive to cool temperatures during winter and extreme heat during summer which risks desiccation.

The number of highly suitable months each year for the egg life stage is likely to increase by 1 to 2 months across the state under both emissions scenarios (*moderate to high confidence*). The alpine region is likely to retain historical numbers of highly suitable months under both emissions scenarios (*moderate to high confidence*) (Appendix Figure A1).

Figure 16, the egg calendar plot, shows the expected change in monthly climate suitability throughout the year around sites of importance for buffalo fly. These changes in climate suitability are:

- **increased climate suitability** in spring and autumn for Coffs Harbour, Boggabilla, Moree, Bourke, Dubbo and Maitland under both emissions scenarios (*moderate to high confidence*).
- **maintain historical climate suitability** in summer and winter for Coffs Harbour, Boggabilla, Moree, Bourke, Dubbo and Maitland under both emissions scenarios (*moderate to high* confidence).

### Larvae

The larvae live inside the dung and feed for 4 to 5 days until they pupate. The larvae are sensitive to cooler temperatures during winter and extreme heat during summer.

The number of highly suitable months each year for the larvae life stage is likely to increase by 1 to 2 months in the endemic region and in the northeast of the seasonal region under both emissions scenarios (*moderate to high confidence*). West of the Great Dividing Range is likely to retain historical numbers of highly suitable months under both emissions scenarios (*moderate to high confidence*). (Appendix Figure A2).

Figure 17, the larvae calendar plot, shows the expected change in monthly climate suitability throughout the year around sites of importance for buffalo fly. These changes in climate suitability are:

- **increased climate suitability** in spring and autumn for Coffs Harbour, Boggabilla, Moree, Bourke, Dubbo and Maitland and for Coffs Harbour in June under both emissions scenarios (*moderate to high confidence*).
- **decreased climate suitability** in March for Boggabilla and Moree under the intermediate emissions scenario and additionally November in the high emissions scenario and in summer for Coffs Harbour and Maitland under the high emissions scenario (*moderate to high confidence*).

## Pupae

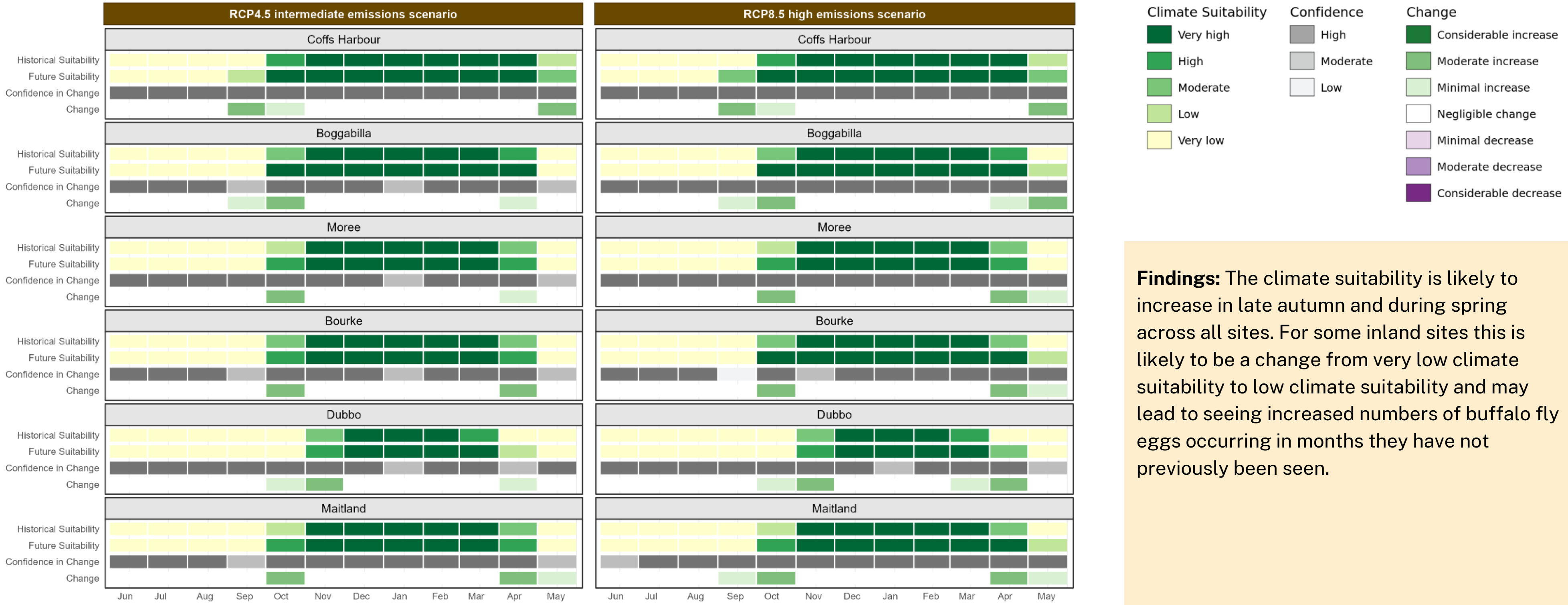
The larvae migrate from the dung and burrow into the soil to pupate. Adults emerge in 3 to 5 days. This stage is less sensitive to climate due to its limited exposure to air temperatures.

The number of highly suitable months each year for the pupae life stage is likely to increase by 1 to 2 months across the state under both emissions scenarios (*moderate to high confidence*). The alpine region is likely to retain historical numbers of highly suitable months under both emissions scenarios (*moderate to high confidence*) (Appendix A3).

Figure 18, the pupae calendar plot, shows the expected change in monthly climate suitability throughout the year around sites of importance for buffalo fly. These changes in climate suitability are:

- **increased climate suitability** in spring and autumn for Coffs Harbour, Boggabilla, Dubbo and Maitland under both emissions scenarios (*moderate to high confidence*) and for Moree and Bourke under the high emissions scenarios (*low to high confidence*). Additionally, June for Coffs Harbour under the high emissions scenario (*high confidence*).
- **decreased climate suitability** in late spring through to early autumn for Boggabilla, Moree, Bourke and Dubbo under both emissions scenarios (*moderate to high confidence*) and for Maitland in January under the high emissions scenario (*moderate confidence*).

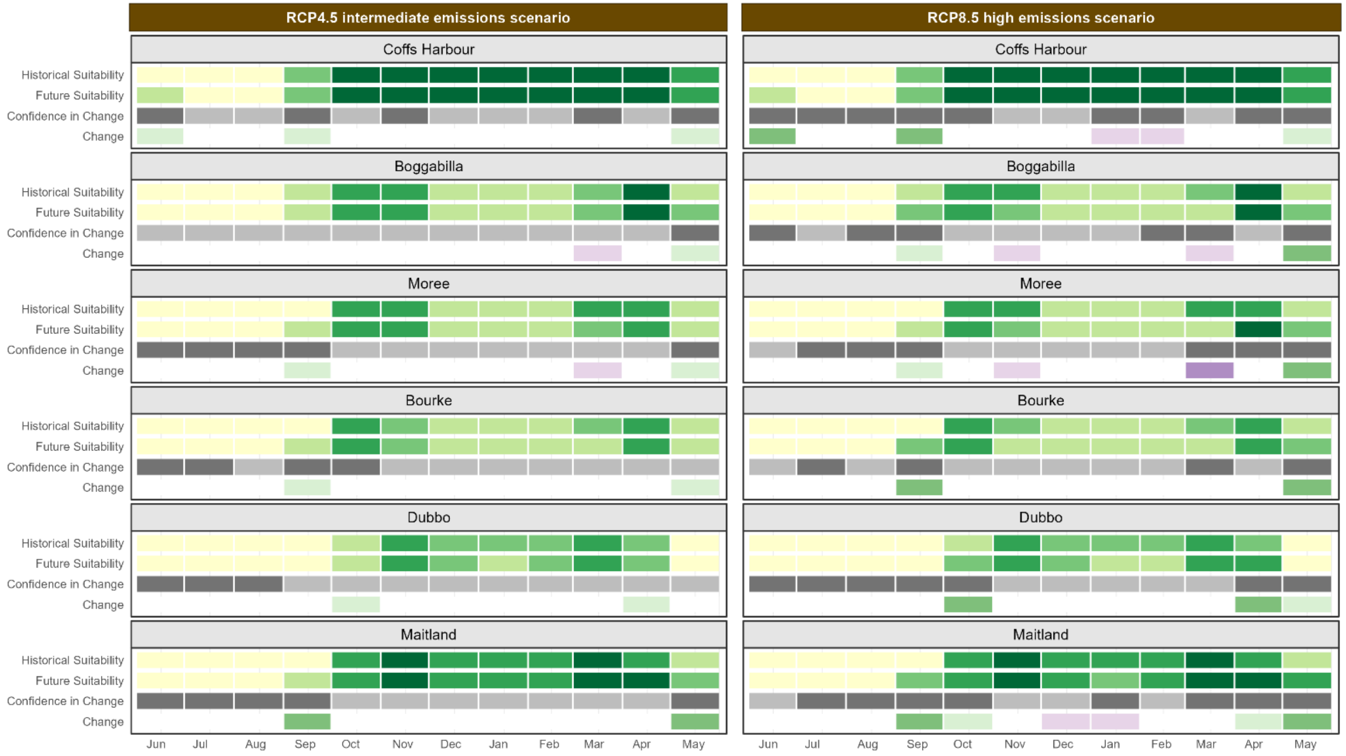
# Buffalo fly: climate suitability calendar for the egg life stage

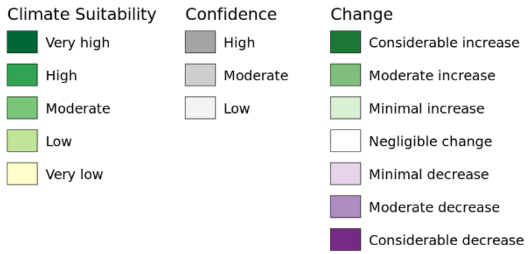



**Findings:** The climate suitability is likely to increase in late autumn and during spring across all sites. For some inland sites this is likely to be a change from very low climate suitability to low climate suitability and may lead to seeing increased numbers of buffalo fly eggs occurring in months they have not previously been seen.

