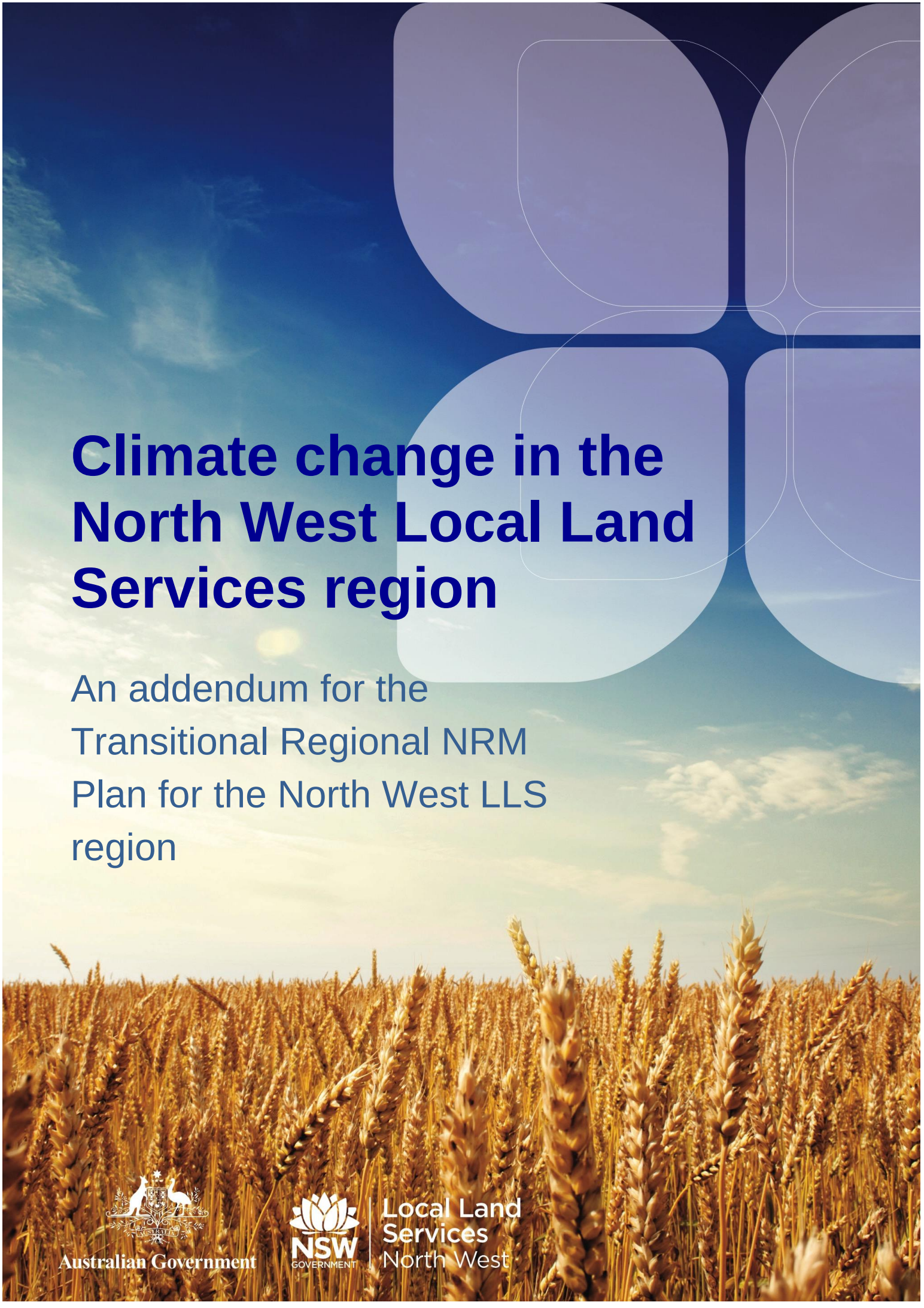
Climate change in the North West Local Land Services region

An addendum for the Transitional Regional NRM Plan for the North West LLS region



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Climate Change in the North West Local Land Services Region:

An addendum for the Transitional Regional NRM Plan for the North West LLS region

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More information

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Disclaimer: The information contained in this publication is based on knowledge and understanding at the time of writing, July 2015. However, because of advances in knowledge, users are reminded of the need to ensure that information upon which they rely is up to date and to check the currency of the information with the appropriate Local Land Services officer or the user's independent adviser.

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1 Preparing our community

Understanding the impacts of climate change is vital for regional planning. The impacts of climate variability on the environment and society will depend not only on the response of the Earth's systems but also on how humankind responds through changes in technology, economy, lifestyle and policy.

The North West Local Land Services (North West LLS) is collating and analysing the latest climate change data. We are also looking at ways to adapt to variations in climate to increase agricultural productivity while enhancing the resilience of the landscape.

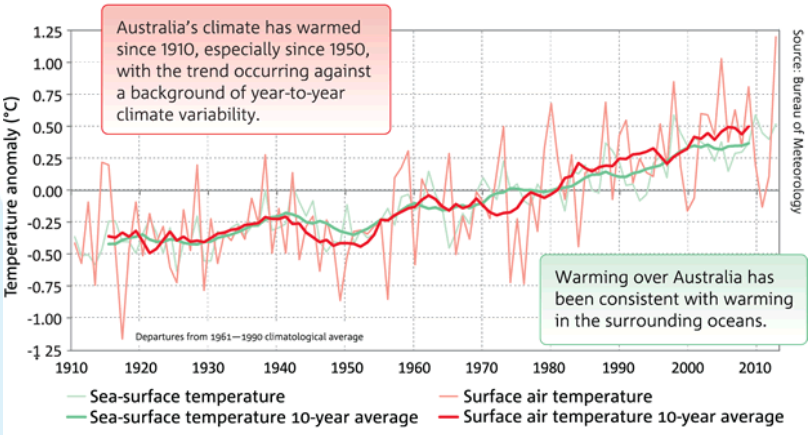
This report is a summary of our findings. The report is an addendum to the North West LLS Transitional Regional NRM Plan, which provides detailed data modelling results on climate change and its impacts on the region.

2 Is our climate changing?

Globally, average air temperatures have risen by around 0.85°C since 1880, almost certainly due to human activities such as agriculture, clearing and burning fossil fuels (IPCC 5th assessment Working Group I report). Over the past 15 years in Australia, the frequency of very warm months has increased five-fold. The frequency of very cool months has declined by around a third, compared to 1951–1980. Mean temperature has increased between 1910 and 2013 by around 0.8°C and the duration, frequency and intensity of heatwaves has increased across large parts of Australia.

Australia's mean surface temperature has warmed by 0.9°C since 1910 and sea-surface temperatures in the Australian region have warmed by 0.9°C since 1900. Since the 1970s, there has also been a rise in extreme fire weather accompanied by a longer fire season across large parts of Australia (Bureau of Meteorology and CSIRO State of Climate Report 2014).

Figure 1. Time series of anomalies in sea-surface temperature and temperature over land in the Australian region



Anomalies are the departures from the 1961–1990 average climatological period. Sea-surface temperature values are provided for a region around Australia (from 4°S to 46°S and from 94°E to 174°E). Adapted from: Bureau of Meteorology and CSIRO 2014 State of the Climate 2014.

Our rainfall patterns are changing too. Rainfall, averaged across Australia, has increased slightly since 1900, with a large increase in northwest Australia since 1970. In the southeast, since 1990, autumn and winter rainfall has mostly been below average.

Figure 2. Northern wet season (October–April) rainfall deciles since October 1995

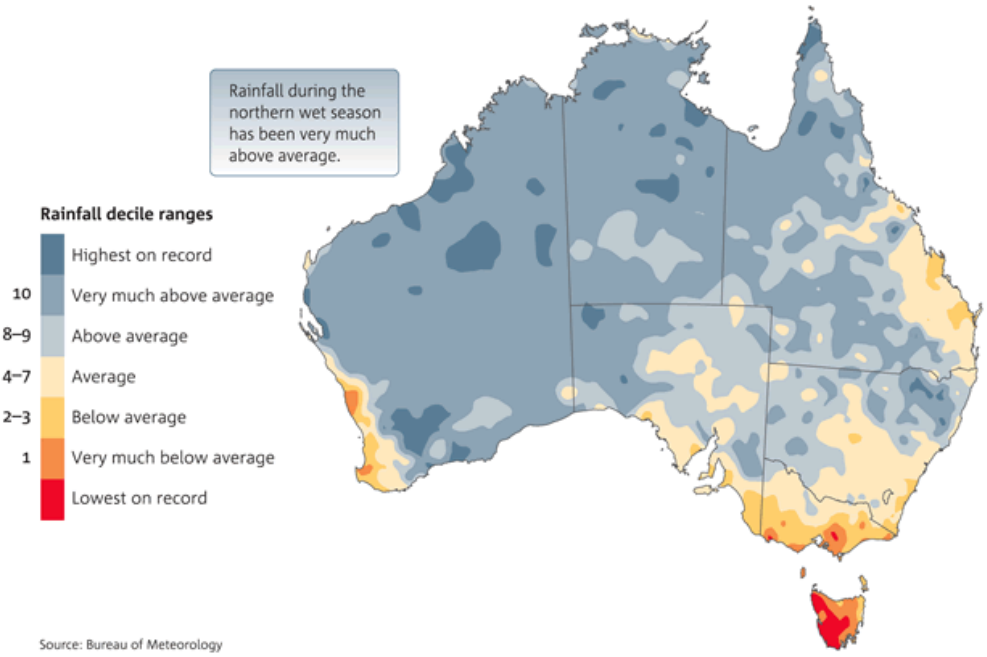
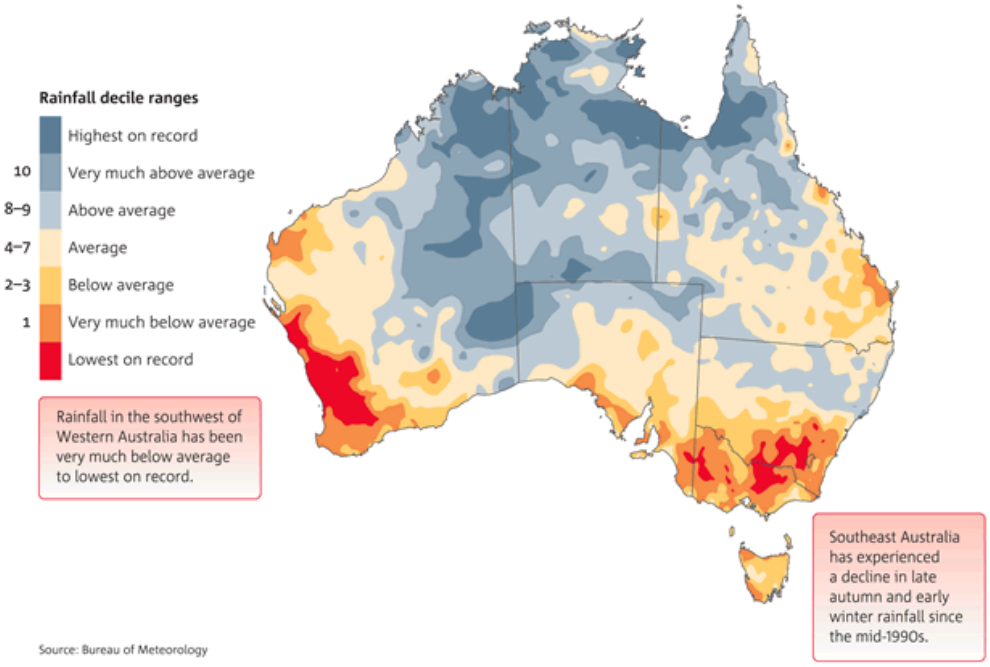


Figure 3.Southern wet season (April to November) rainfall deciles since 1996

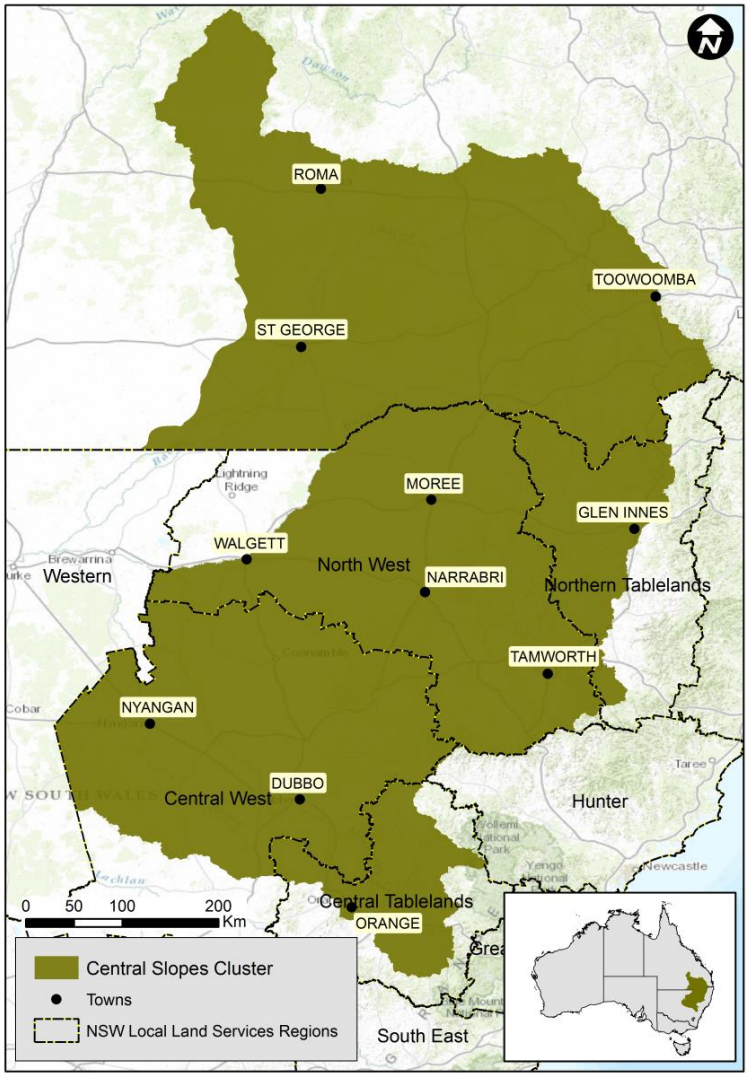


A decile map shows the extent that rainfall is above average, average or below average for the specified period, in comparison with the entire rainfall record from 1900. The Northern wet season is defined as October to April and the southern wet season is defined as April to November by the Bureau of Meteorology.

3 What climate variability can we expect in the North West region?

Our region is particularly vulnerable to climate change. The North West LLS region is part of a bioclimatic grouping called the Central Slopes cluster. The Central Slopes stretches from the Darling Downs in Queensland to the central west of New South Wales (NSW) and has a range of climates from sub-tropical in the north, through to temperate in the south. The region features a number of important headwater catchments for the Murray-Darling Basin. The area is extensively developed for dryland and irrigated agriculture, grazing and forestry.

Figure 4. Map of the Central Slopes cluster



Much hotter temperatures and a more variable climate will affect the natural and socio-economic systems in our region. Although natural variability from year to year can mask or enhance long-term trends (particularly for the near future and for rainfall), it is nevertheless possible to predict certain events with varying levels of confidence under various emission scenarios.

Table 1. Indicative future climate scenarios for the Central Slopes cluster region. Climate scenarios are projected by the Global Circulation Models (GCM) under three emission scenarios represented by the concentration pathways (i.e. RCP2.6 low emission scenario, RCP4.5 intermediate emission scenario, and RCP8.5 high emission scenario). Source: Climate Future Tool: www.climatechangeinaustralia.gov.au/en/climate-projects; accessed on 24 April 2015.

Indicative future climate	Associated period and emission scenario (RCPs)	Description	Climate analogue[1] for major towns of North West region (i.e. future climate of selected town would be more like the current climate of other towns) with a tolerance ±0.5^{0}C for annual temperature and ±5% annual precipitation.					
			Tamworth	Gunnedah	Narrabri	Moree	Walgett	Matching climate description in analogue tool
Warmer (0.5 to 1.5^{0}C warmer) and ***wetter*** (5 to 15% increase)	2030 (all RCPs) 2050 (RCP2.6 & RCP4.5) 2090 (RCP2.6)	This is **possible** by 2030 under all RCPs and may persist through to late in the century under RCP2.6	*Kingaroy, Singleton*[2]	Narrabri, Murgon	Mount Morgan, Gatton, Gayndah	Monto, Gayndah	Augathella, St George	Least hot and wettest case for 2030 under RCP2.6.
Warmer (0.5 to 1.5^{0}C warmer) with ***little change*** *in rainfall* (-5 to +5%)	2030 (**all RCPs**) 2050 (**RCP2.6**) 2090 (RCP2.6)	This **could occur** by 2030 under any emission scenario, but may persist through to late in the 21st century.	Kingaroy, Singleton	Narrabri, Dalby, Moree	Monto,	Tara, Goondiwindi, Miles	Dirranbandi, Charleville	Maximum consensus case for 2030 under RCP8.5.
Hotter (1.5 to 3.0^{0}C warming) with ***little change in rainfall*** (-5 to +5%).	2030 (None) 2050 (RCP4.5 & **RCP8.5**) 2090 (**RCP4.5**)	This **could occur** by 2050 under RCP4.5 & RCP8.5 and may persist through to late in the century under RCP4.5.	Murgon	Goondiwindi, Miles	Biloela, Taroom	Taroom	*Alpha*[2]	Maximum consensus case for 2050 under RCP8.5.
Hotter (1.5 to 3.0^{0}C warming), but ***drier*** (5 to 15% reduction)	2030 (RCP8.5) 2050 (all RCPs) 2090 (RCP4.5)	This is **possible** by 2030 under RCP4.5 or RCP8.5, or later in the century under RCP2.6.	Dalby, Coonamble,	Eneabba, St George, Lightning Ridge	Augathella, Tambo	Tambo	*Quilpie*[2]	Hottest and driest case for 2050 under RCP4.5
Much hotter (>3.00C warming) and ***much drier*** (>15% reduction)	2030 (none) 2050 (none) 2090 (RCP8.5)	This is **possible** by late in the century under RCP8.5.	Moranbah, Blackwater, Tambo, Dysart, Alpha	Blackall, Barcaldine	*Hughenden*[2]	Hughenden	*Warrego, Winton*[e]	Hottest and driest case for 2090 under RCP8.5

[1] The climate analogues tool matches the proposed future climate of a location of interest white the current climate experienced in another location using annual average rainfall and maximum temperature.