*Figure 16: Climate suitability calendar for the buffalo fly egg life stage. 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.*

# Buffalo fly: climate suitability calendar for the larvae life stage



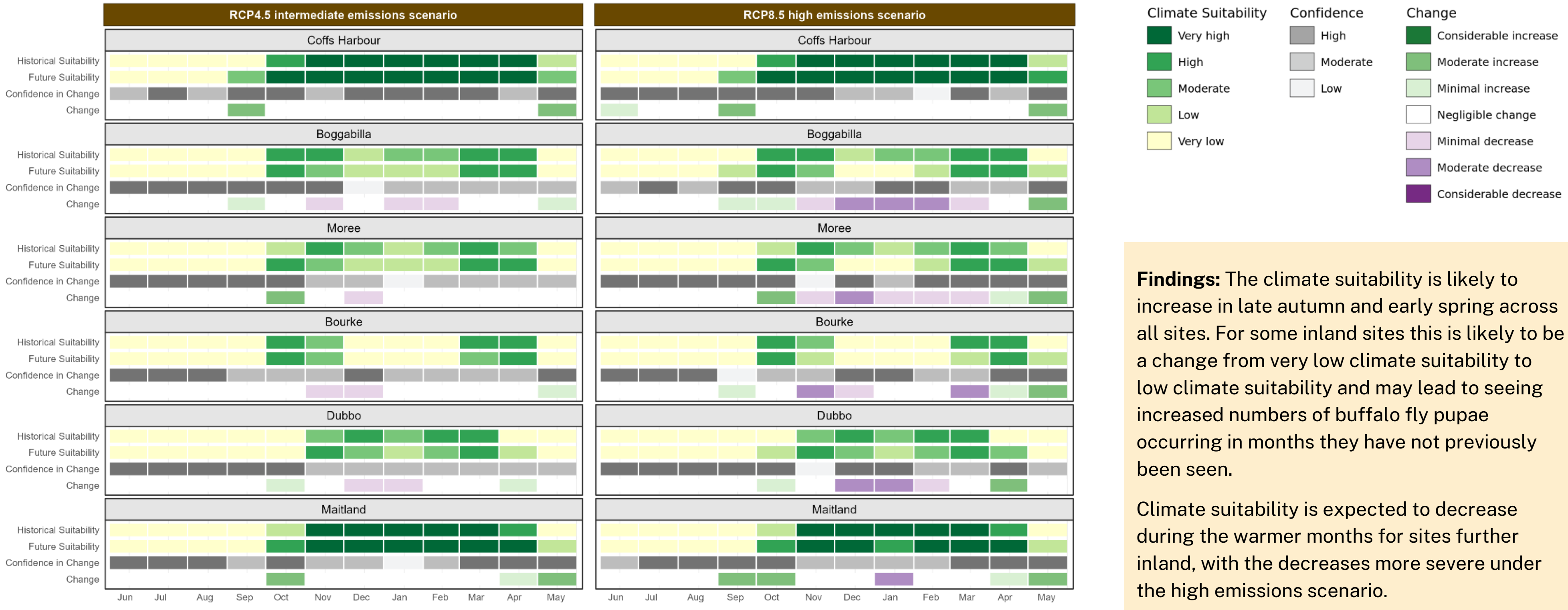




**Findings:** The climate suitability is likely to increase in late autumn and early spring across all sites. For some inland sites this is likely to be a change from very low climate suitability to low climate suitability and may lead to seeing increased numbers of buffalo fly larvae occurring in months they have not previously been seen.

Climate suitability is expected to decrease during the warmer months for sites closer to the coast, with the decreases more severe under the high emissions scenario.

*Figure 17: Climate suitability calendar for the buffalo fly larvae life stage. 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.*

# Buffalo fly: climate suitability calendar for the pupae life stage




**Findings:** The climate suitability is likely to increase in late autumn and early spring across all sites. For some inland sites this is likely to be a change from very low climate suitability to low climate suitability and may lead to seeing increased numbers of buffalo fly pupae occurring in months they have not previously been seen.

Climate suitability is expected to decrease during the warmer months for sites further inland, with the decreases more severe under the high emissions scenario.

*Figure 18: Climate suitability calendar for the buffalo fly pupae life stage. 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.*

# 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 buffalo fly regions and life stages.

## Key insights for the endemic region

Buffalo fly is endemic in the northeast of NSW (Figure 11). A key observation is that the endemic region consistently has a high number of highly suitable months, and the number of highly suitable months is likely to increase by 2050. The future projections show increased climate suitability, especially around Coffs Harbour and along the Great Dividing Range where the insect is already well established.

## Key insights for the seasonal region

A key observation in areas of the seasonal region is that the number of highly suitable months is likely to increase by 2050 (Figure 12). The future projections show increased climate suitability across the region, particularly along the Great Diving Range. An increase in highly suitable months results from the milder winters and higher mean temperatures.

## Key findings across life stages

An increase in climate suitability due to milder winters with fewer frosts and higher mean temperatures may result in all assessed life stages experiencing more favourable climate suitability in the future, with the most suitable areas being those where populations already do not face severe climatic restrictions. The decreases in climate suitability are unlikely to restrict the pupae populations as they are less sensitive when burrowed in the soil (Figures 16-18)

# Expected challenges for primary industries

The effects of buffalo fly on beef and dairy industries in NSW will depend on the following:

- the future distribution of those industries,
- changes in production timings, and
- the overlap between the susceptible life stages of cattle and the lifecycle of buffalo fly.

Increased suitability under a warmer climate is likely to lead to a greater impact of buffalo fly on beef and dairy industries in NSW.

Increased climate suitability to the south and west of the current endemic and seasonal regions for buffalo fly during the spring months may lead to a new and significant impact on the beef and dairy industries in areas not currently affected.

Some breeds of cattle in the southern regions of Australia, such as *Bos taurus*, are more susceptible to buffalo fly than other breeds, such as *Bos indicus*. Production loss for dairy cattle due to buffalo fly is greater than for beef cattle. This is because dairy cattle are high-performing production animals and even a modest infestation of 30 flies lowers milk production.

Due to cooler temperatures in southern NSW, there are generally fewer buffalo flies than in the north of the state, and so management practices are quite different: southern cattle producers may need education on the increasing risk of buffalo fly and management strategies if a warmer future facilitates a southward spread.

# Buffalo fly: Where to from here?

## Future priorities

We have assessed the future climate suitability for buffalo fly as it 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 buffalo fly that are likely to have a moderate impact on the beef and dairy industries in NSW. More research is needed to best advise impacted industries on adaptations and new management techniques for buffalo fly, looking forward to 2050. Effective management approaches must be carefully planned, evaluated, and deployed to minimise disruptions and costs. The beef and dairy industries may need to consider adjusting control measures to start earlier in spring and later in autumn as well as implementing broad-reaching buffalo fly education programs. These programs would raise awareness of the increased risk and provide management strategies for regions that have not previously been affected.

Additional work is needed to understand the financial and market access impacts of increased pressure from buffalo fly.

## Addressing the gaps, barriers and challenges

The new information generated by this project has helped to identify expected future changes in climate suitability for buffalo fly. However, many knowledge gaps were identified during the development of the MCA model.

In some cases, these knowledge gaps were barriers to developing the models, leading to the exclusion of key climate criteria because there were no data to justify their inclusion in the model. The following areas are key knowledge gaps in need of further research:

- impact of maximum temperatures of pupae life stage,
- impact of dung moisture on the egg, larvae and pupae life stages

Many studies have been conducted under lab conditions which may not reflect the field observations. These studies also lack clarity on whether stated temperatures were minimum, mean or maximum.

This report aims to highlight these 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[11]. Expanding the range of the current modelling to be 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.

[11] 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 and enhance cattle production and limit the impacts of climate change on buffalo fly.

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 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 Buffalo fly are the impacted hosts:

- Cattle

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 four experts who participated in the buffalo fly focus groups. These experts ensured that the model contents reflected published knowledge and lived experiences, and they 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, 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: Joanna Pardoe, Rebecca Darbyshire, Gary Allan, Mary Timms, James Lawson, Lachlan Philips, Bethany Ellis, Jane Kelley, Samantha Currie, Rachael Young, Paris Capell, David Allingham, and Chris Nunn.

All images provided by L. Bolin and have been used with permission.