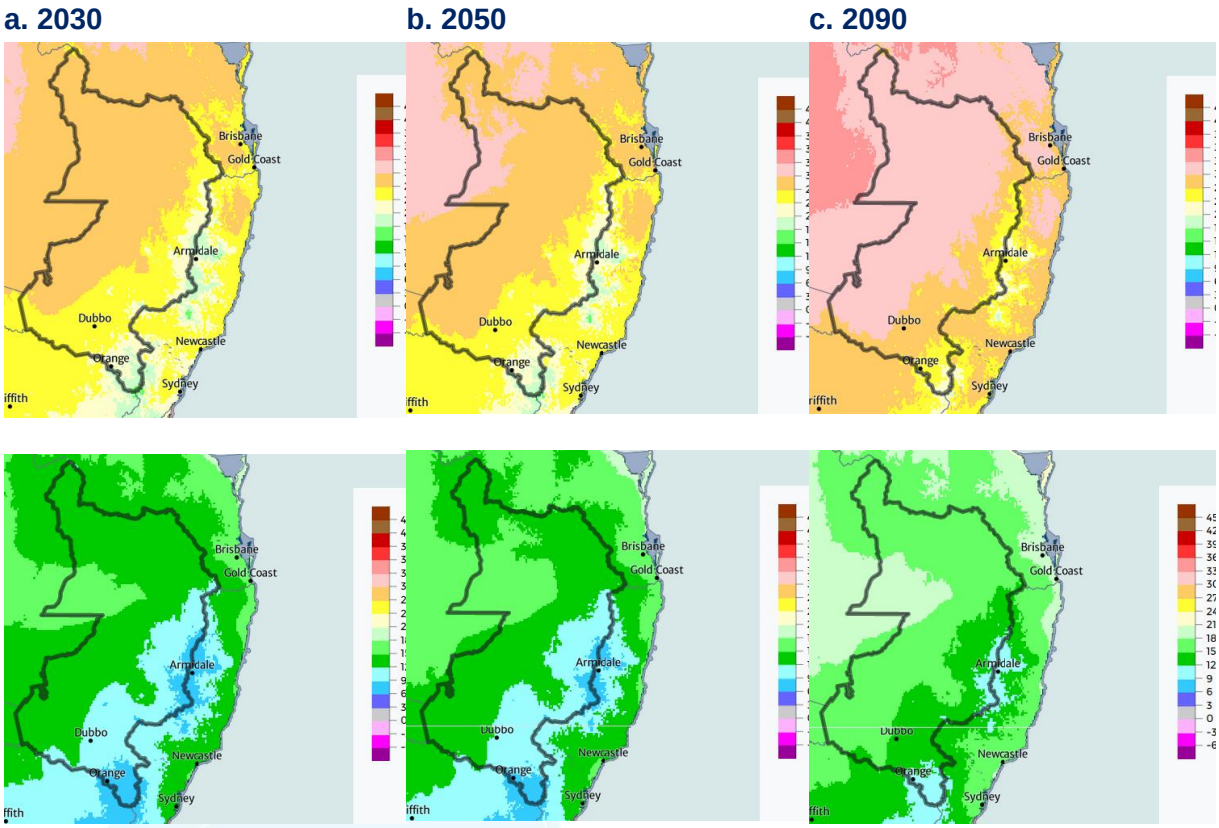
[2] Analogue tolerances slightly adjusted to ±0.5^{0}C for annual temperature and ±10% for annual precipitation.

Consistent with other parts of Australia, there is very high confidence that average temperatures will continue to increase in all seasons in the North West region. Most parts of the cluster could experience above twice the average number of days above 35°C under intermediate emission and high emission scenarios by late in the century.

There will be more hot days, longer warm spells and fewer frosts.

Extreme temperatures are projected to increase at a similar rate to mean temperature, with the temperature reached on hot days significantly higher. There is high confidence that frost-risk days (minimum temperatures under 2°C) will decrease.

Figure 5. Projected future maximum and minimum daily temperature



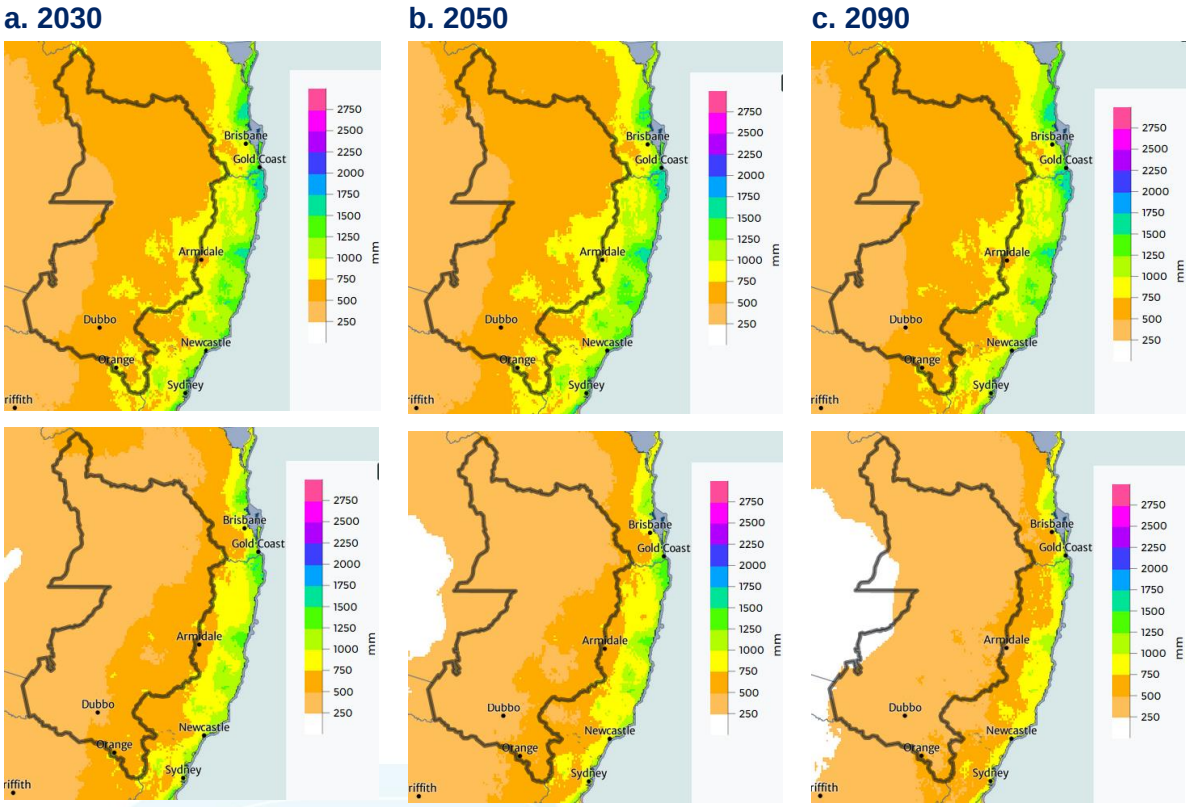
Projected future maximum daily temperature (top) and minimum daily temperature (bottom) for the Central Slope region under the high emission scenario simulated by CESM1-CAM5 for each 20-year period centred on 2030, 2050 and 2090. Source: www.climatechangeinaustralia.gov.au; accessed April 2015.

Average winter rainfall is likely to decrease and time spent in drought to increase.

The intensity of rainfall events will increase and the mean sea level will continue to rise with the height of extreme sea level events also increasing.

Time spent in drought is projected, with medium confidence, to increase over the course of the century in a high emission scenario (RCP 8.5). The projected decline in winter rainfall means winter solar radiation is likely to increase. Like rainfall, it is difficult to project drought with certainty and there is no clear indication of changes to drought condition in the cluster.

Figure 6. Projected average annual rainfall for two climate change models



The projected average annual precipitation (mm) is simulated by CESM1-CAM5 (top row) and GFDL-ESM2M (bottom row) for the Central Slopes region under the high emission scenario (RCP8.5) for each 20-year period, centred on 2030, 2050 and 2090 from left to right. Source: www.climatechangeinaustralia.gov.au; accessed April 2015.

We can expect a harsher fire-weather climate in the future.

There is high confidence that climate change will result in a harsher fire-weather climate in the future – the magnitude of this change will depend on rainfall.

Table 2. Cluster mean annual values of maximum temperature (°C), rainfall (mm), drought factor (no units), and the number of severe fire danger days

SEV: Forest Fire Danger Index (FFDI)* greater than 50 days per year, and cumulative FFDI (ΣFFDI; no units) for the 1995 baseline and projections for 2030 and 2090 under RCP 4.5 and RCP 8.5 (adapted from Ekström et al. 2015).

Variable	1995 Baseline	2030, RCP4.5	2030, RCP8.5	2090, RCP4.5	2090, RCP8.5
Maximum temperature (^{0}C)	25.2	26.5	26.8	27.8	29.6
Rainfall (mm)	586	541	526	519	504
Drought factor (no unit)	6.8	7.2	7.3	7.5	7.8
Severe fire danger days (FFDI greater than 50 days per year)	2.2	3.0	3.7	4.1	7.2
Cumulative FFDI (no unit)	3857	4183	4446	4600	5357

* FFDI - McArthur Forest Fire Danger Index (McArthur, 1967)

As warming progresses, there is high confidence that evapotranspiration will increase. A decline in relative humidity is projected with high confidence for winter and spring, and medium confidence for summer and autumn. The magnitude of the changes is uncertain and it is likely that changes in the near future will be small. Changes in summer and autumn are possible but unclear; however, there is medium confidence that spring will become shorter and less temperate.

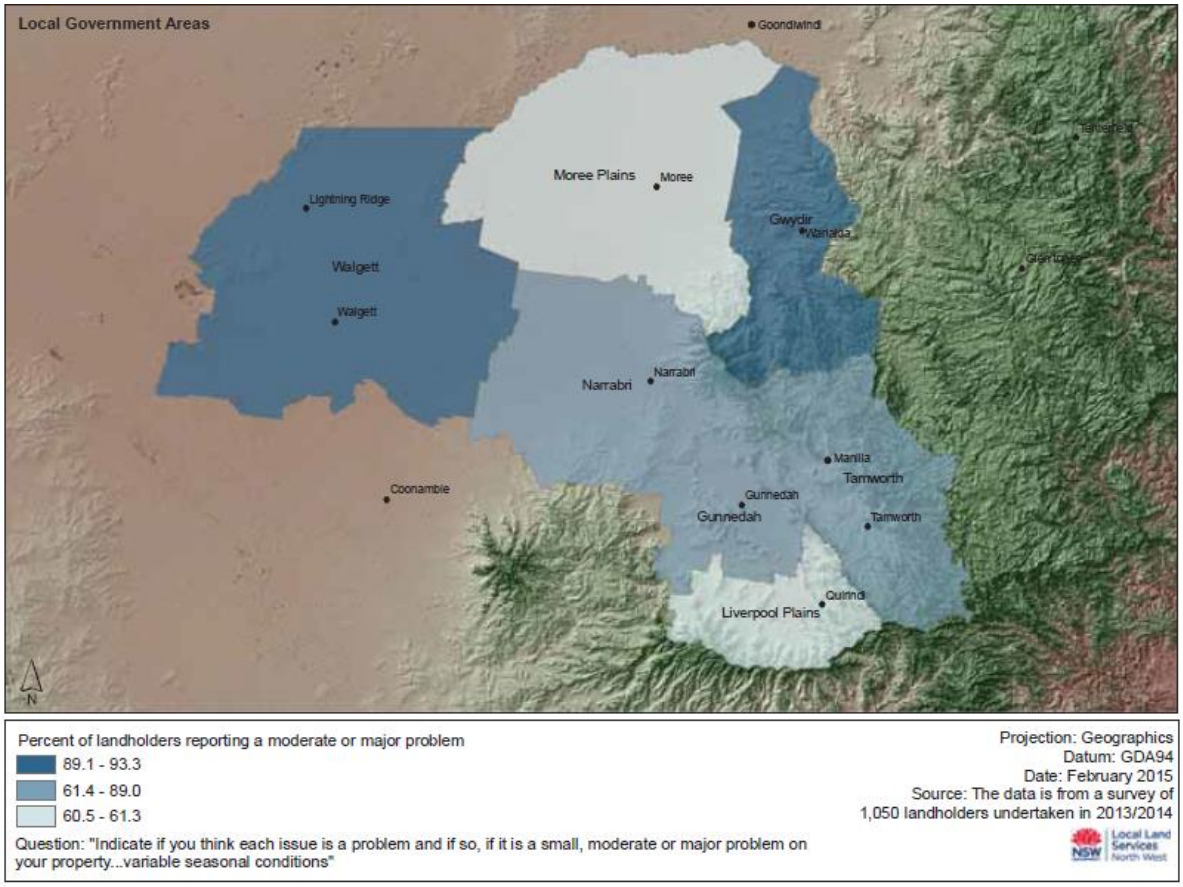
Note: The projections presented in this section of the report have been drawn from the CSIRO's Central Slopes Cluster Report, Climate Change in Australia Projections for Australia's Natural Resource Management Regions.

3.1 How North West LLS landholders responded to this variability

We surveyed a random sample of 1,050 landholders in the North West LLS region between November 2014 and February 2015. One of the key objectives of the survey was to find out what landholders think of climate change and how they plan to adapt to climate variabilities.

While 79% of landholders believed that 'human activities have a significant impact on climate change', 70% also believed that 'the evidence for climate change was unreliable'. Most landholders indicated they are adapting the way they manage their property in anticipation of long-term climate change (68%) and believed climate change will impact their property or the way they live (66%). However, only 57% believed they would be personally affected by climate change in the next five years.

Figure 7. Landholder responses to variable seasonal conditions in the North West LLS

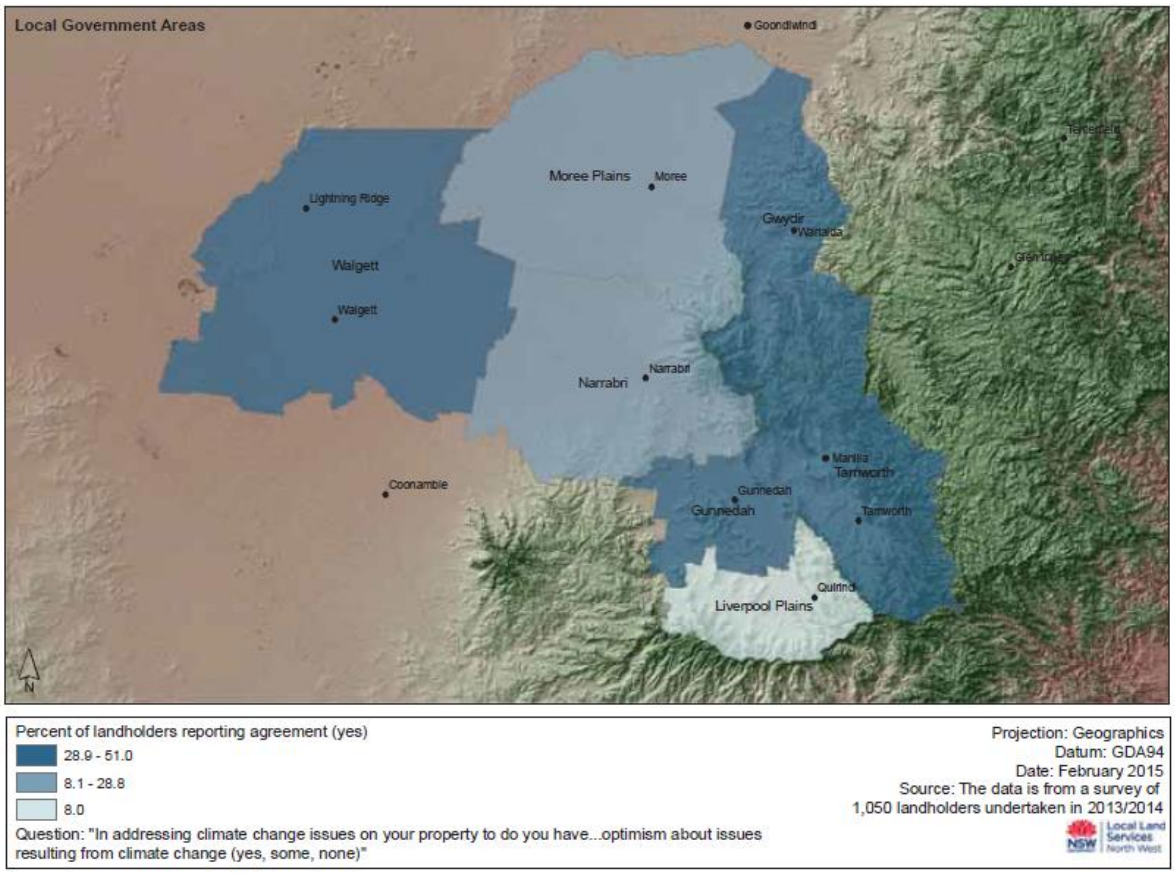


Production more so than lifestyle landholders were more likely to indicate they were adapting the way they managed their property in anticipation of long-term climate change. Older landholders were more likely to believe the evidence for climate change to be unreliable and were less likely to believe climate change will impact their property or the way they lived.

Most landholders believed they will be able to adapt to climate change while a small number indicated they would not change their practices in response to climate change.

Most landholders believed they had the knowledge, optimism, support and access to tools to address the impacts of climate change on their properties. Younger landholders, and those involved in production, demonstrated a significantly greater capacity to adapt to climate change than older landholders or those on lifestyle properties.

Figure 8. Landholder self-assessed capacity to adapt to climate change



Twenty-four per cent of landholders could not or did not identify specific changes they would make in running their properties in response to climate change. They did state, however, that they recognised the need for change. In addition, 21% of landholders indicated they would not change their practices in response to climate change as they did not believe long-term climate change would occur or would be any different from the pattern of climate change that had occurred in the past.

A further 14% of landholders indicated they did not know what changes they might make and 7% indicated there was no need for change as they did not believe long-term climate change would occur in their lifetime.

Many practice changes indicated by landholders were associated with water management, conservation and efficiency.

Amongst those landholders who were able to identify specific practice changes in response to climate variability, the most common practices were to:

- destock or reduce the number of livestock on their land
- conserve water through better water management
- store more on-farm water
- install or develop bore water
- develop more on-farm dams.

4 How will climate change affect our region?

The results presented in Section 4 of this report are preliminary results that provide relative patterns of change due to climate variability only. They are not exact measures of climate change and have not been field verified.

4.1 Agriculture

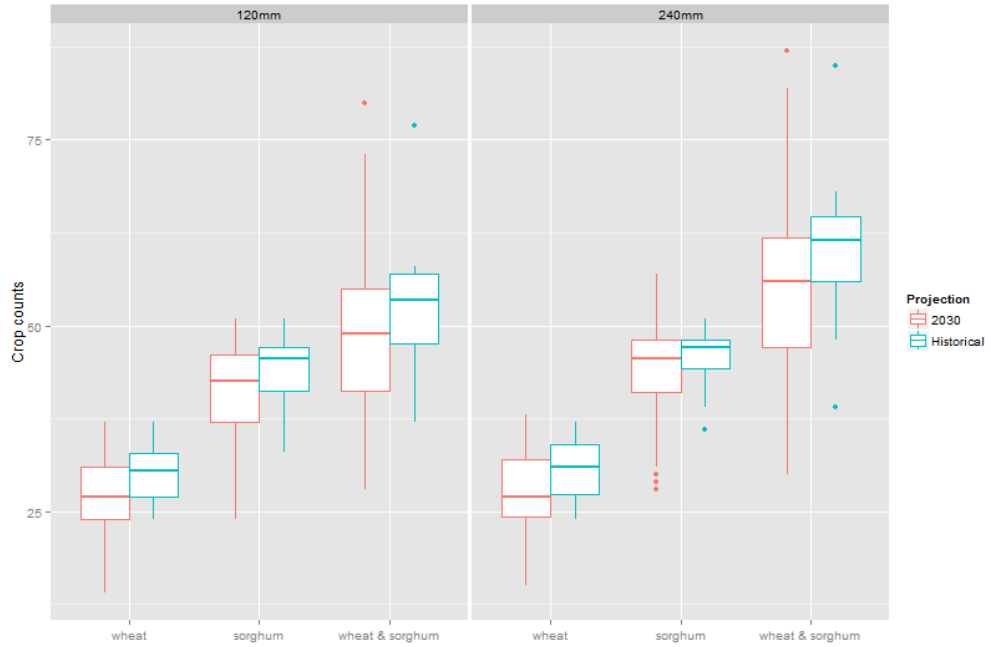
Agriculture (particularly cropping and grazing) is the main land use across the North West LLS region. Higher temperatures, changes in rainfall patterns and the frequency and intensity of extreme events like drought, bushfire and flood, all affect our agriculture.

Wheat and sorghum

Increased temperatures and periods of reduced rainfall events will result in fewer opportunities to plant. This has had the flow-on effect of reducing overall production for both wheat and sorghum crops as the agronomic parameters to initiate crop planting for wheat and sorghum are that 1) rainfall over 7 days must be greater than 25mm and that 2) stored soil water must be greater than 100mm. However, projected climate for 2030 will have little effect on wheat and sorghum yield compared to historical levels.

Increased temperatures and periods of reduced rainfall events will result in changes in planting opportunities.

Figure 9. Planting opportunities under historical and projected future climates



This figure shows the number of successful planting opportunities of wheat, sorghum, and wheat and sorghum cropping systems across the central slopes region for historical climate (light blue) and projected future climate for 2030 (red).

Cotton

Agricultural Production Systems sIMulator (APSIM) simulation showed that there is less difference in cotton yield (non-irrigated) by projected near-future climate compared to historical climate. However, if there is no water restriction for irrigation, warmer climate and elevated carbon dioxide may have few positive effects on cotton yield in the major crop-growing areas in the region.

Figure 10a. Effects of climate change on irrigated cotton yields with one irrigation event

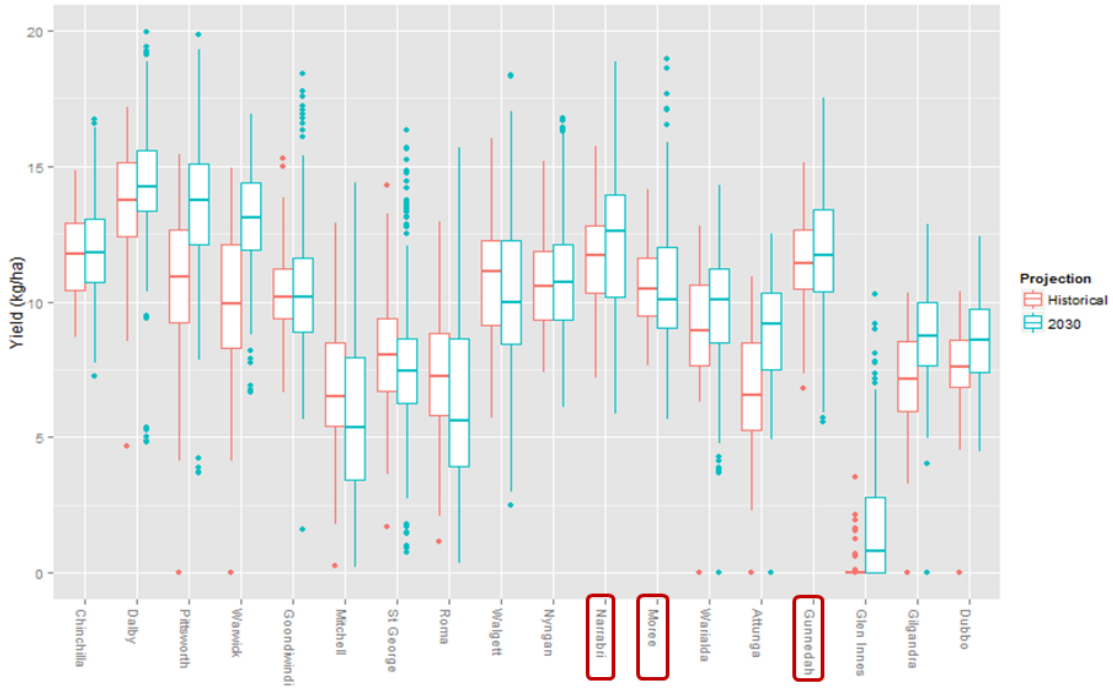
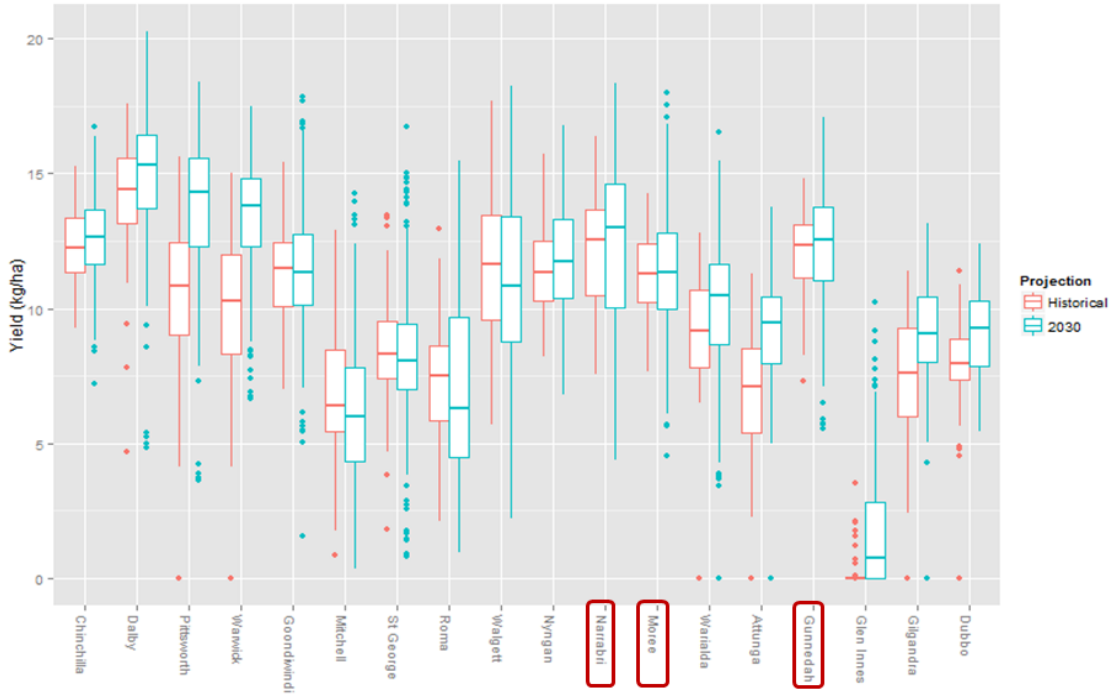


Figure 10b. Effects of climate change on irrigated cotton yields with two irrigation events



Figures 10a and 10b show the effects of climate change on irrigated cotton yields (kg/ha) for the Central Slope regions as simulated by APSIM model under high emission scenario (A1FI, CMIP3) for historical climate (red) and projected future climate 2030 (blue). Major irrigated cotton growing areas of North West LLS are highlighted in a dark red box.

Grazing

Climate variability is likely to pose future risk to the primary production systems, including grazing enterprises, of the North West region. To find out how climate variability will affect grazing, the North West LLS collaborated with Agriculture NSW using the CSIRO tool, GrassGro.

GrassGro can simulate the variation in pasture and animal production using historical climate data and projected future climate data as an indication of climate change risk on a grazing system. The tool also helps the landholder use their grasslands more profitably and sustainably.

Climate variability is likely to pose future risk to primary production, including grazing enterprises, of the North West region.

Using the historical climate data inbuilt in GrassGro, a natural pasture system with self-replacing Angus beef enterprises is simulated to assess the optimum stocking rate while maintaining above 70% groundcover for more than 70% of the total simulation period. In addition, tentative gross margin from the grazing enterprise is also calculated using 2013 prices for all the required economic information.

Data representing 30 years of potential weather centred at 2030 was used for a rapid assessment of climate change impacts on grazing. As projected, annual rainfall for 2030 period varies largely from drier (5–15% reduction) to wetter (5–15% increase) conditions. Data from three global circulation models was used to capture this variability.

Preliminary results showed that climate change poses risk to grazing enterprises in the region. Annual pasture production is likely to be reduced under all future climate conditions for 2030.

Table 3. Climate change impacts on grazing enterprises

Stocking rate, long-term average pasture production and indicative gross margin based on 2013 prices for a self-replenishing beef enterprise (Angus) at the four locations of North West region as estimated by GrassGro model under the historical climate and near future climate scenarios.

a. Tamworth

Climate and location	CO_2 (ppm)	Rainfall (mm)	Stocking rate	Ground cover (%)	Pasture production (kg/ha)	Indicative Gross margin ($/ha)
Historic climate (1960 -2013)	350	679	0.7	76	8306	152
2030: warmer and drier (HadGEM2)	444	616	0.4	71	7276	38
2030: warmer and little change in annual rainfall (MPI-ESM)	444	694	0.4	75	8375	34
2030: warmer and wetter (GFDL-CM3)	444	727	0.6	72	7940	92

b. Warialda

Climate and location	CO_2 (ppm)	Rainfall (mm)	Stocking rate	Ground cover (%)	Pasture production (kg/ha)	Indicative Gross margin ($/ha)
Historic climate (1960 -2013)	350	627	0.7	58	5360	73
2030: warmer and drier (HadGEM2)	444	678	0.4	64	6088	31
2030: warmer and little change in annual rainfall (MPI-ESM)	444	754	0.4	63	7032	34
2030: warmer and wetter (GFDL-CM3)	444	813	0.4	75	6865	38

c. Gunnedah

Climate and location	CO_2 (ppm)	Rainfall (mm)	Stocking rate	Ground cover %)	Pasture production (kg/ha)	Indicative Gross margin ($/ha)
Historic climate (1960 -2013)	350	627	0.4	71	5509	22
2030: warmer and drier (HadGEM2)	444	569	0.4	56	4658	-8
2030: warmer and little change in annual rainfall (MPI-ESM)	444	632	0.4	56	5121	-10
2030: warmer and wetter (GFDL-CM3)	444	689	0.4	52	5146.0	-11

d. Narrabri

Climate and location	CO_2 (ppm)	Rainfall (mm)	Stocking Rate	Ground cover (%)	Pasture production (kg/ha)	Indicative Gross margin ($/ha)
Historic climate (1960–2013)	350	678	0.4	70	5155	13
2030: warmer and drier (HadGEM2)	444	785	0.4	53	4668	-5
2030: warmer and little change in annual rainfall (MPI-ESM)	444	632	0.4	58	5083	-9
2030: warmer and wetter (GFDL-CM3)	444	689	0.4	56	5058	-10

4.2 Land management

The Soil and Water Assessment Tool (SWAT) model has proven to be affective in assessing water resource and nonpoint source pollutions (e.g. sediments) for a wide range of scales and environmental conditions across the globe (Gassman et al. 2007). The SWAT model was used by the University of Southern Queensland (land management sub-project team of the Central Slopes cluster project) for assessing likely impact of climate change on surface run-off and sediment yields across the Central Slopes region.

To assess the surface run-off and associated sediment, a 90-metre resolution digital elevation model (DEM) was used to delineate micro-catchment areas across the north of the Central Slopes cluster region for assessment yields.

At each micro-catchment level, the SWAT model was simulated under two climate scenarios including historical climate (1979–2010) and projected near the future climate centre of 2030. The near-future climate under the medium emission scenario (A1B emission scenario from CMIP3) was represented by the projected data from ECHAM5 global circulation model.

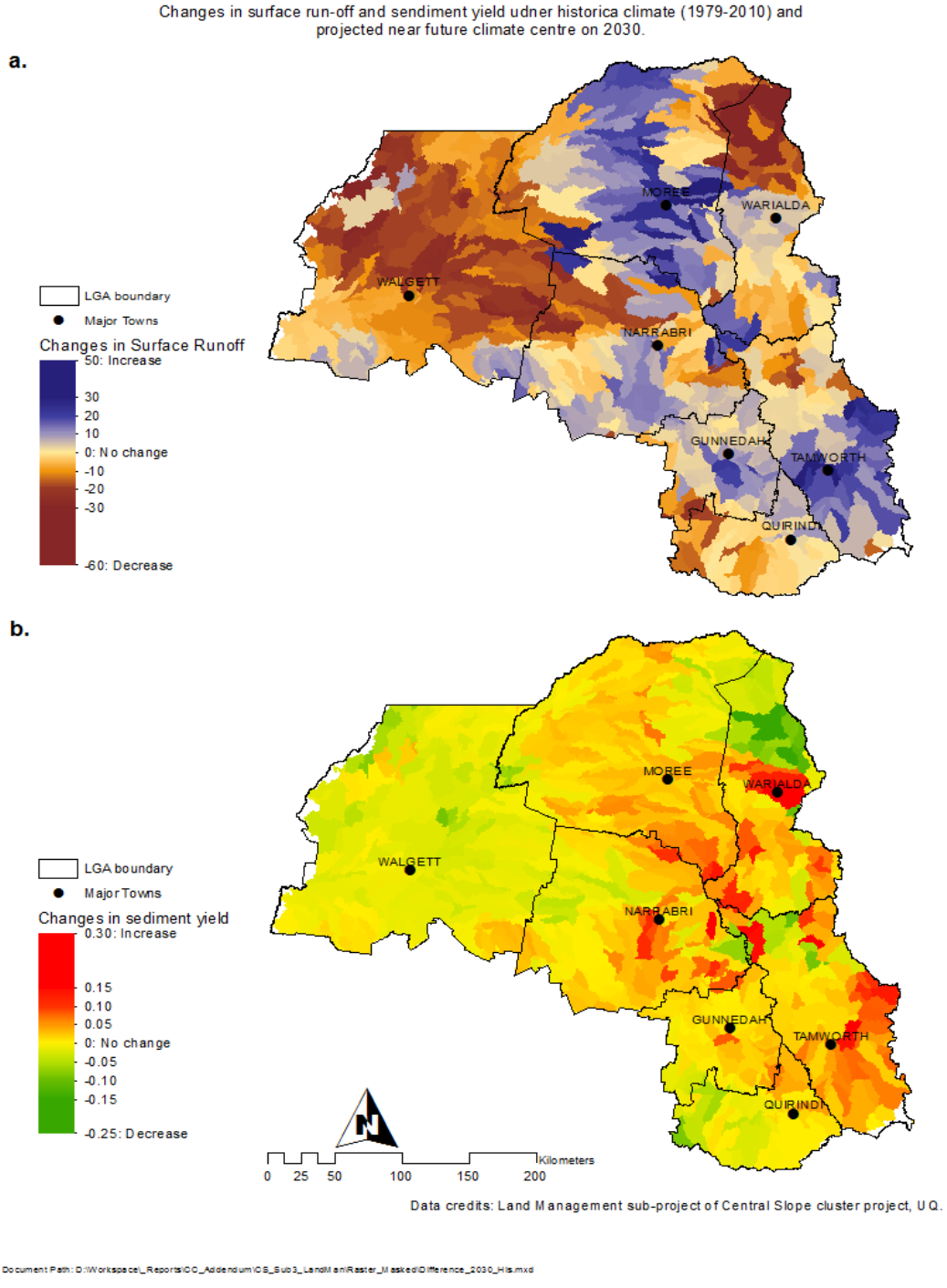
Table 4. Long-term average annual run-off and sediment yields across the North West LLS region estimated by SWAT tool

The assessment was under the historical climate (1979–2010), and projected the near-future climate centre of 2030 under the medium emission scenarios (A1B of CMIP3) represented by ECHAN5 global circulation model. Values inside the bracket represent range across North West region.