NSW GOVERNMENT

# Appendix

**Figure A1: Number of Highly Suitable Months for buffalo fly egg stage**

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 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 of importance where buffalo fly are currently found are marked by black crosses, and the blue polygons show the endemic (northeast) and seasonal (north) buffalo fly regions

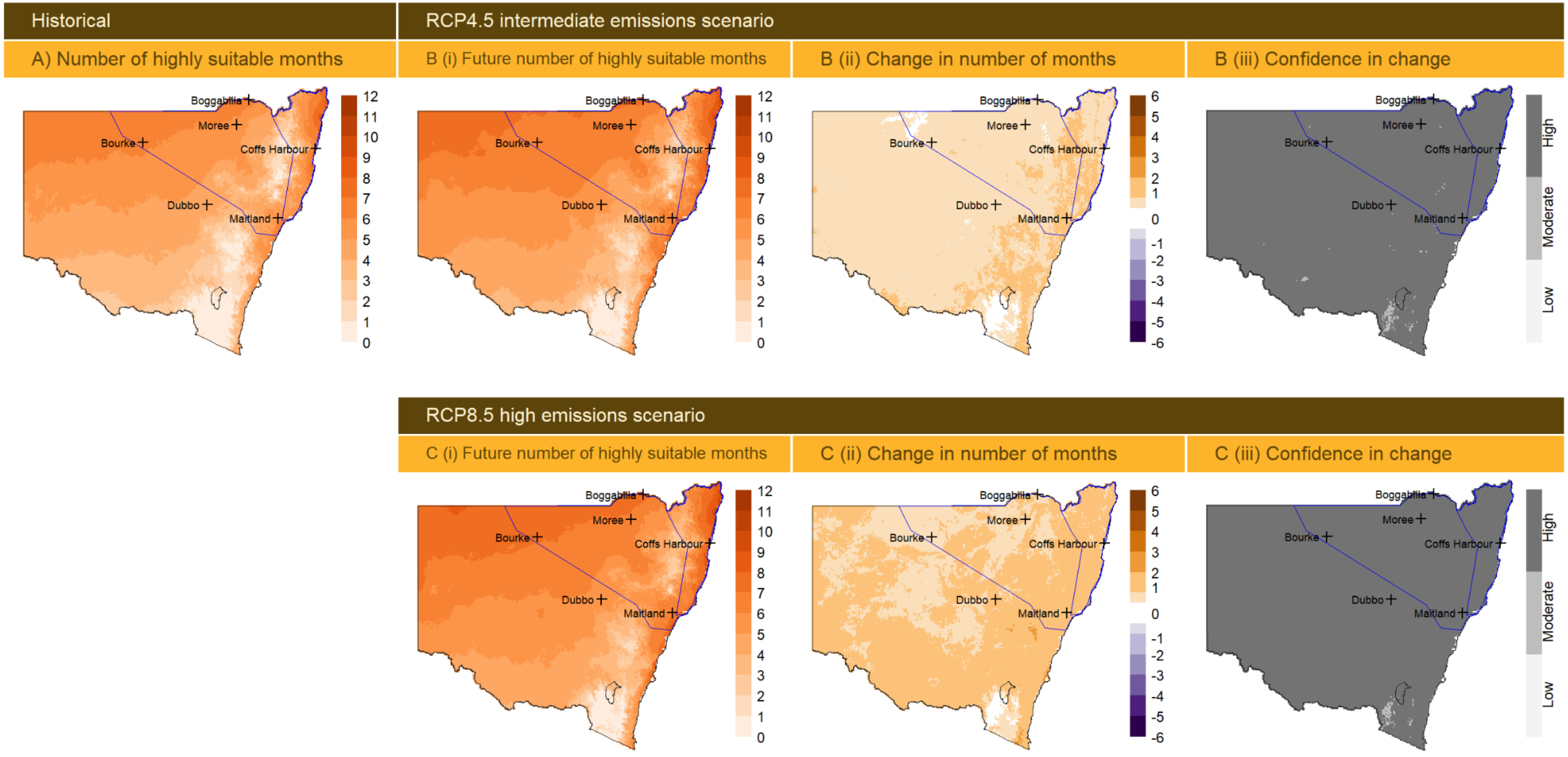


**Figure A2. Number of Highly Suitable Months for buffalo fly larvae stage**

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 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 of importance where buffalo fly are currently found are marked by black crosses, and the blue polygons show the endemic (northeast) and seasonal (north) buffalo fly regions

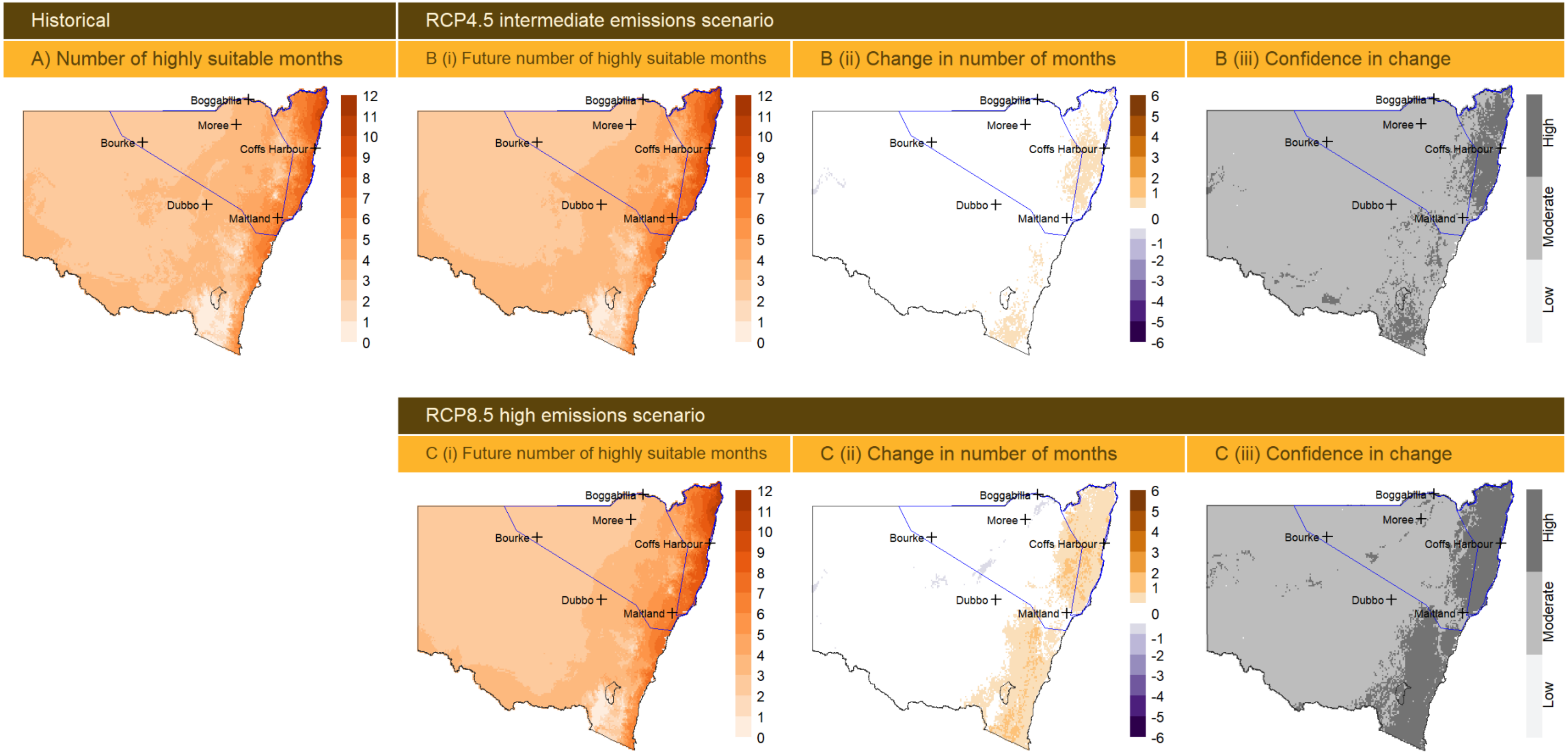


**Figure A3. Number of Highly Suitable Months for buffalo fly pupae stage**

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 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 of importance where buffalo fly are currently found are marked by black crosses, and the blue polygons show the endemic (northeast) and seasonal (north) buffalo fly regions