Variable	Historical climate (1979-2010)	Projected near future climate center on 2030
Surface run–off (mm)	15.4 (0 to 77)	17.6 (0 to 95)
Sediment yield (tons/ha)	0.04 (0 to 0.58)	0.05 (0 to 0.78)

Figure 11. Likely impact of climate change on surface run-off and sediment yields across the North West LLS region

a. Magnitude of changes in surface run-off (mm) under projected near-future climate compared to historical climate
b. Magnitude of changes in sediment yields (tons/ha) under projected near-future climate compared to historical climate. Positive value indicates likely increase in 2030, and negative values indicate likely decrease.



4.3 Biodiversity

It is widely recognised that climate change and biodiversity are interconnected. Biodiversity supports our ecosystem and plays an important role in our ability to adapt to variability in climate as well as lessen the impact of climate change. Conserving biodiversity is crucial.

Habitat loss, fragmentation of habitats and threats from invasive species in today's environment has significantly depleted biodiversity's ability to adapt naturally. Australian fauna and flora are already responding to the relatively small climate changes that have occurred (Dunlop 2013). The impacts of climate change on biodiversity are expected to accelerate sharply through this century. We will see extinction of species, transformation of ecological communities and reduction of the ecosystem services that sustain human well-being and the economy (ESA, 2014).

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For the North West region, we can expect:

- changes in the composition of ecosystems
- movement of ecotone boundaries
- changes in species' geographical ranges
- changes in the life cycle of species (due to seasonality shifts)
- change in populations (accretion, reduction, extinction).

Threats that have indirect impacts on biodiversity include:

- human population growth
- global markets
- primary industries
- incentives for fisheries, forestry, land clearing, agriculture and grazing that have a harmful effect on biodiversity.

Current conservation planning objectives may not be effective in future climate change scenarios. North West LLS has, therefore, identified several adaptation strategies and priority actions to reduce and manage the risks of potential climate change. The strategy or action recommended will depend on the potential degree of change, the nature of change and our ability to adapt the way we manage these changes.

Strategies and actions are set out by the North West LLS Biodiversity Prioritisation Plan 2015. They will be reviewed and updated when revised change modelling and new research into climate change impacts and adaptation become available.

Modelling climate change impacts on biodiversity

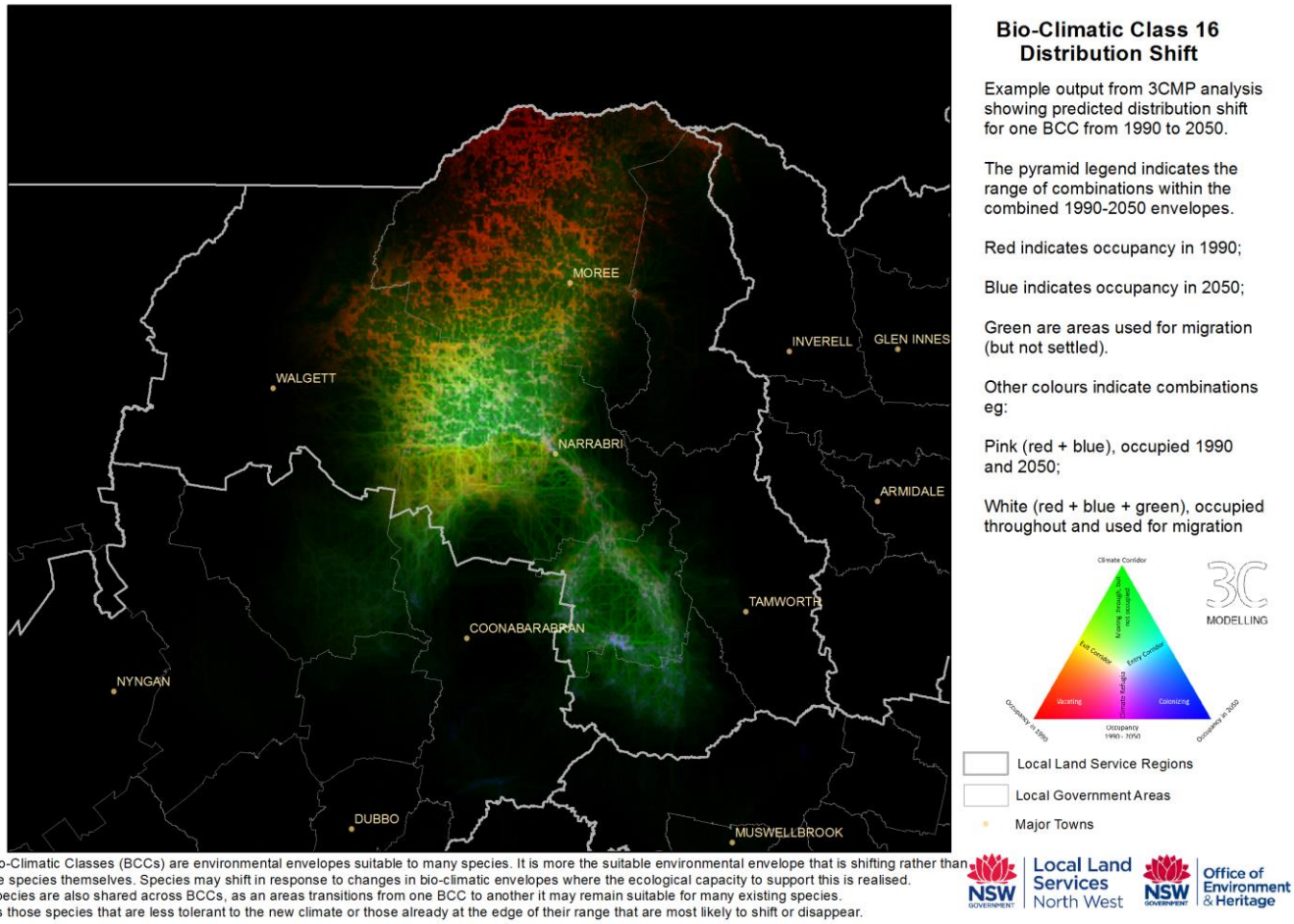
Three major scientifically based research projects that focus on modelling climate change impacts on biodiversity have provided the basis for identifying the impact of biodiversity within our region. Completed in 2014–2015, these research projects were the 3C Model Report (led by NSW Office of Environment and Heritage), the AdaptNRM (national initiative led by CSIRO), and koala and koala fodder tree distribution research (by Christine Adams-Hosking).

3C Model Report. This project aims to guide North West LLS on what conservation actions are needed and which part of the region would benefit the most from these actions. Actions will depend on the degree and pattern of past disturbances and anticipated future climate change (Drielsma 2014). The 3C approach was applied across the East Coast, Central Slopes (including the North West LLS region) and Murray-Basin NRM Cluster regions and extended to include all of NSW (Drielsma 2014).

The main product of the 3C modeling for the North West LLS region was the analysis of predicted distribution shifts of bio-climatic classes (BCCs) over time from 1990 to 2050. BCCs are environmental envelopes suitable to many species. Species may occur across a wide range of BCCs. Hence, a shift in one BCC to another BCC because of climate change indicates change in a suitable environmental envelope rather than in the species itself. As an area changes from one BCC to another, the area may remain suitable for many existing species more tolerant to climate. Species that are less tolerant to the new climate, or those at the edge of their range, are most likely to shift or disappear.

The 3C Modelling project identified 12 BCCs that will either shrink, disappear or emerge into the North West LLS region by 2050 due to climate change. Overall, the BBCs are shifting towards a south-easterly direction. Due to the topographic barrier in the eastern region (Great Dividing Range), some BCCs will also shrink or disappear by 2050, as they will be unable to shift past this barrier.

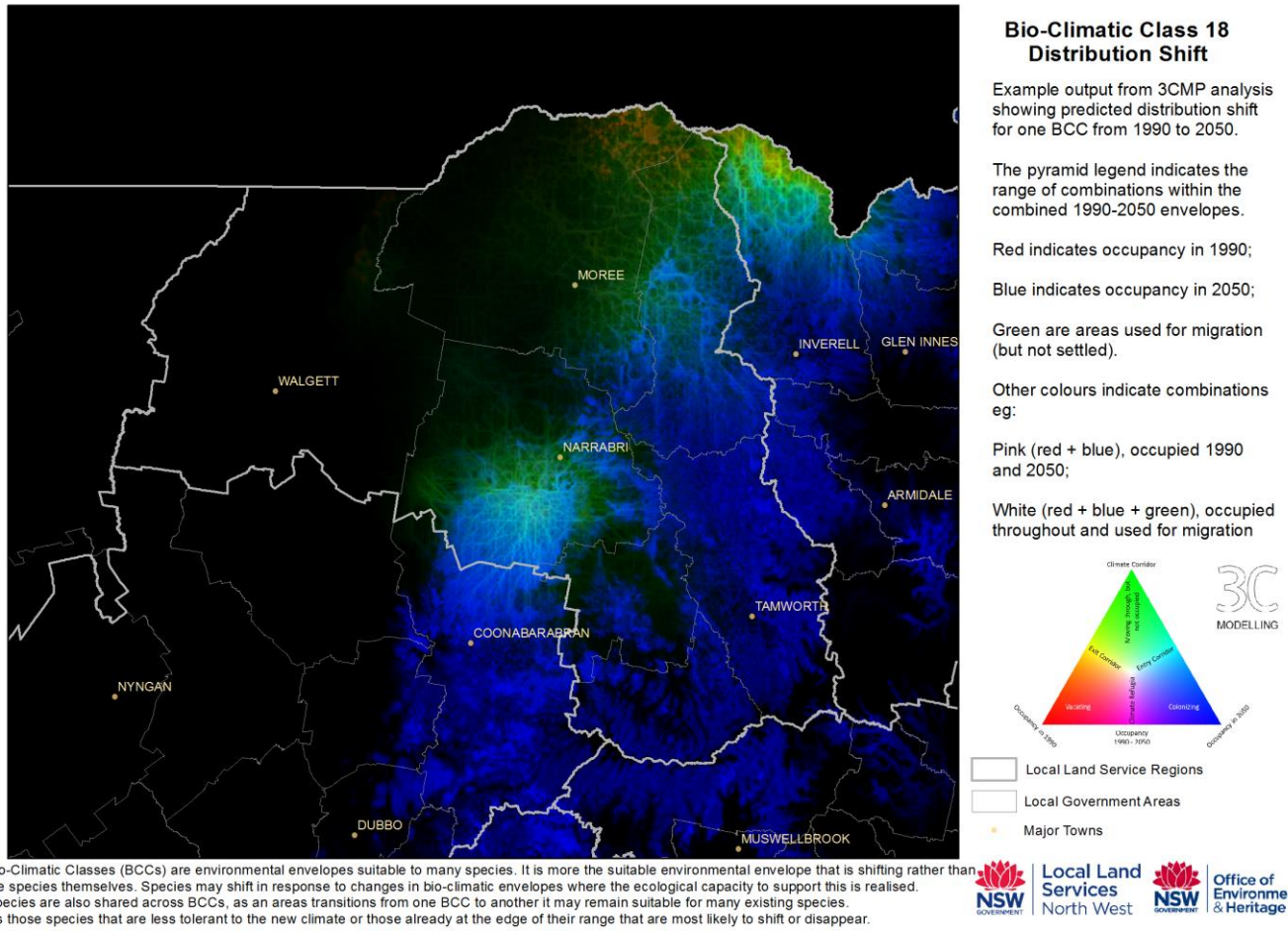
Figure 12. Predicted distribution shift of BCC16



Bio-Climatic Classes (BCCs) are environmental envelopes suitable to many species. It is more the suitable environmental envelope that is shifting rather than the species themselves. Species may shift in response to changes in bio-climatic envelopes where the ecological capacity to support this is realised. Species are also shared across BCCs, as an areas transitions from one BCC to another it may remain suitable for many existing species. It's those species that are less tolerant to the new climate or those already at the edge of their range that are most likely to shift or disappear.

This figure represents an example output from 3C Modelling project showing predicted distribution shift of BCC16, which may shift to Namoi floodplain areas from the Border River-Gydir (BRG) floodplain areas but will be confined to riverine areas by 2050.

Figure 13. Predicted distribution shift of BCC18



Bio-Climatic Classes (BCCs) are environmental envelopes suitable to many species. It is more the suitable environmental envelope that is shifting rather than the species themselves. Species may shift in response to changes in bio-climatic envelopes where the ecological capacity to support this is realised. Species are also shared across BCCs, as an areas transitions from one BCC to another it may remain suitable for many existing species. It's those species that are less tolerant to the new climate or those already at the edge of their range that are most likely to shift or disappear.

This figure represents an example output from the 3C Modelling project showing predicted distribution shift of BCC18, which may emerge within the eastern part of North West region by 2050.

Other products of the 3C model project include:

- target areas for habitat connectivity benefits
- combined conservation benefits for 1990–2050
- revegetation benefits
- management of benefits
- climate influence on benefits
- a representation of how the current bioclimatic classes fit into the projected 2050 climate (degree of fit).

We will continue to investigate how these products can be used in our planning.

AdaptNRM. This national initiative led by CSIRO aims to help NRM groups update NRM plans to include climate change planning. To assess the potential for change in biodiversity under climate change, the CSIRO developed several products based on ecological similarity. The Australia-wide datasets can be used on a regional scale.

CSIRO worked with us to develop a climate change assessment framework for the Biodiversity Prioritisation Plan (BPP). The assessment included elements such as adaptive capacity of an area under climate change as well as the potential degree of change of an area under climate change scenarios. CSIRO biodiversity planning modules were also used to develop priority actions in the Biodiversity Prioritisation Plan for climate change. North West LLS will continue to investigate the potential use of CSIRO datasets to further develop our planning mechanisms into the future.

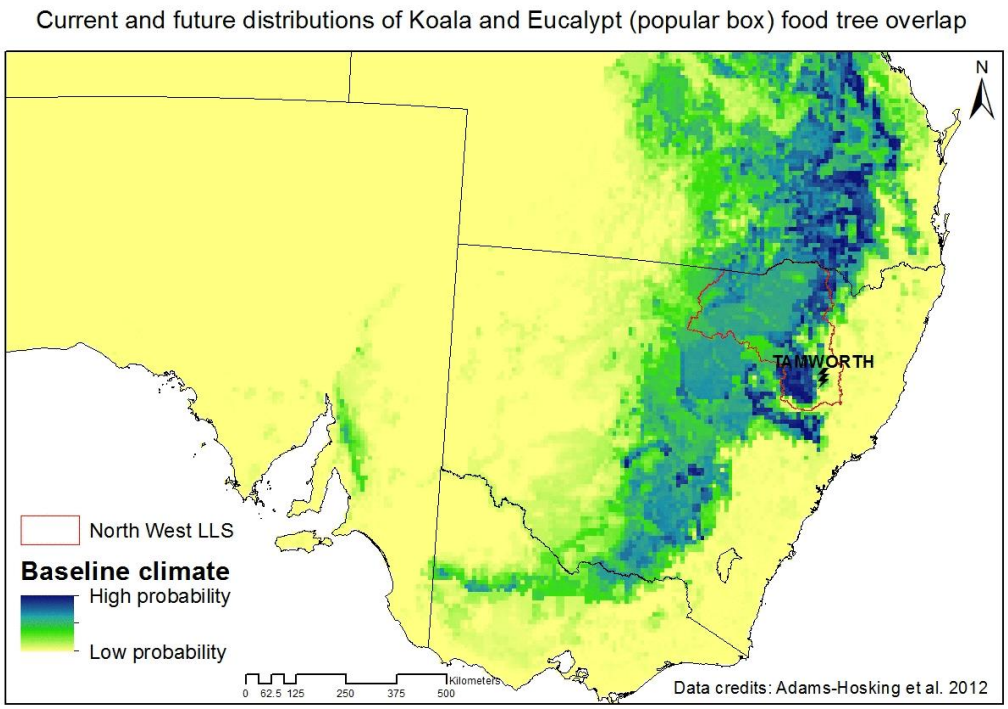
Koala and koala food tree distribution. The International Union for Conservation of Nature (IUCN) lists the koala as one of 10 species globally that is most vulnerable to climate change because of their limited capacity to adapt to rapid environmental changes (IUCN 2009). The IUCN states that the koala faces malnutrition and ultimate starvation as the nutritional quality of Eucalyptus leaves declines with increasing CO2 levels.

Koala and koala fodder tree distribution research by Dr Christine Adams-Hosking looked at how koalas are adapting to climate change. The results indicated that the koala and its food trees are predicted to experience significant range contractions as climate change progresses. This change includes distributions currently outside the distribution range. For example, some species contracted eastwards and southwards with a fragmented distribution, while other species contracted from the more arid interior but persisted in some eastern and southern regions of the koalas' predicted range. The research identified that the highest probabilities of overlap between koalas and their food sources were in fragmented coastal and southern regions of the koala's current range in Australia.

Adams-Hosking advises that it is not enough to consider the effects of climate change on an animal in isolation; it must be done while also considering the impacts on its critical food and habitat resources. Planting food tree species and restoring habitats will help protect koalas and provide them with critical refuge from climate change. Finer scale modelling will help identify regional and local priorities to conserve the koala.