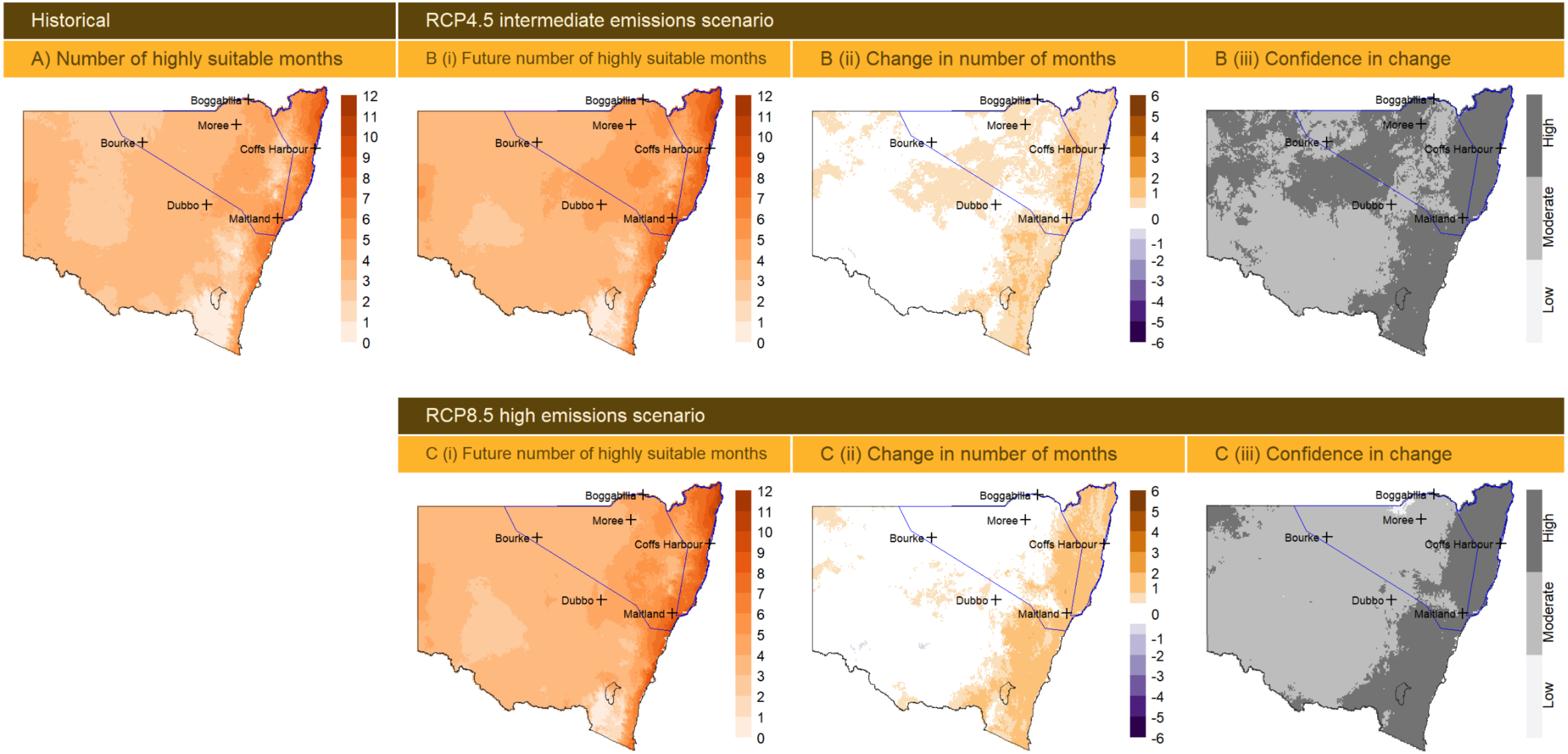


**Figure A4. January climate suitability for buffalo fly.**

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 of importance where buffalo fly are currently found are marked by black crosses, and the blue polygons show the endemic (northeast) and seasonal (north) buffalo fly regions.

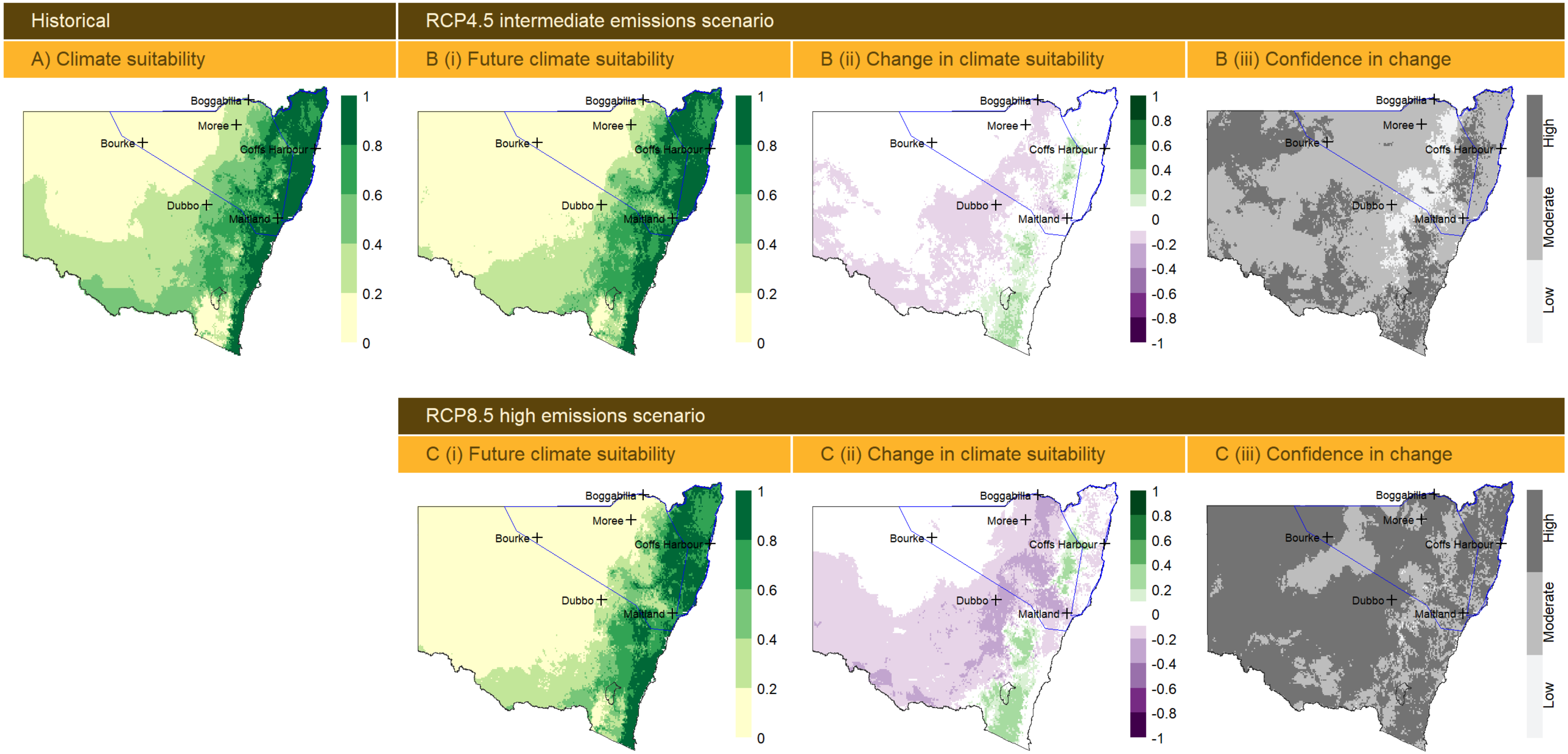


**Figure A5. February climate suitability for buffalo fly.**

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 of importance where buffalo fly are currently found are marked by black crosses, and the blue polygons show the endemic (northeast) and seasonal (north) buffalo fly regions.

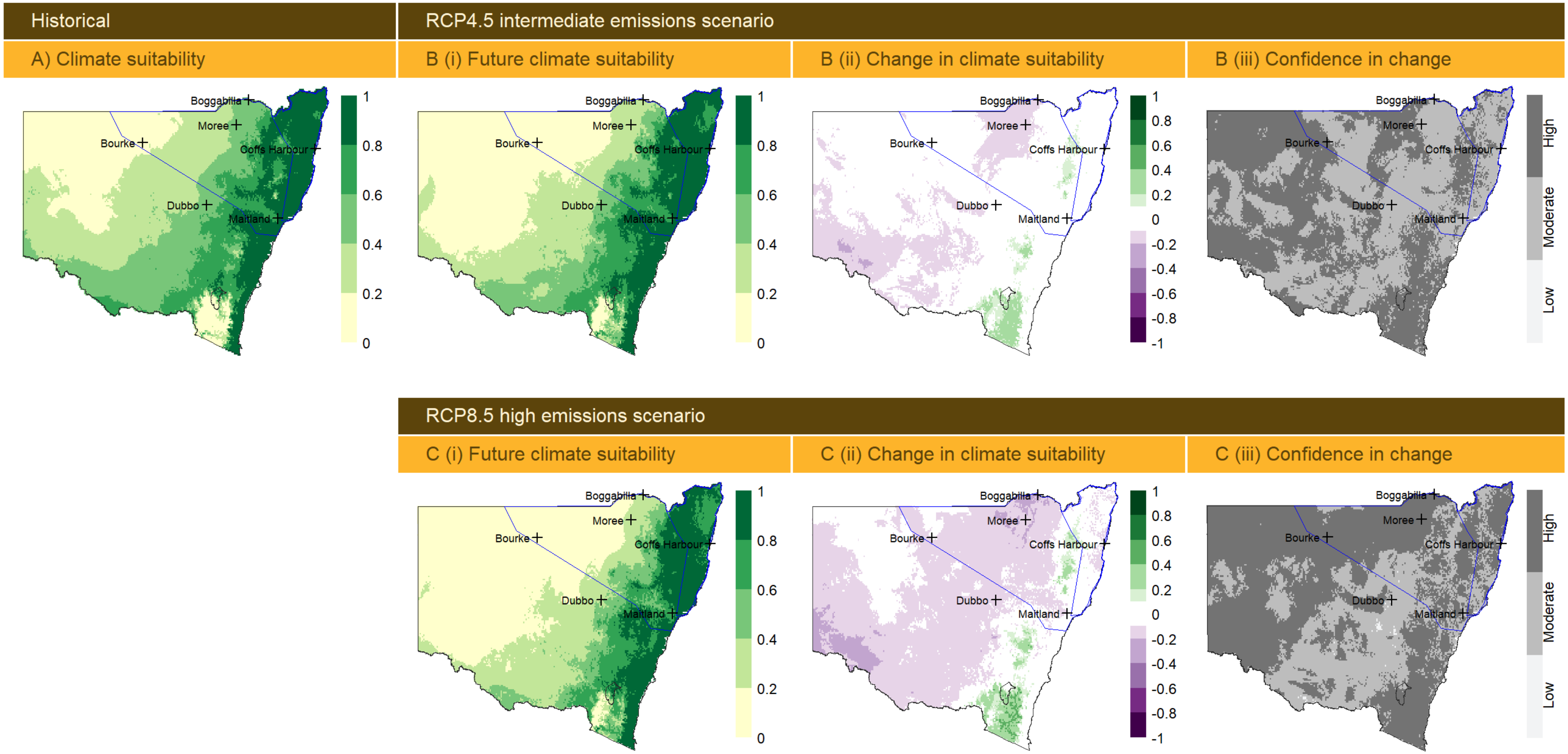


**Figure A6. March climate suitability for buffalo fly.**

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 of importance where buffalo fly are currently found are marked by black crosses, and the blue polygons show the endemic (northeast) and seasonal (north) buffalo fly regions.

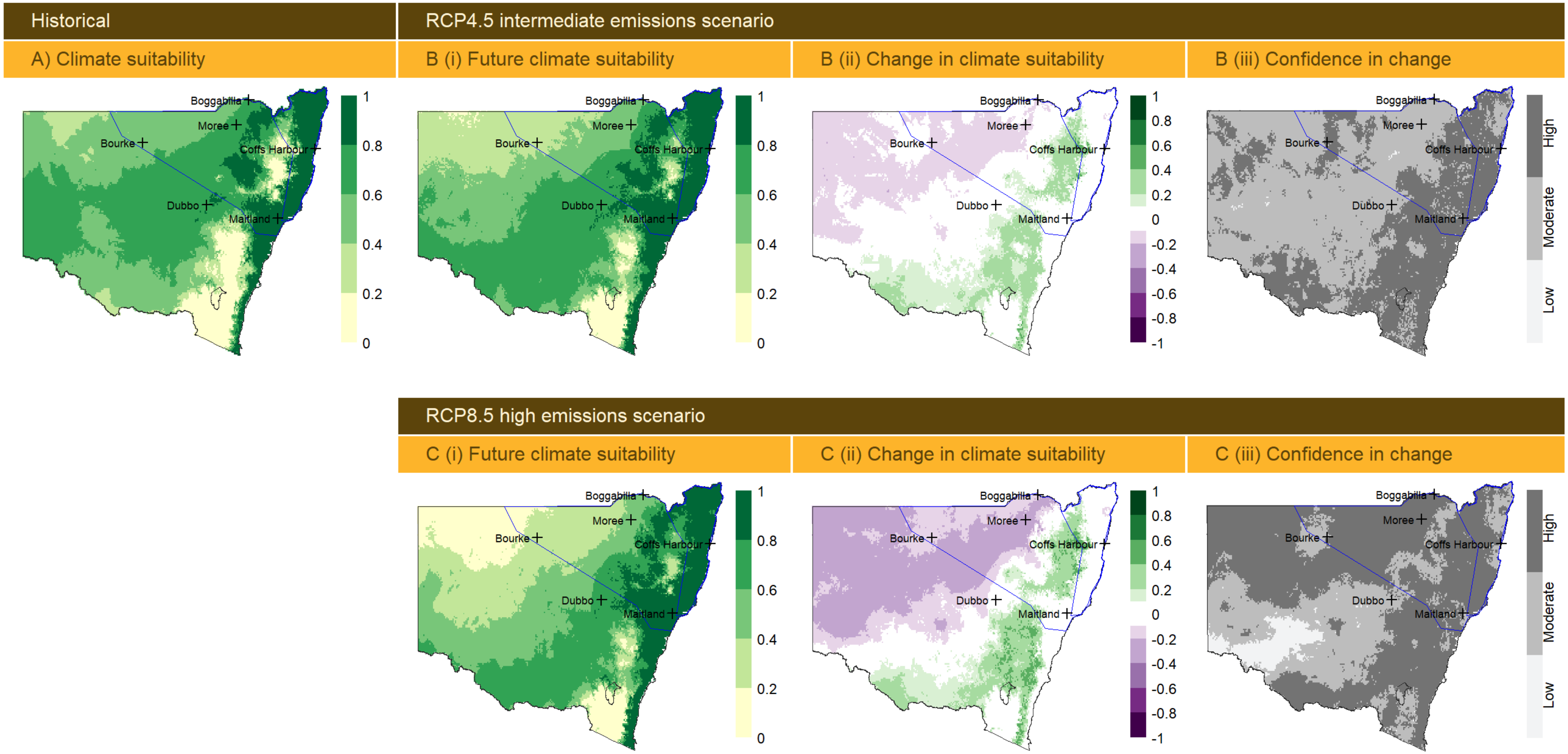


**Figure A7. April climate suitability for buffalo fly.**

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 of importance where buffalo fly are currently found are marked by black crosses, and the blue polygons show the endemic (northeast) and seasonal (north) buffalo fly regions.

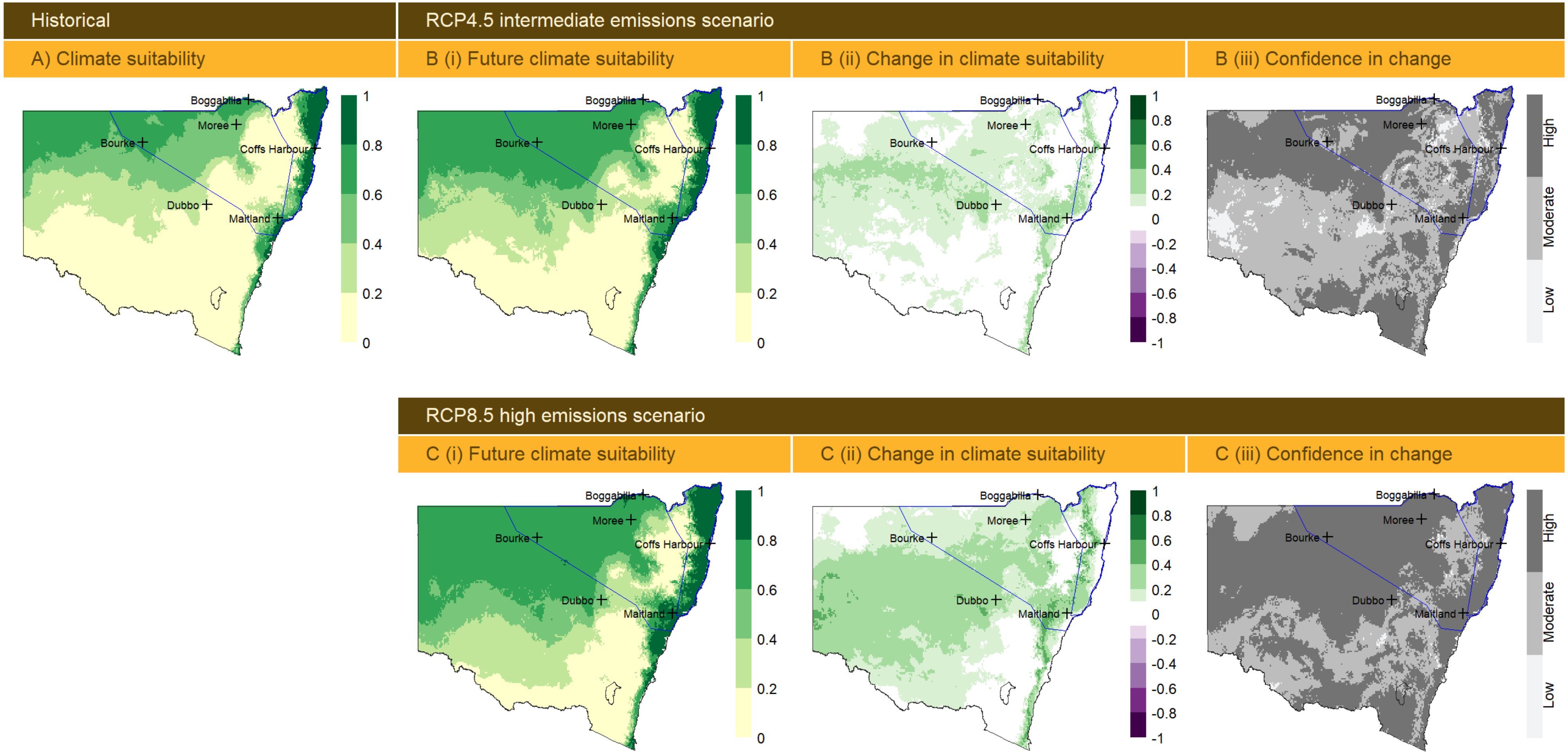


**Figure A8. May climate suitability for buffalo fly.**

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 of importance where buffalo fly are currently found are marked by black crosses, and the blue polygons show the endemic (northeast) and seasonal (north) buffalo fly regions.