Although the Biodiversity Prioritisation Plan does not specifically identify koalas or koala food trees as a priority action, it does encompass priorities that will indirectly enhance koala habitat. Local government areas may look at specific koala conservation strategies in the future.

Figure 14 Current and future distributions of koala and eucalypt food tree overlap



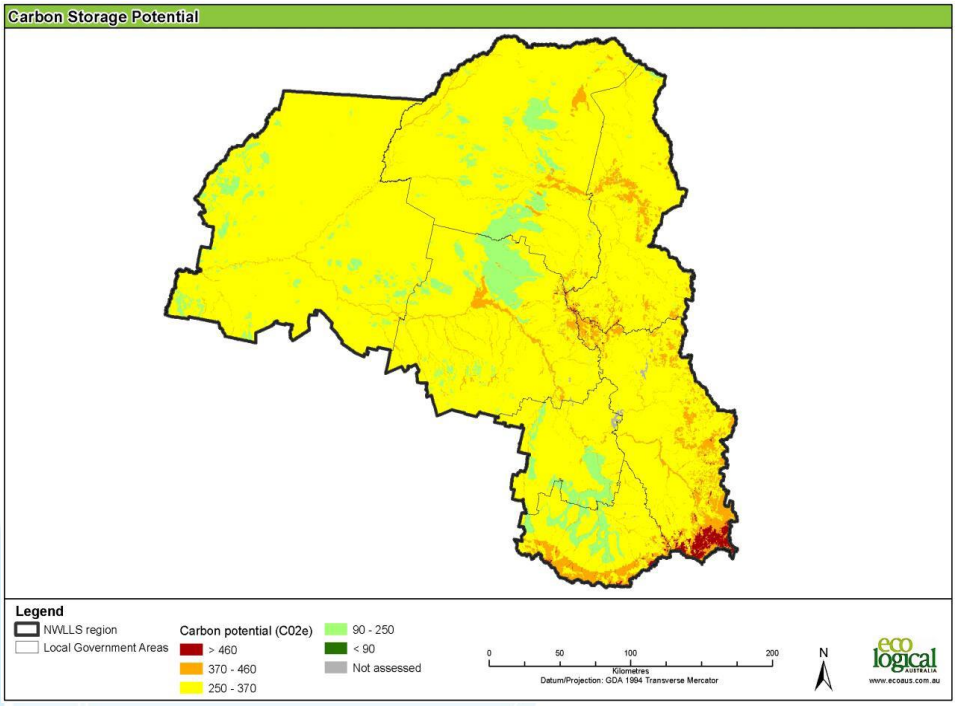
Investigating carbon sequestration and storage potential

Carbon sequestration is the process of capturing carbon dioxide from the atmosphere and storing it. To better prepare the North West LLS for future carbon sequestration partnership opportunities, our research team studied broad carbon storage potential across the North West LLS. This research took into account site quality, soil characteristics and vegetation type.

Landholders and managers of permanent plantings of mixed native species in the North West LLS region may be able to use carbon sequestration to generate income by trading credits.

The results of the North West LLS 2015 carbon sequestration study show that carbon potential equivalent (CO_2e) ranges from less than 90 tonnes per hectare (degraded sites with low rainfall) to very high carbon sequestration potential over 450 CO_2e (areas with higher rainfall that support stronger tree growth). Carbon potential equivalent was derived from vegetation characteristics and modelled site quality index, and was classified from very high to low potential. The higher elevation areas (such as Mount Kaputar, Nandewar Ranges and the Liverpool Ranges) also return a high carbon potential. Poor quality sites constrain carbon potential in areas with lower soil fertility and lower rainfall.

Figure 15. Carbon storage potential in the North West LLS

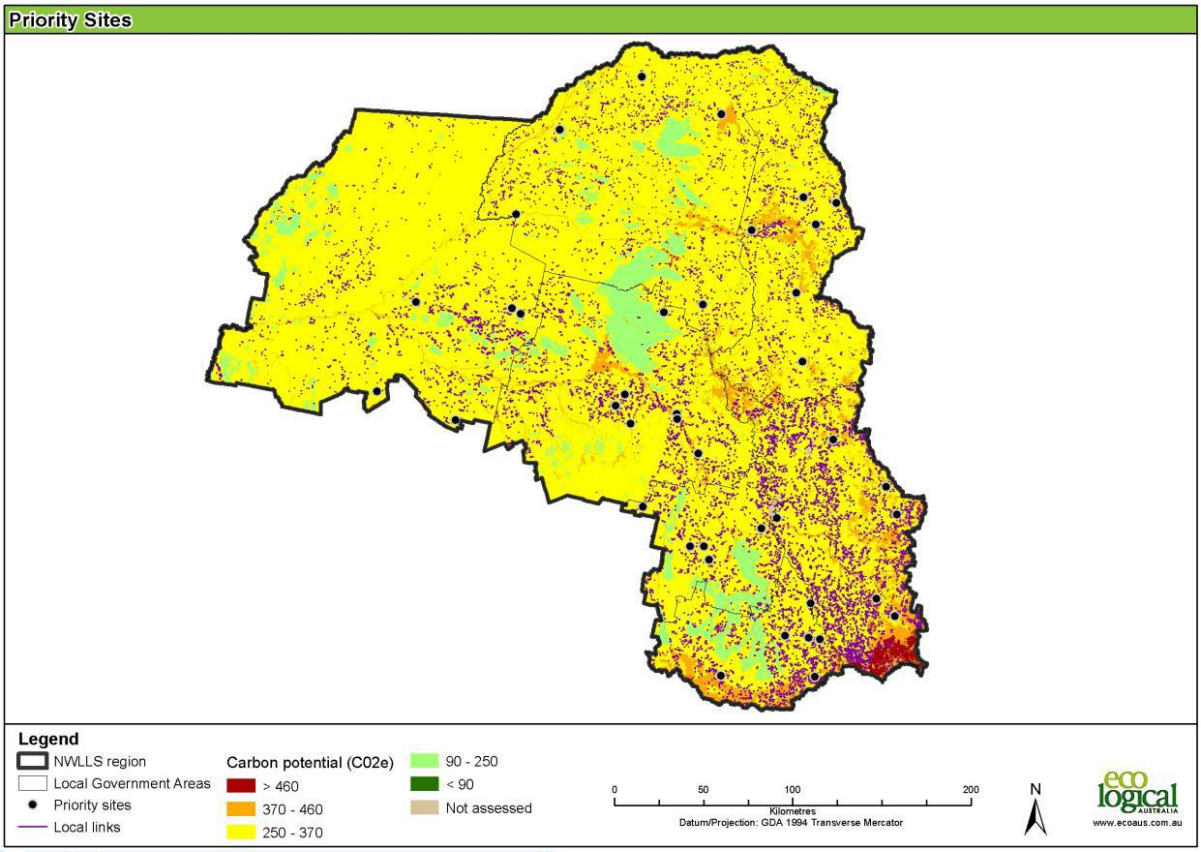


Note: This map was built tenure-blind and does not consider whether the biomass accumulation rate may be converted into tradable carbon credits.

The carbon sequestration study also assessed the suitability of 35 potential carbon sequestration sites in the region (five sites in each local government area). We selected the 35 sites in cleared areas modelled as high and very high carbon sequestration potential. Sites that traversed roads and settlements or other barriers were avoided where possible. Site quality was optimised for soil fertility and climate characteristics as these were embedded into carbon potential and for position in the landscape based on aerial photo interpretation of surrounding land use.

To analyse the carbon sequestration potential of each of the 35 sites over 100, our research team used the national carbon accounting tool FullCAM. This tool is designed to track carbon stocks changes associated with land use and management. Outcomes show the theoretical carbon harvest available at each site from permanent environmental plantings with native species.

Figure 15. Potential carbon sequestration sites in the North West LLS



The preliminary results of the FullCAM analysis indicated some sites in the North West LLS have better carbon sequestration potential than others. Further investigation is needed into carbon sequestration potential for landholders.

5 Conclusion

Our research shows that climate change in the North West region will affect both agricultural productivity and biodiversity. Our community, including farmers, have largely accepted that we need to consider the impacts of climate change and adapt to these changes, now and into the future. This document will help give landholders clarity and guidance in planning and decision-making. While some of the news appears to be pessimistic, we are confident in the resilience and adaptability of our community to ensure a positive future for both our agricultural industry and the environment.

6 Acknowledgments

We acknowledge the Australian Government for funding this project through the Stream 1 of the Regional Natural Resource Management Planning for Climate Change Fund.

We gratefully acknowledge the Australian Government Bureau of Meteorology and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) for the observed and projected future climate data and maps used in this report.

We acknowledge the World Climate Research Programme's Working Group on Coupled Modelling, which is responsible for CMIP, and we thank the climate modeling groups (listed in Table 3.3.1 of CSIRO and Bureau of Meteorology, Climate Change in Australia Information for Australia's Natural Resource Management Regions: Technical Report) for producing and making available their model output. For CMIP, the U.S. Department of Energy's Program for Climate Model Diagnosis and Intercomparison provides coordinating support and led development of software infrastructure in partnership with the Global Organization for Earth System Science Portals.

We acknowledge the University of Southern Queensland and other research teams of Stream 2 – Central Slopes cluster project and sub-projects for their contributions. Our sincere thanks go to Phillip Graham, Technical Specialist Livestock Systems, Agriculture, NSW Department of Primary Industries for collaborating with us in a rapid assessment of climate change impact on grazing enterprises of the North West region. We acknowledged Dr Christine Adams-Hosking for sharing her research data of current and future distribution of koala and food tree distributions. Dr Alyson Williams (University of Southern Queensland), Brendan Power (formerly Department of Agriculture and Fisheries, Queensland) and Dr John Clark (CSIRO) were regularly contacted while compiling this report. We acknowledge their support.

Last but not least, we would like to express our sincere thanks to all Central Slopes cluster colleagues, researchers and NRM colleagues; it was an excellent forum for sharing each other's expertise and experiences.

7 Glossary

agronomic parameter	The crop agronomic parameters of leaf area index (LAI), nitrogen (N) uptake, and total chlorophyll (Chl) content are very important for the prediction of crop growth.
bioclimatic classes	Environmental envelope suitable to a broad set of species.
biodiversity value	Biodiversity values are natural elements that support the functioning of biodiversity, including (but not limited to) terrestrial ecosystems (forests, woodlands, grasslands, aquatic and floodplain ecosystems (rivers, wetlands), corridors and linkages.
carbon sequestration	Carbon sequestration is the process of capturing and storing atmospheric carbon dioxide (CO_2).
decile	A ranking compared with the average for an area (e.g. for rainfall).
environmental envelope	A broad group of species suited to a particular landscape and climate now, but which might move to another spatial area due to the impact of climate change.
emission scenario	Emissions scenarios describe future releases into the atmosphere of greenhouse gases, aerosols, and other pollutants. Along with information on land use and land cover, they assist in climate change analysis, including climate modelling and the assessment of impacts, adaptation, and mitigation.
ecotone	A transition area where two plant communities meet and integrate.
eutrophication	Excess of nutrient to the water that may result in an algal bloom.
evapotranspiration	The process of transferring moisture from the earth to the atmosphere by evaporation of water and transpiration from plants.
habitat connectivity	The degree to which the landscape facilitates the movement of organisms and other ecological flows.
hydrologic boundaries	Hydrologic units are drainage areas that are delineated so as to nest into a multi-level hierarchical drainage system. Surface waters are collected within the boundary. The areas may accept water from one or more points outside the unit's boundary.
micro-catchment level	Delineation of hydrological boundaries at the local level.
	In biology, the range of a species is the geographical area

	within which that species can be found.
range contraction	A reduction of the area in which a species can be found.
solar radiation	Energy radiated from the sun in the form of electromagnetic waves, including visible and ultraviolet light and infrared radiation.
threat	A threat is a process that threatens, or could potentially threaten, the survival or evolutionary development of a species, population or ecological community.

8 Acronyms

APSIM	Agricultural Production Systems sIMulator (APSIM)
BCC	bioclimatic class
BOM	Bureau of Meteorology
BPP	Biodiversity Prioritisation Plan
CO_2	carbon dioxide
CO_2e	carbon equivalent
DEM	digital elevation model
FFDI	Forest Fire Danger Index
IPCC	Intergovernmental Panel on Climate Change
NRM	Regional natural resource management
	Regional NRM organisations plan and deliver programs that support healthy and productive country, viable communities and sustainable industries.
RCP	Representative concentration pathways.
	The pathways are expressed as RCP8.5, RCP6, RCP4.5 and RCP3-PD2 with RCP8.5 representing a high emissions scenario.
SWAT	Soil and Water Assessment Tool

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Appendix 1. Climate observations

Figure 1. Comparison of observed and simulated change in continental surface temperatures including average global temperatures

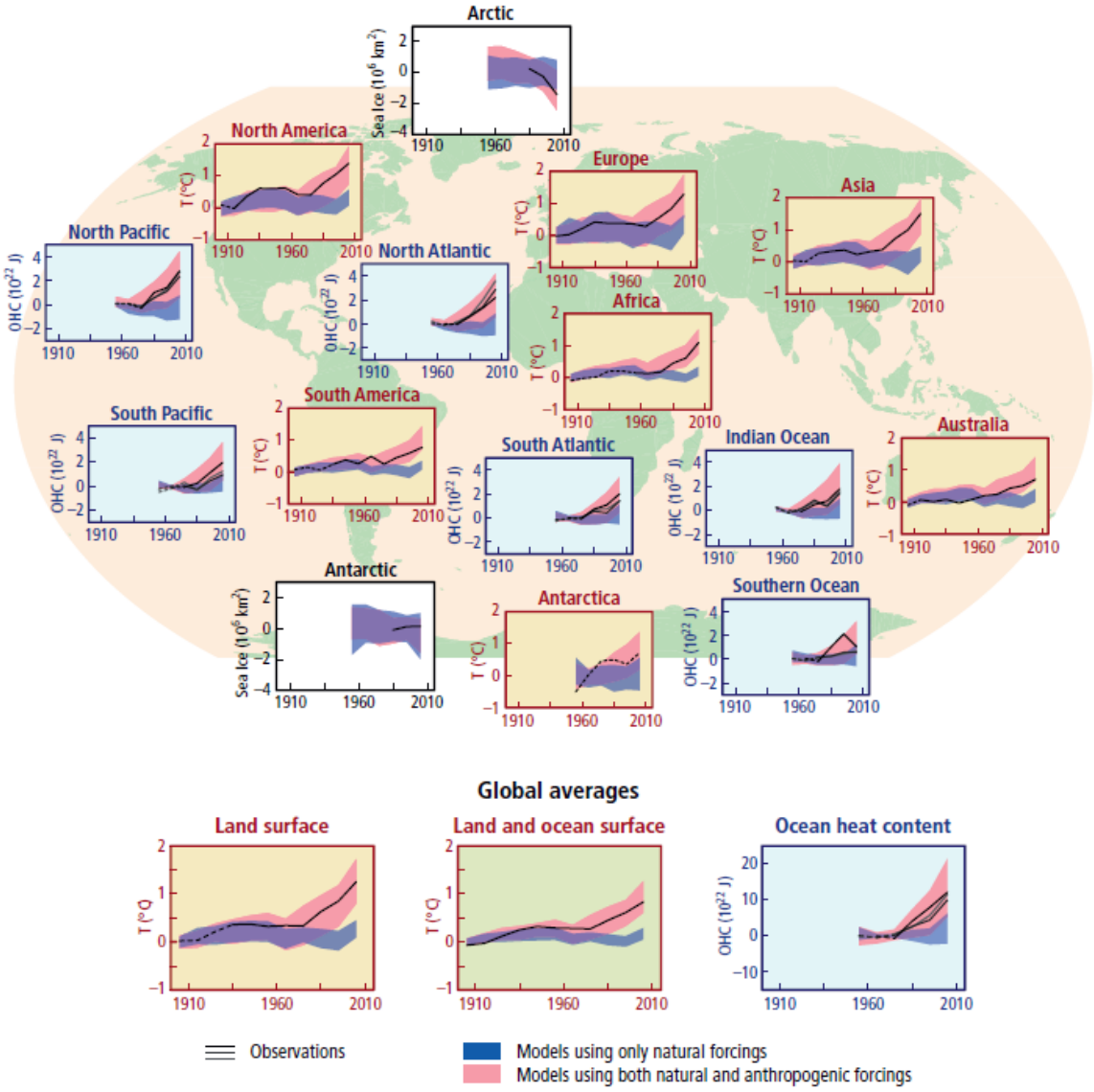
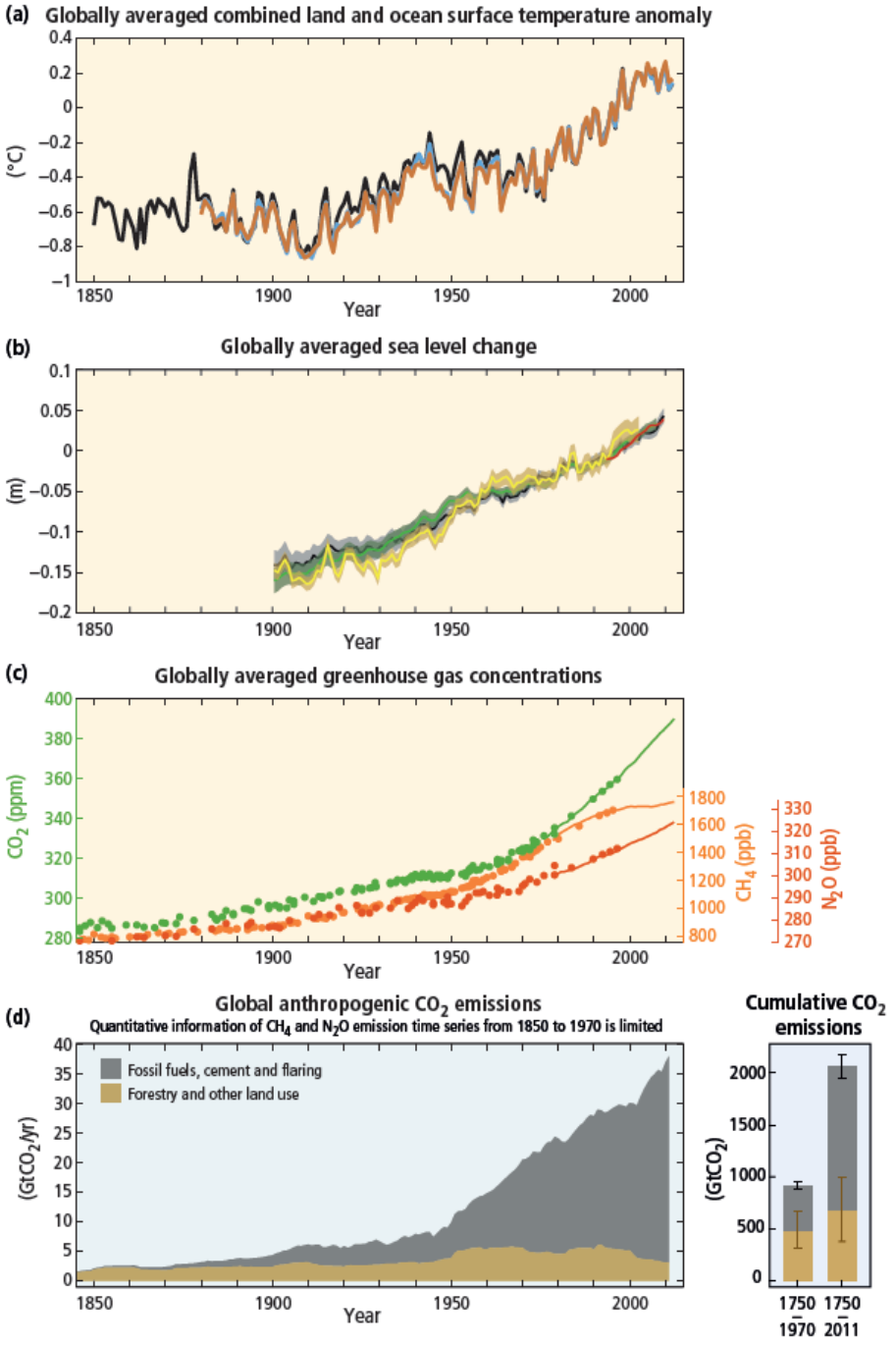