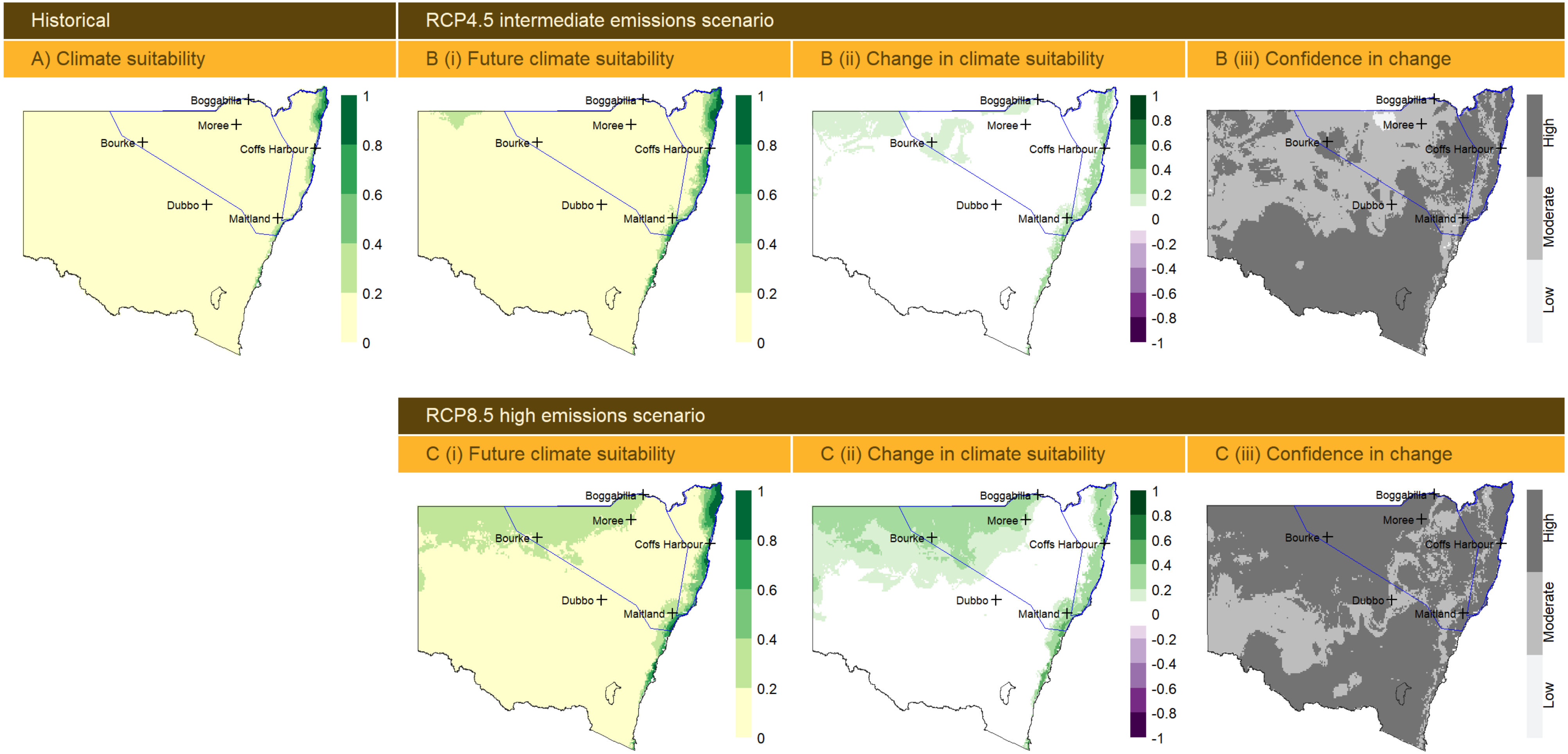


**Figure A9. June climate suitability for buffalo fly.**

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 of importance where buffalo fly are currently found are marked by black crosses, and the blue polygons show the endemic (northeast) and seasonal (north) buffalo fly regions.

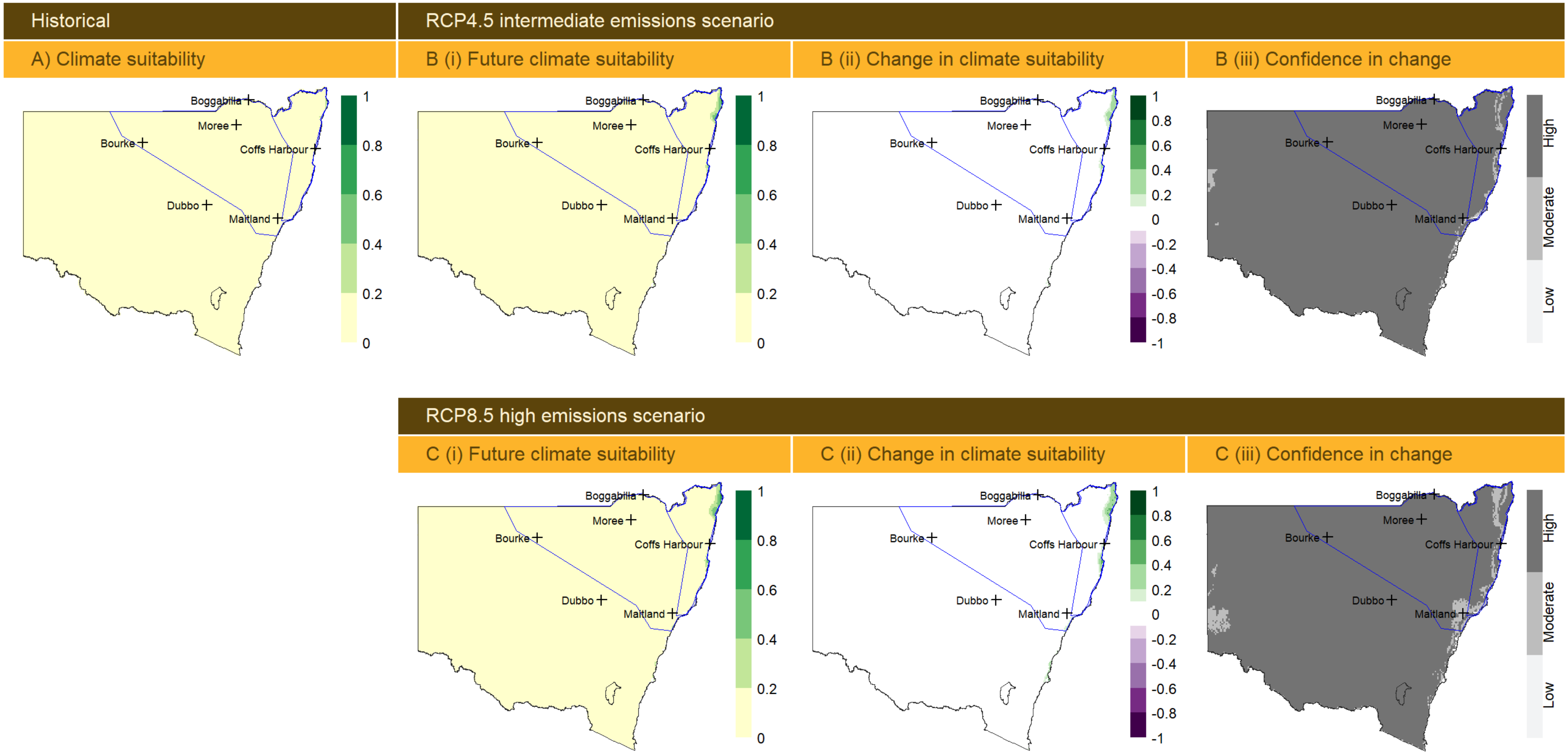


**Figure A10. July climate suitability for buffalo fly.**

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 of importance where buffalo fly are currently found are marked by black crosses, and the blue polygons show the endemic (northeast) and seasonal (north) buffalo fly regions.

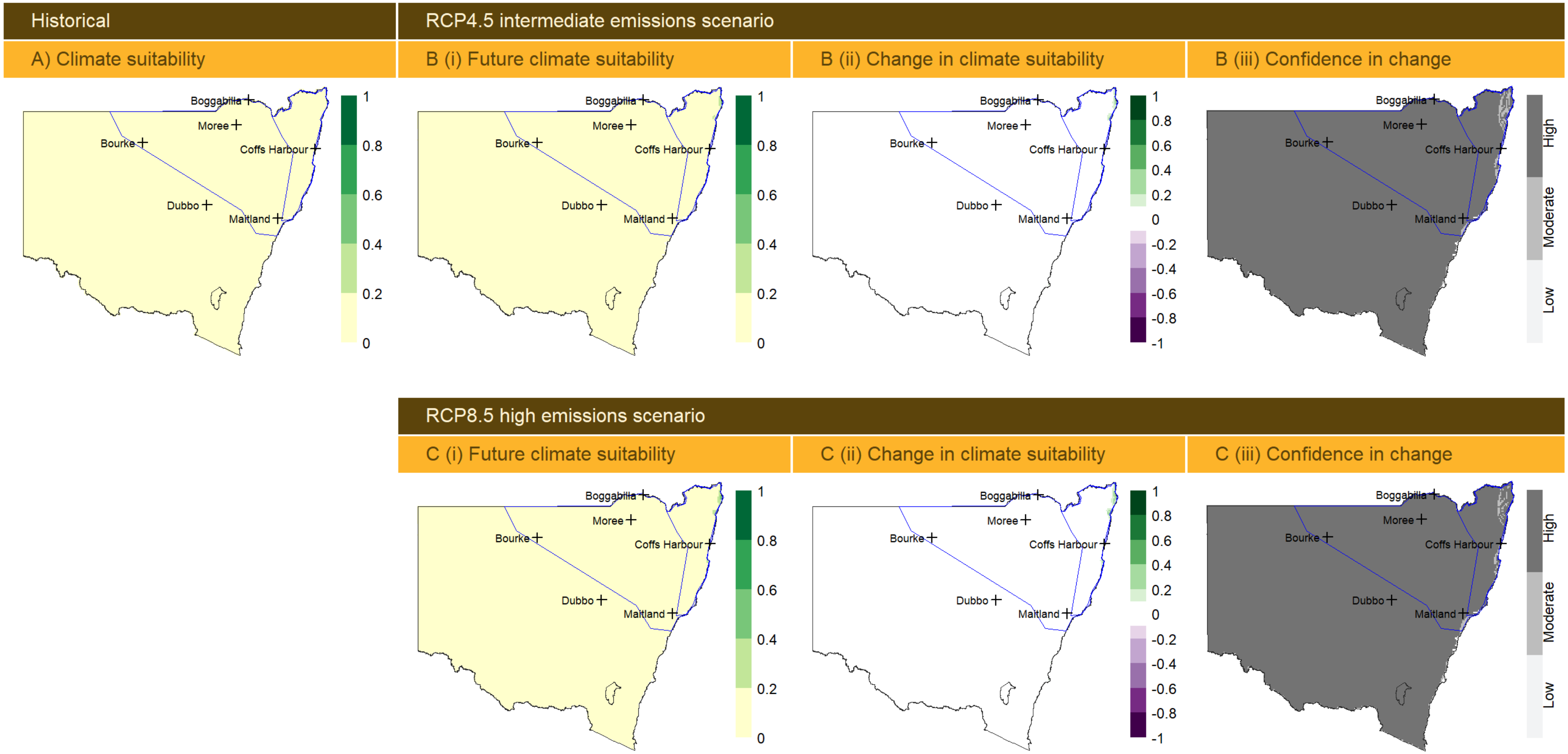


**Figure A11. August climate suitability for buffalo fly.**

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 of importance where buffalo fly are currently found are marked by black crosses, and the blue polygons show the endemic (northeast) and seasonal (north) buffalo fly regions.

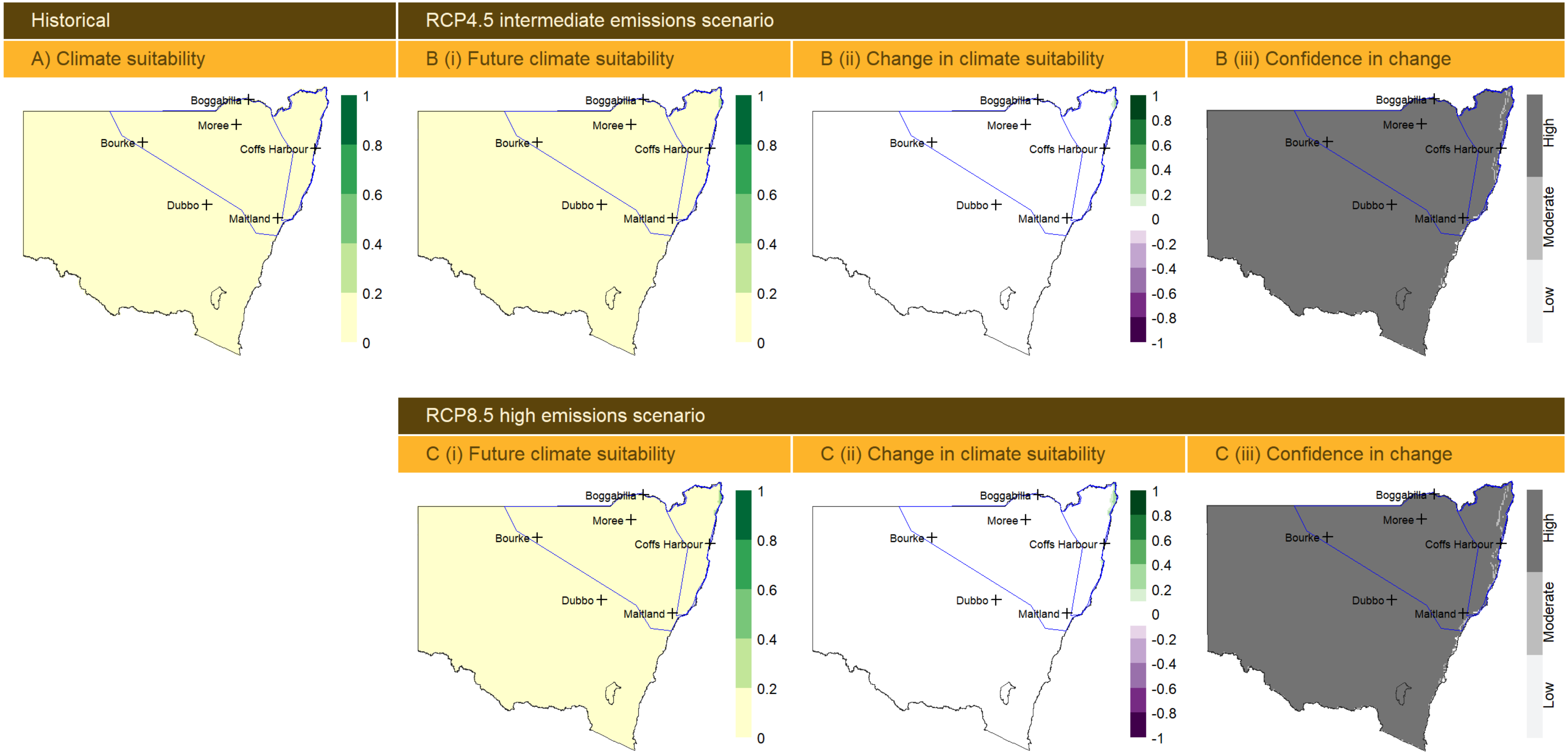


**Figure A12. September climate suitability for buffalo fly.**

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 of importance where buffalo fly are currently found are marked by black crosses, and the blue polygons show the endemic (northeast) and seasonal (north) buffalo fly regions.

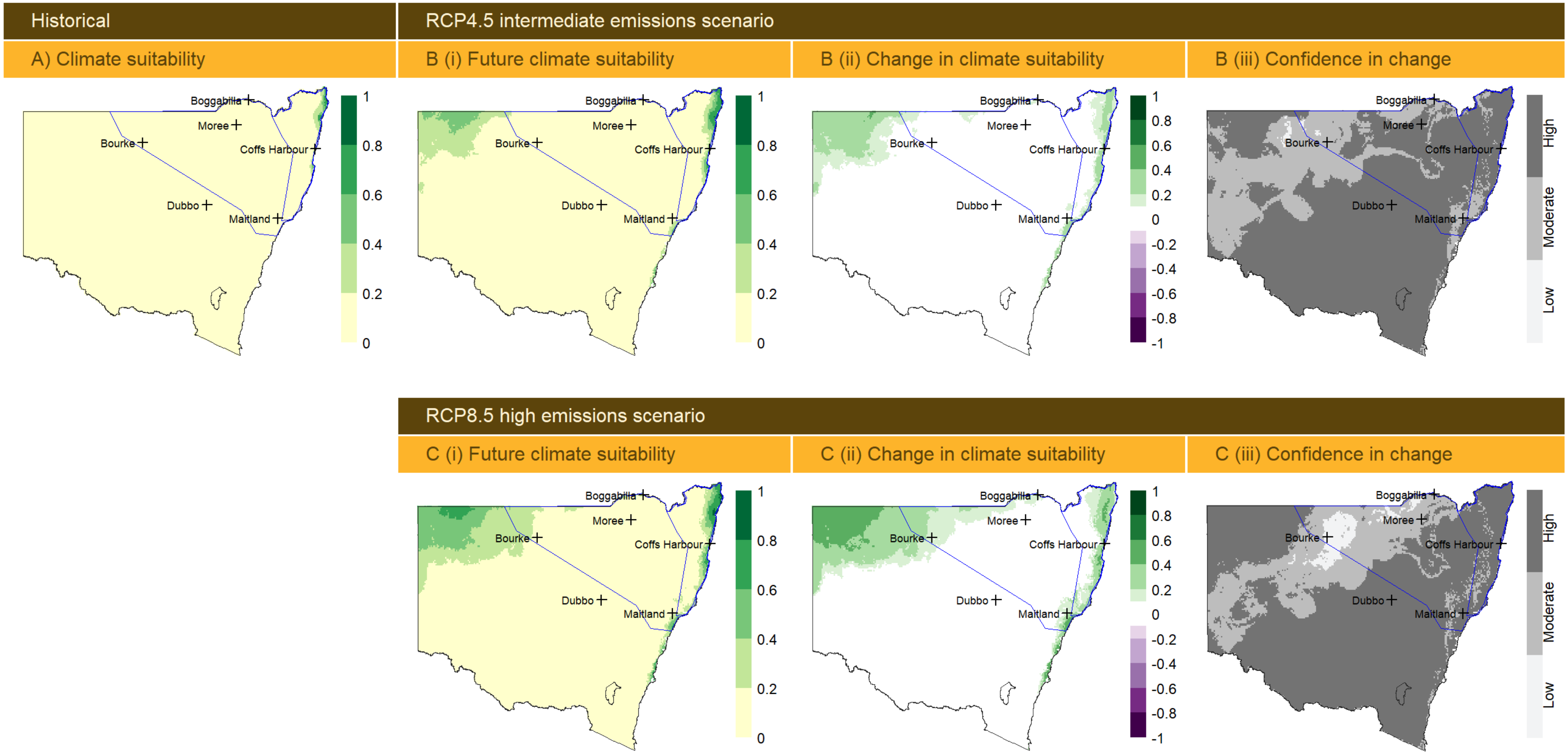


**Figure A13. October climate suitability for buffalo fly.**

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 of importance where buffalo fly are currently found are marked by black crosses, and the blue polygons show the endemic (northeast) and seasonal (north) buffalo fly regions.