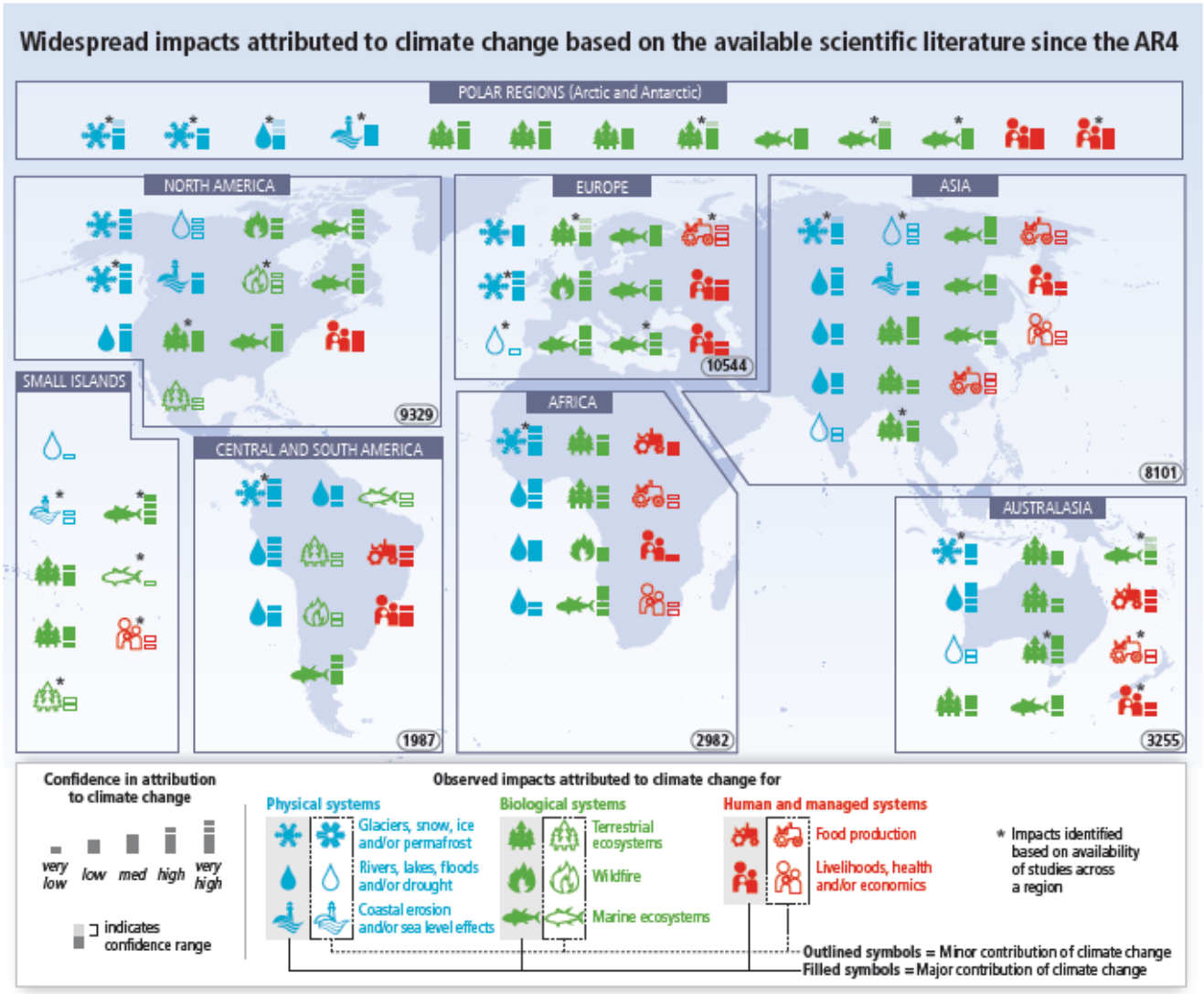
Figure 1 shows changes on land (yellow panels), Arctic and Antarctic September sea ice extent (white panels), and upper ocean heat content in the major ocean basins (blue panels). Anomalies are given relative to 1880–1919 for surface temperatures, to 1960–1980 for ocean heat content, and to 1979–1999 for sea ice. All time-series are decadal averages, plotted at the centre of the decade. For temperature panels, observations are dashed lines if the spatial coverage of areas being examined is below 50%. For ocean heat content and sea ice panels, the solid lines are where the coverage of data is good and higher in quality, and the dashed lines are where the data coverage is only adequate, and, thus, uncertainty is larger (note that different lines indicate different data sets; for details, see WGI Figure SPM.6). Model results shown are Coupled Model Intercomparison Project Phase 5 (CMIP5) multi-model ensemble ranges, with shaded bands indicating the 5 to 95% confidence intervals. [Adapted from IPCC 2014].

Figure 2. Observations and other indicators of a changing global climate system



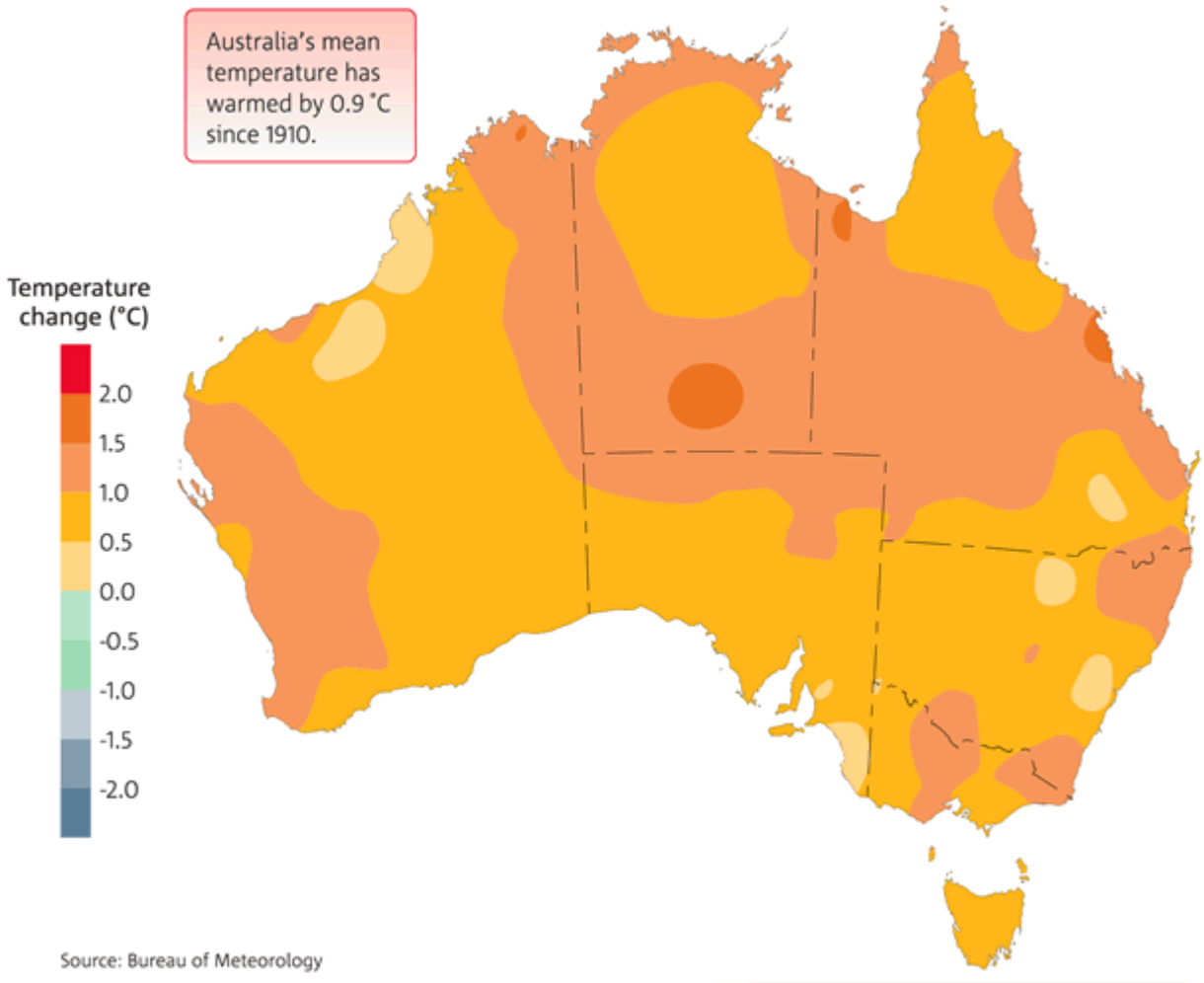
Observations: **(a)** Annually and globally averaged combined land and ocean surface temperature anomalies relative to the average over the period 1986 to 2005. Colours indicate different data sets. **(b)** Annually and globally averaged sea level change relative to the average over the period 1986 to 2005 in the longest-running dataset. Colours indicate different data sets. All datasets are aligned to have the same value in 1993, the first year of satellite altimetry data (red). Where assessed, uncertainties are indicated by coloured shading. **(c)** Atmospheric concentrations of the greenhouse gases carbon dioxide (CO_2, green), methane (CH_4, orange) and nitrous oxide (N_2O, red) determined from ice core data (dots) and from direct atmospheric measurements (lines). Indicators: **(d)** Global anthropogenic CO_2 emissions from forestry and other land use as well as from burning of fossil fuel, cement production and flaring. Cumulative emissions of CO_2 from these sources and their uncertainties are shown as bars and whiskers, respectively, on the right hand side. [Adapted from IPCC 2014]

Figure 3. Widespread impacts attributed to climate change



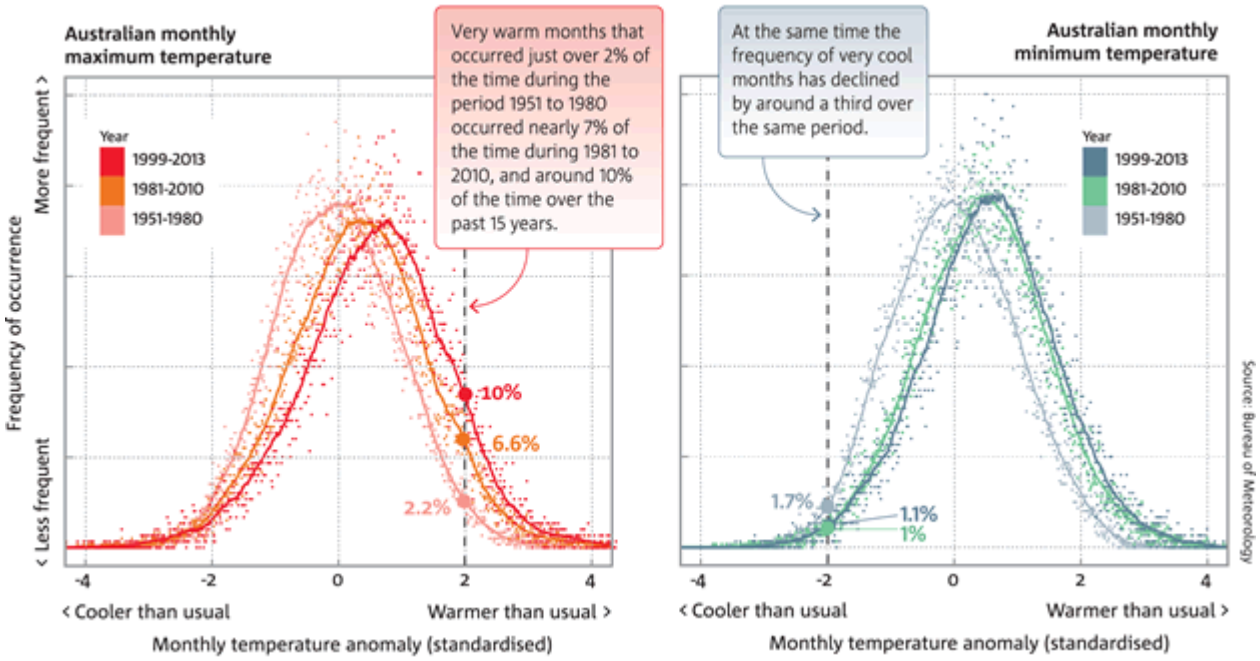
Symbols indicate categories of attributed impacts, the relative contribution of climate change (major or minor) to the observed impact and confidence in attribution. Each symbol refers to one or more entries in WGII Table SPM.A1, grouping related regional-scale impacts. Numbers in ovals indicate regional totals of climate change publications from 2001 to 2010, based on the Scopus bibliographic database for publications in English with individual countries mentioned in title, abstract or key words (as of July 2011). [Further information/explanation refer to IPCC 2014]

Figure 4. Annual mean temperature changes across Australia since 1910



Adapted from Bureau of Meteorology (BOM) and CSIRO State of the Climate 2014.

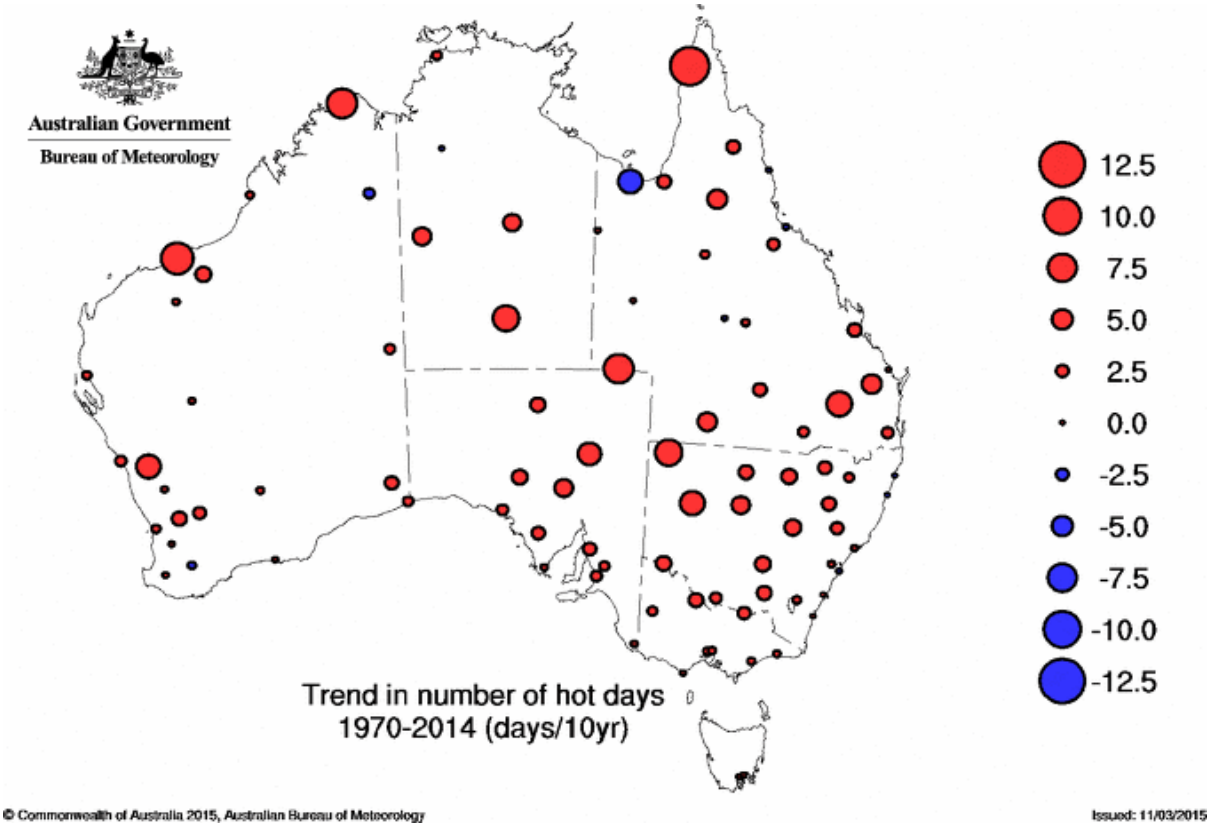
Figure 5. Distribution of monthly maximum and minimum temperature (left) and monthly minimum temperature (right), expressed as anomalies (standardised), aggregated across 104 locations and all months of the year, for three periods: 1951–1980 (pink, grey), 1981–2010 (orange, green) and 1999–2013 (red, blue)



Distribution of monthly maximum (left) and monthly minimum temperature (right) is expressed as anomalies (standardised), aggregated across 104 locations and all months of the year, for three periods: 1951–1980 (pink, grey), 1981–2010 (orange, green) and 1999–2013 (red, blue). Means and standard deviations used in the calculation of the standardised anomalies are with respect to the 1951–1980 base period in each case. Very warm and very cool months correspond to two standard deviations or more from the mean. The vertical axis shows how often temperature anomalies of various sizes have occurred in the indicated periods.