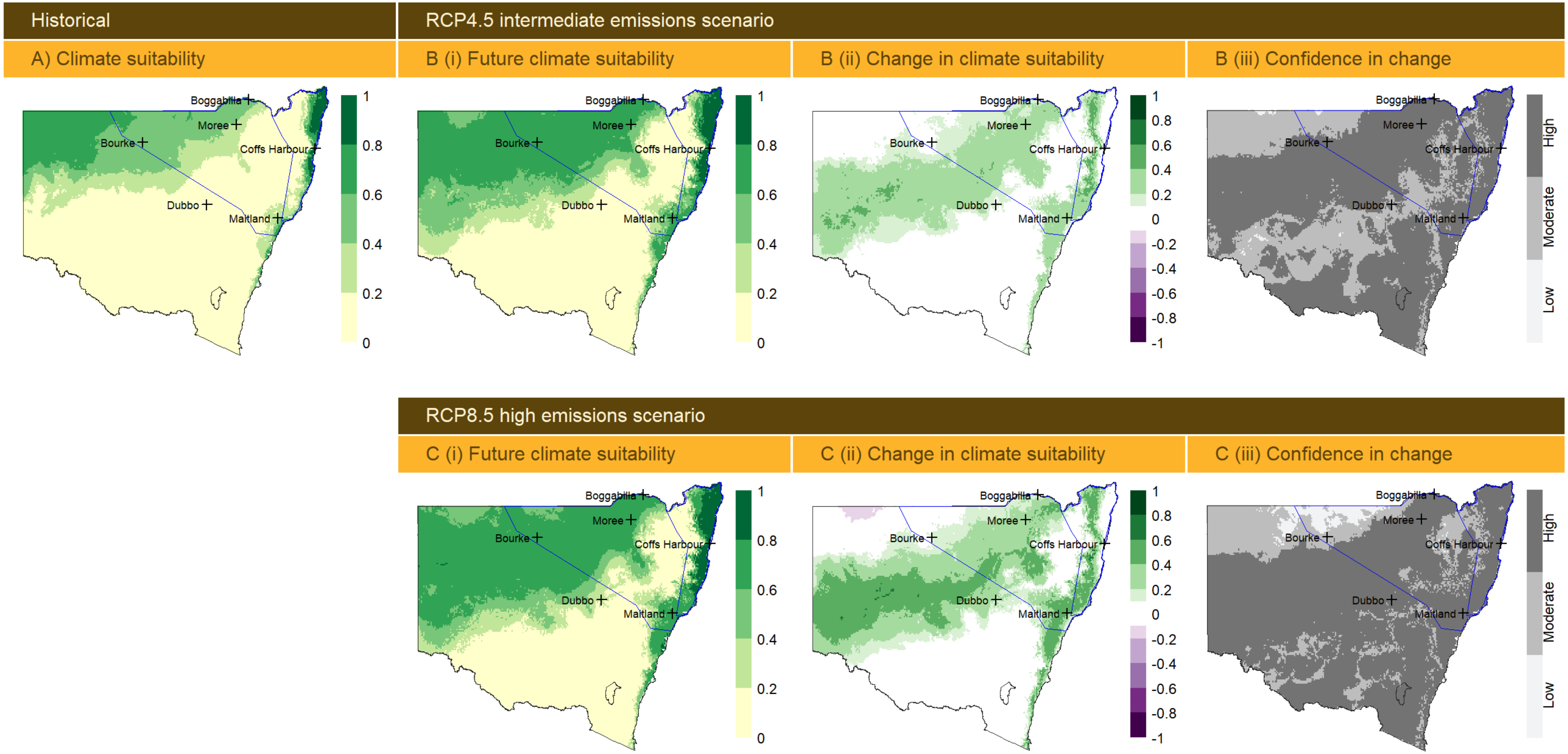


**Figure A14. November climate suitability for buffalo fly.**

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 of importance where buffalo fly are currently found are marked by black crosses, and the blue polygons show the endemic (northeast) and seasonal (north) buffalo fly regions.

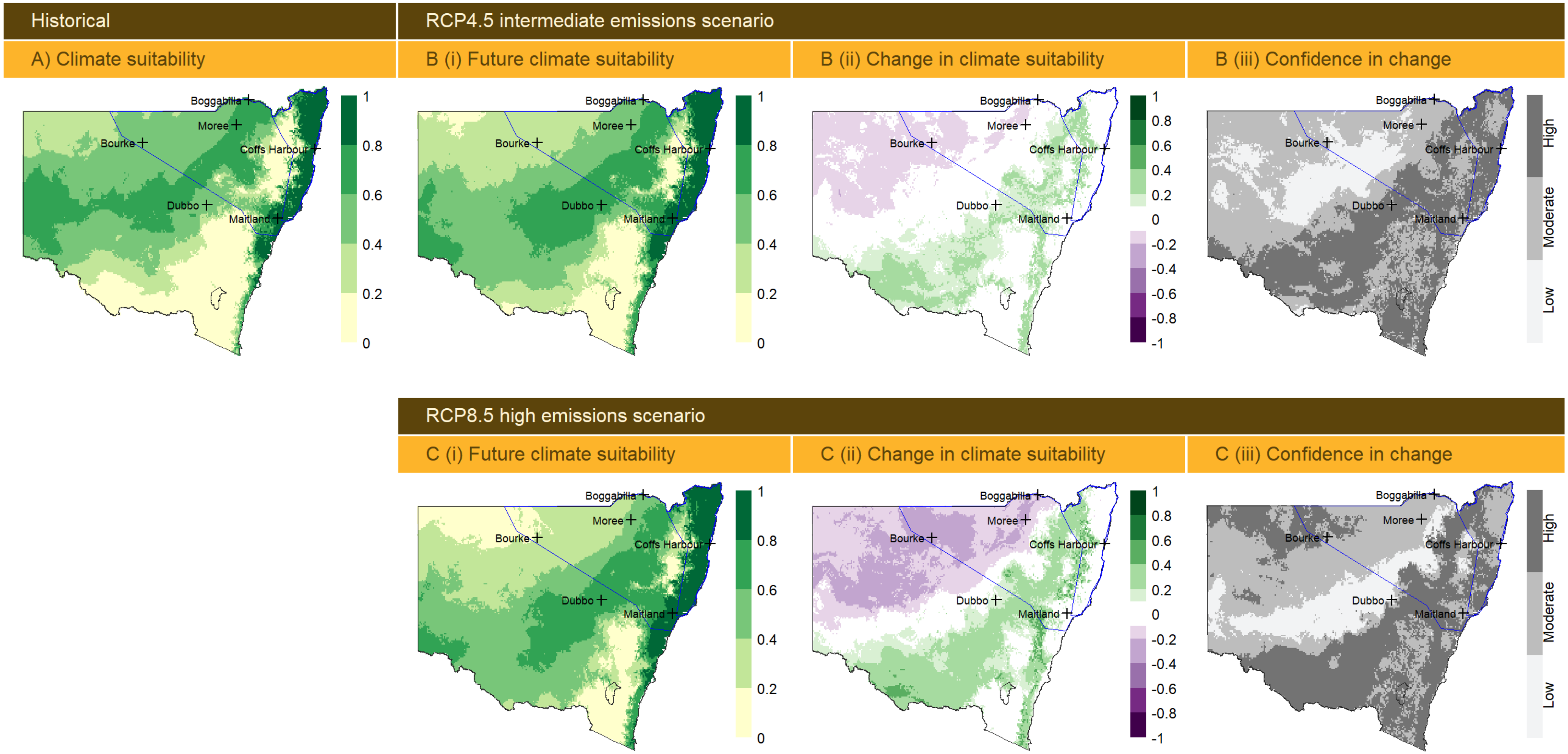
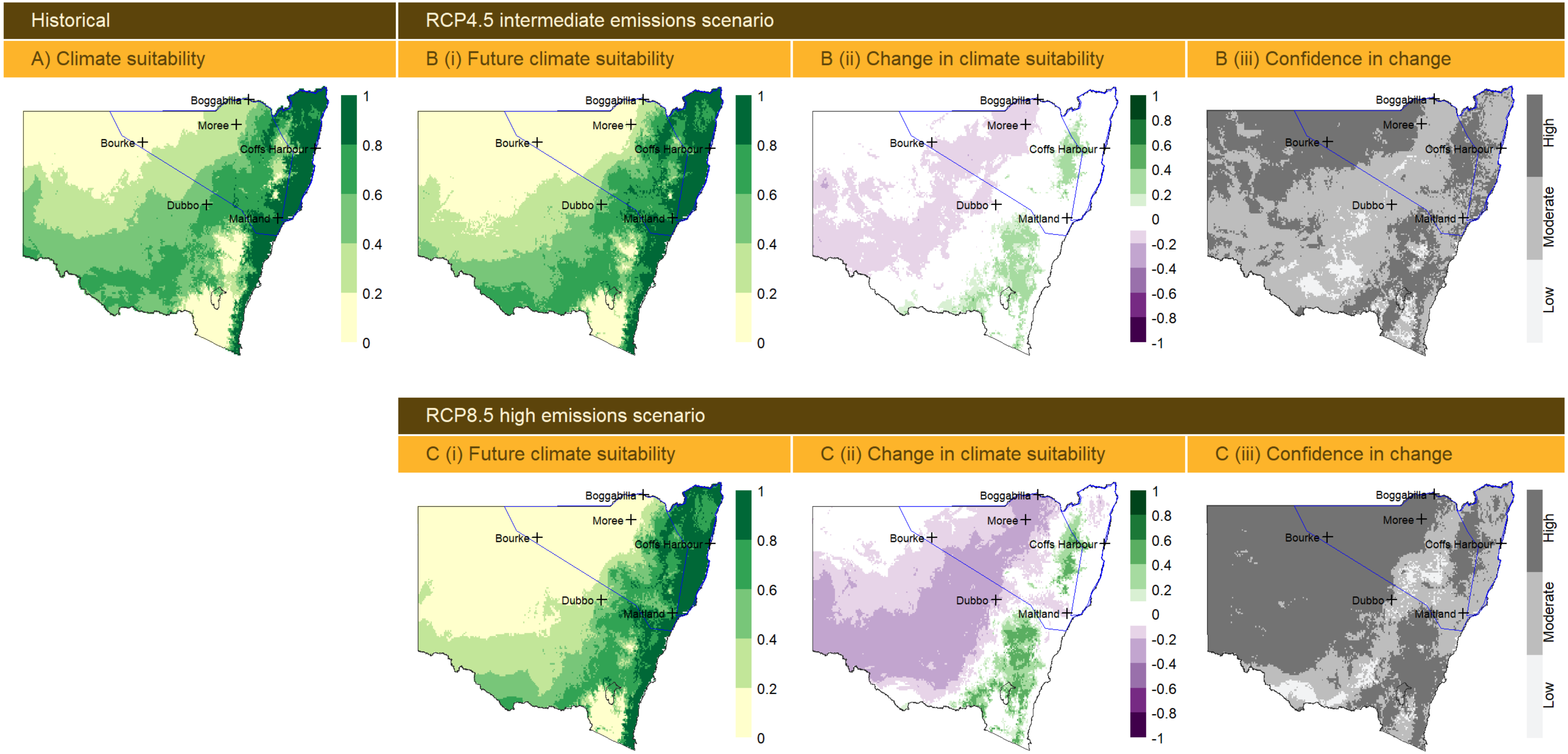


**Figure A15. December climate suitability for buffalo fly.**

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 of importance where buffalo fly are currently found are marked by black crosses, and the blue polygons show the endemic (northeast) and seasonal (north) buffalo fly regions.



Primary Industries Climate Change Research Strategy

# Climate Vulnerability Assessment

Buffalo fly Results Report

NSW GOVERNMENT