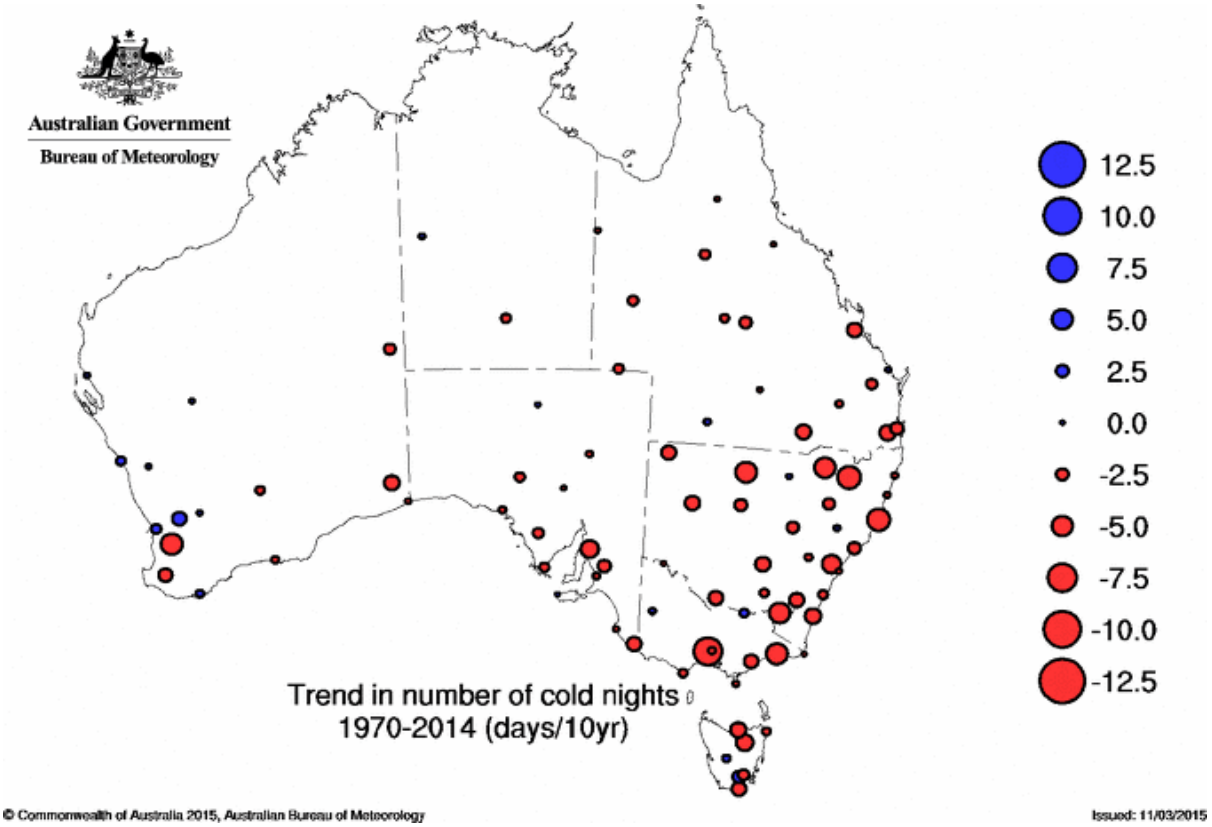
Adapted from Bureau of Meteorology (BOM) and CSIRO State of the Climate 2014.

Figure 6. Trend in number of hot days 1970–2014 (days/10 year)



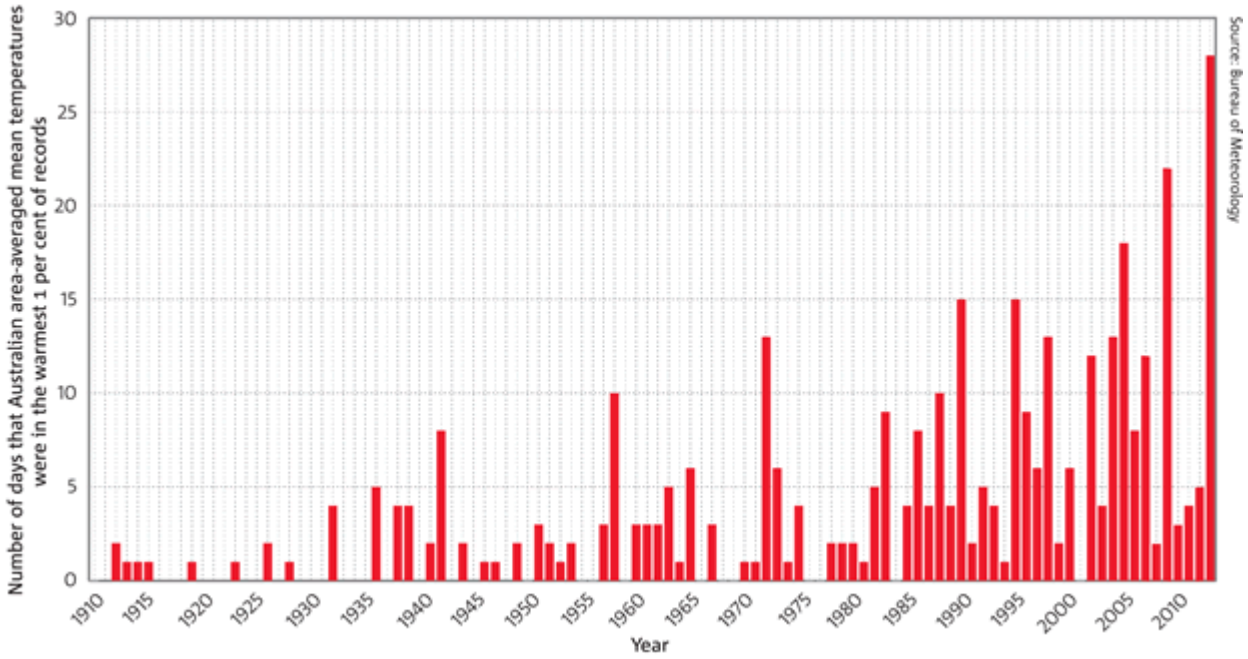
Source: http://www.bom.gov.au/climate/change/, accessed on 2015/06/24.

Figure 7. Trend in number of cold nights 1970–2014 (days/10yr)



Source: http://www.bom.gov.au/climate/change/, accessed on 2015/06/24.

Figure 8. Number of days each year where the Australian area-averaged daily mean temperature is above the 99th percentile for the period 1910–2013

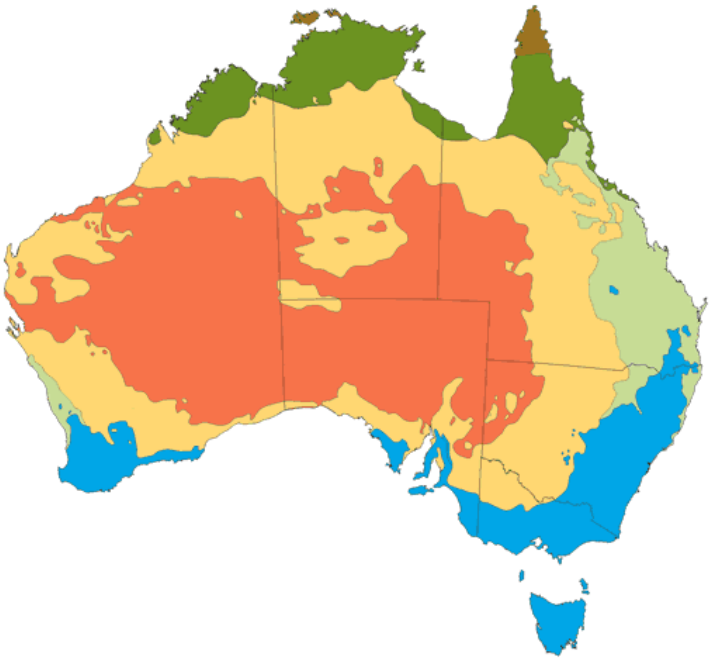


The data are calculated from the number of days above the climatological 99th percentile for each month and then aggregated over the year. This metric reflects the spatial extent of extreme heat across the continent and its frequency. Half of these events have occurred in the past 20 years.

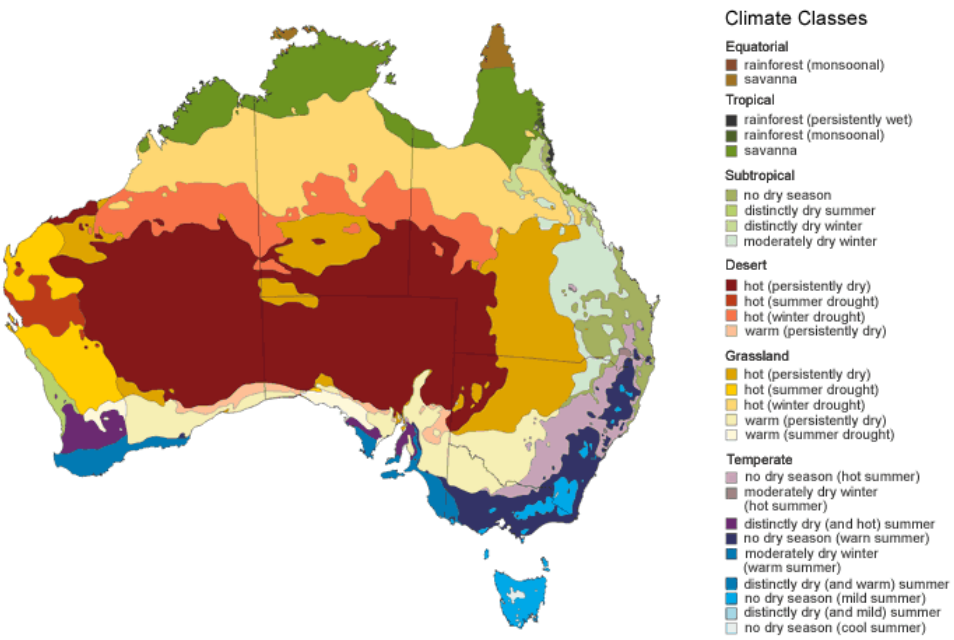
Adapted from Bureau of Meteorology and CSIRO State of the Climate 2014.

Figure 9. Bureau of Meteorology climate zones

a. The key climate groups



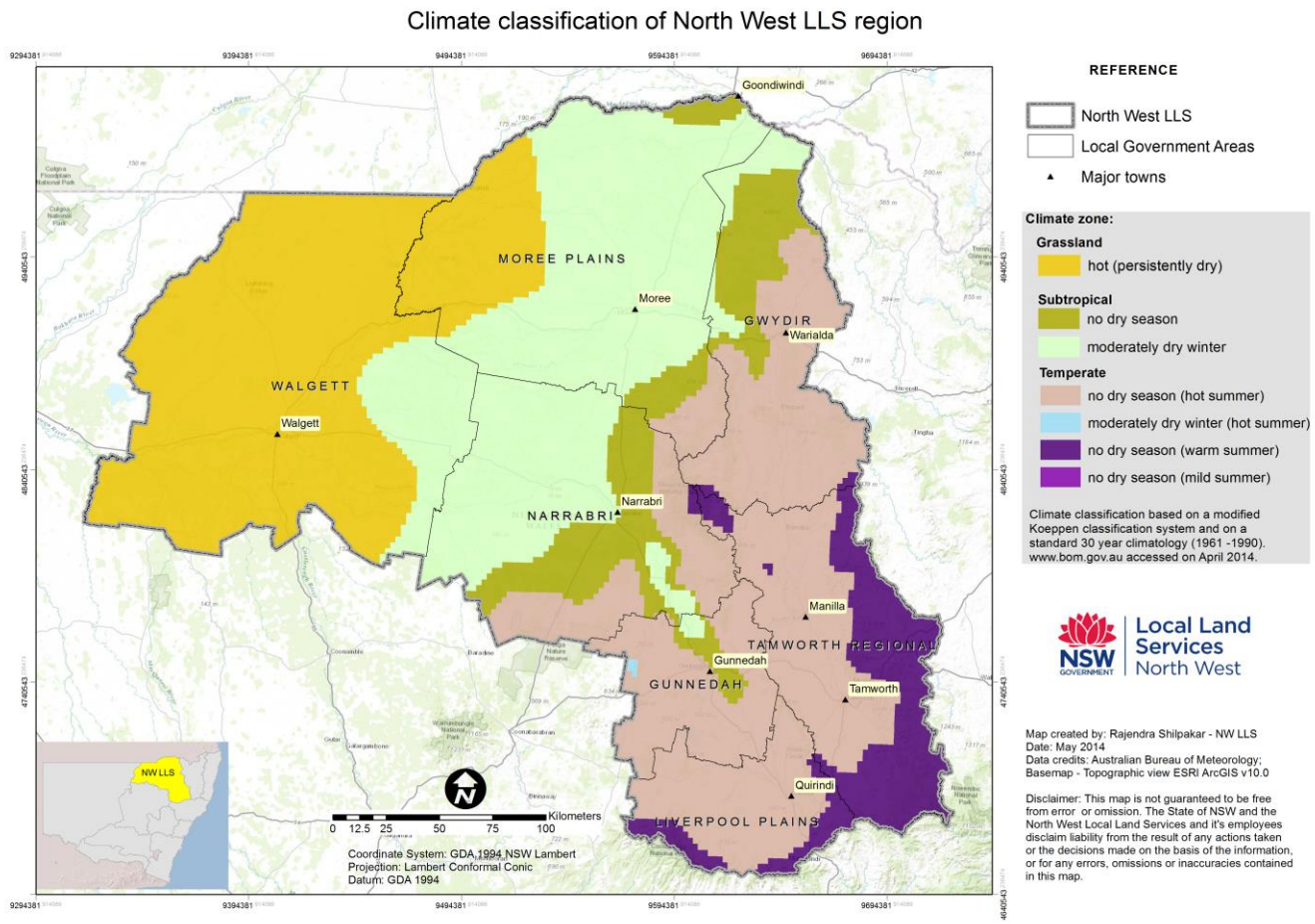
b. Sub divisions within the key climate groups



Climate zones are based on a modified Köppen classification system. Classification is derived from 0.025 x 0.025 degree resolution mean rainfall, mean maximum temperature and mean minimum temperature gridded data. All means are based on a standard 30-year climatology (1961–1990).

Source: http://www.bom.gov.au/iwk/climate_zones/map_1.shtml, accessed on 2014/04/24.

Figure 10. Climate classification of North West LLS region



Classification is based on modified Köppen climate classification system and on a standard 30-year climatology (1961–1990).

Data source: Bureau of Meteorology (BOM).

Main climate zone	Modified Köppen climate zone	Area (km^2)	%
Grassland	hot (persistently dry)	23,199	28
Subtropical	moderately dry winter	22,783	27
	no dry season	7,097	8
Temperate	no dry season (hot summer)	23,703	29
	no dry season (warm summer)	5,736	7
	moderately dry winter (hot summer)	33	<1
	no dry season (mild summer)	4	<1
Total		**82554**	**1000**

Figure 11. Average daily temperature (annual) based on standard 30-year climatology (1961–1991)

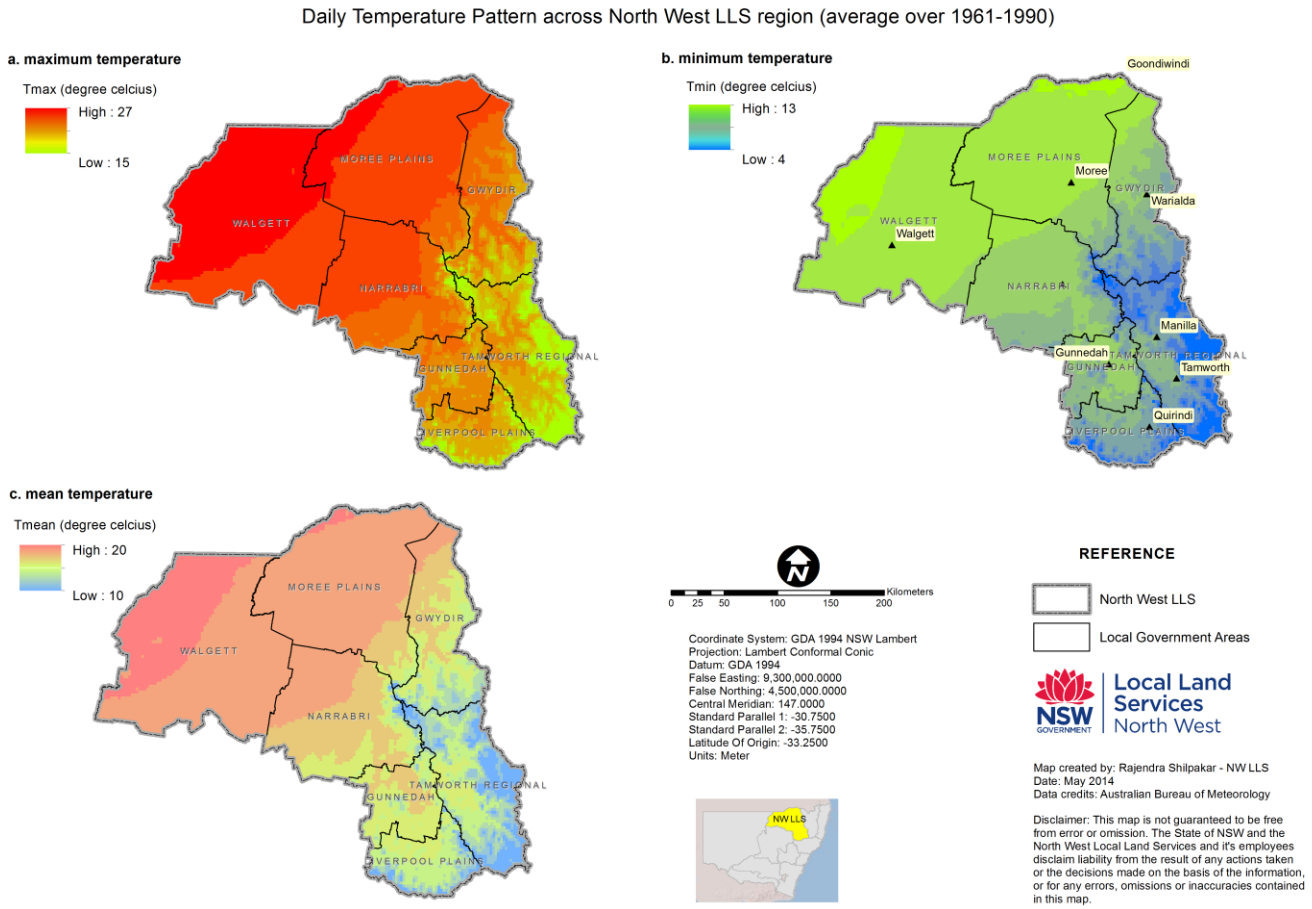


Figure 12. Mean daily temperature by season based on standard 30-year climatology (1961–1990)

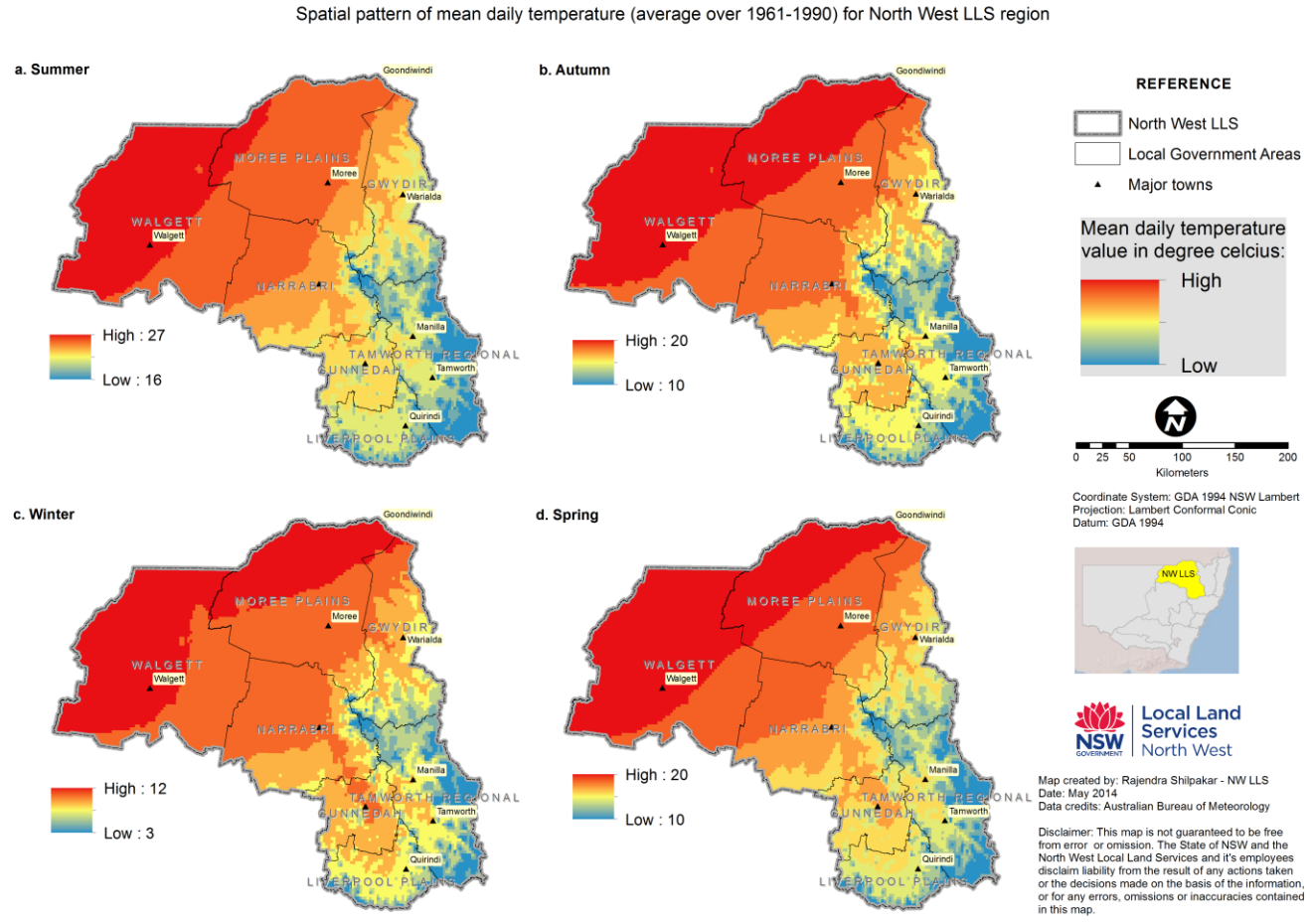


Figure 13. Rainfall pattern across North West LLS region – average annual rainfall total over 1961–1990

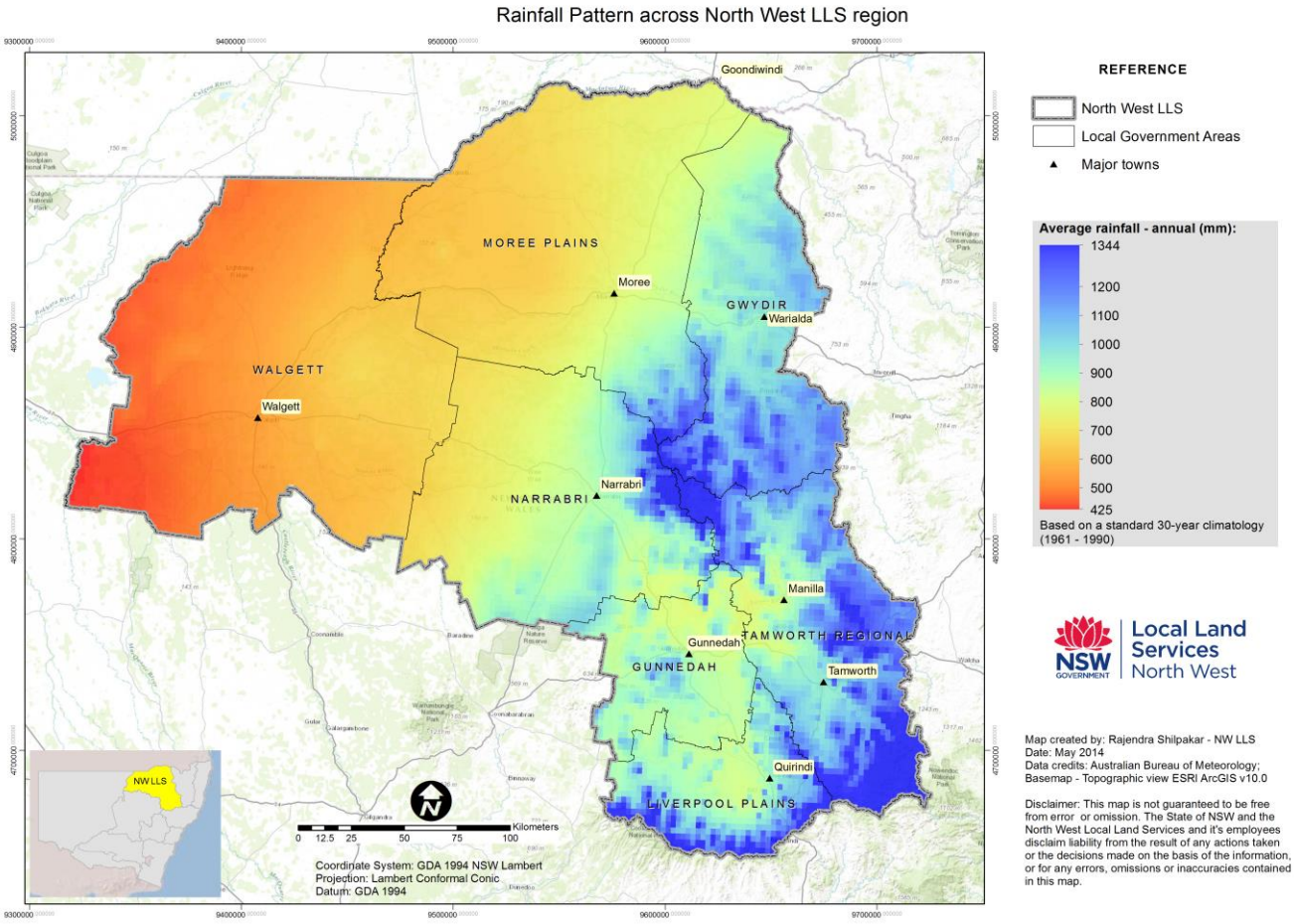


Figure 14. Seasonal rainfall pattern across North West LLS region – average over 1961–1990

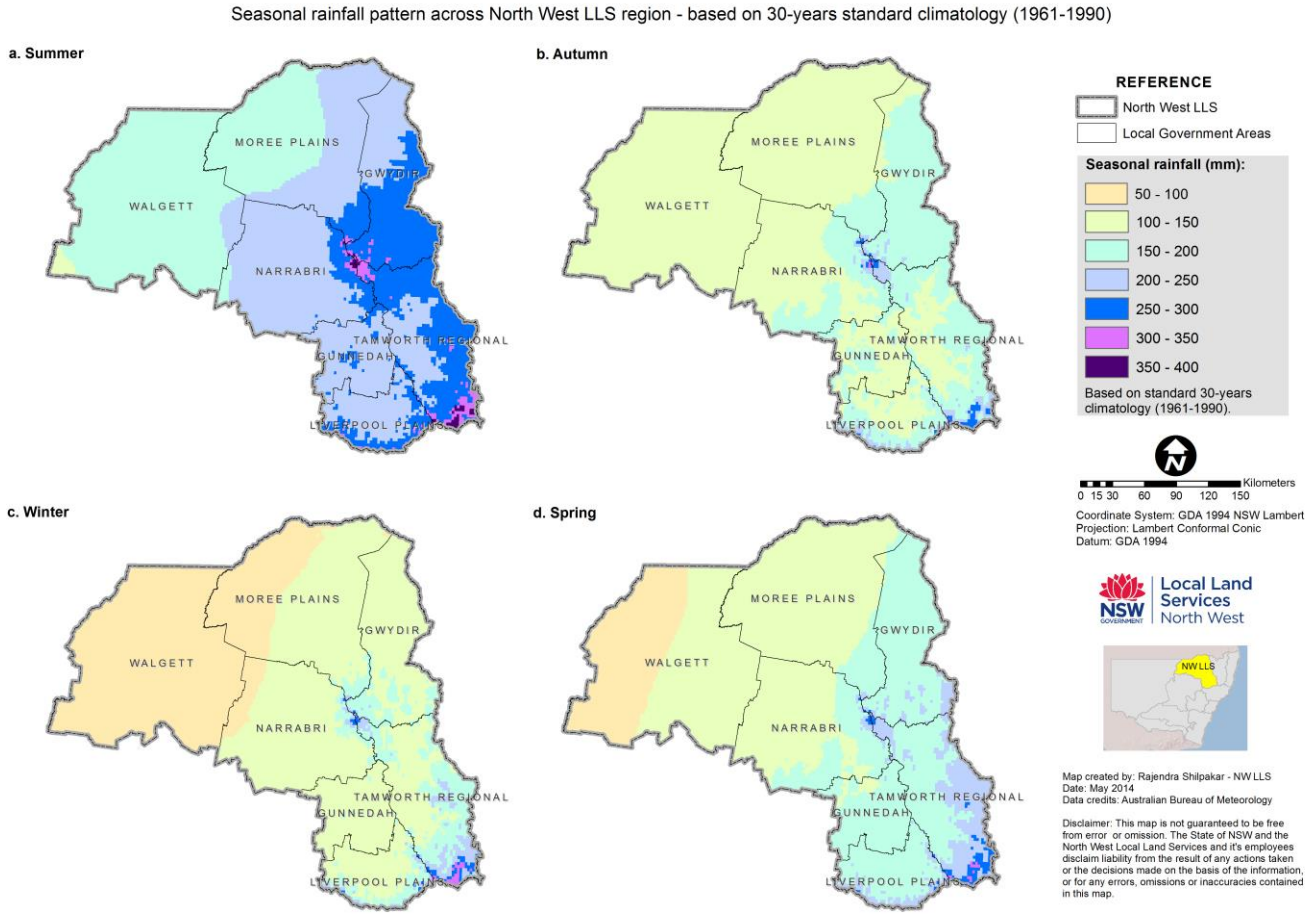


Figure 15. Central slope cluster region, a Natural Resources Management (NRM) cluster adapted by CSIRO and Bureau of Meteorology for preparing tailored climate change projection report

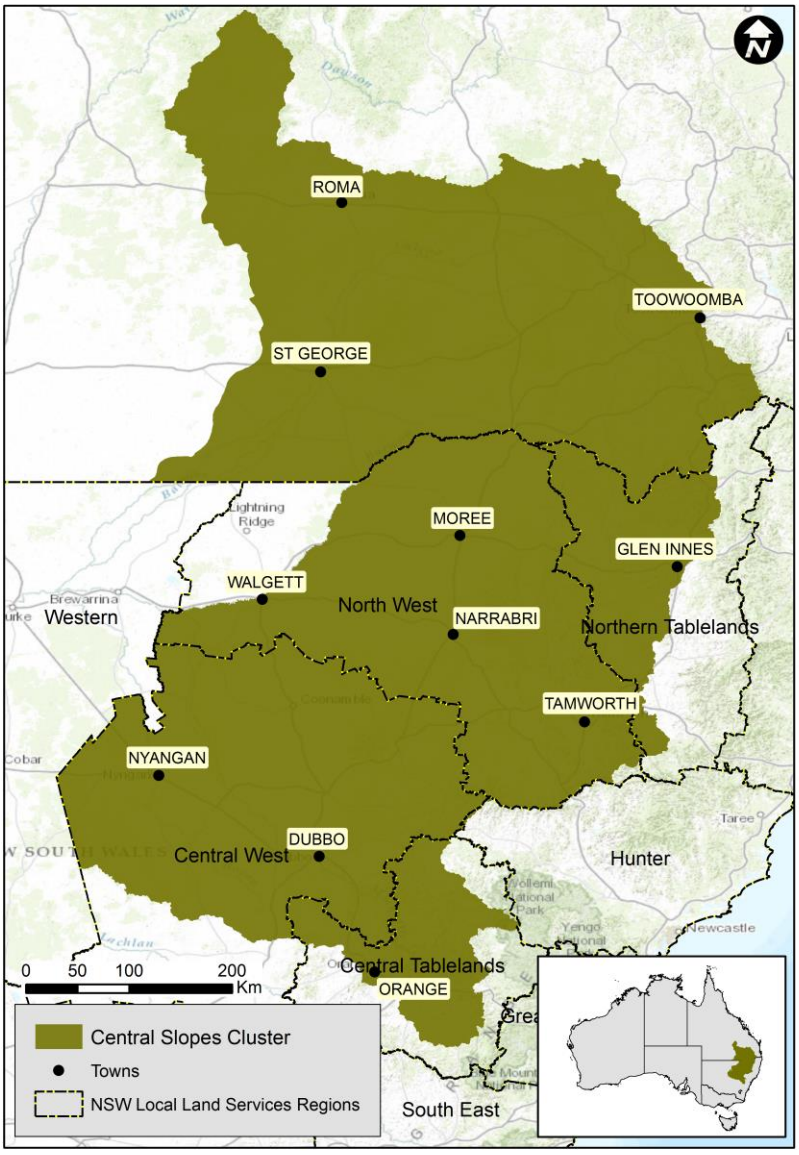


Table 4. Categories of future climate projections for the central slopes cluster as defined by change in annual temperature (Column) and change in rainfall (Rows) Within each future climate categories, model simulations are sorted according to time (2030, 2050 and 2090) and concentration pathway (RCP2.6, RCP4.5 and RCP8.5). The number in the numerator indicating how many model simulations of that particular sub-category fall into the climate category, while denominator indicates the total number of Global Circulation Model (GCM) simulated for the corresponding emission scenario. A colour code indicates how often a particular climate is simulated amongst the considered models (% occurrence). Only those climate category represented by more than 10% models are presented in this table.

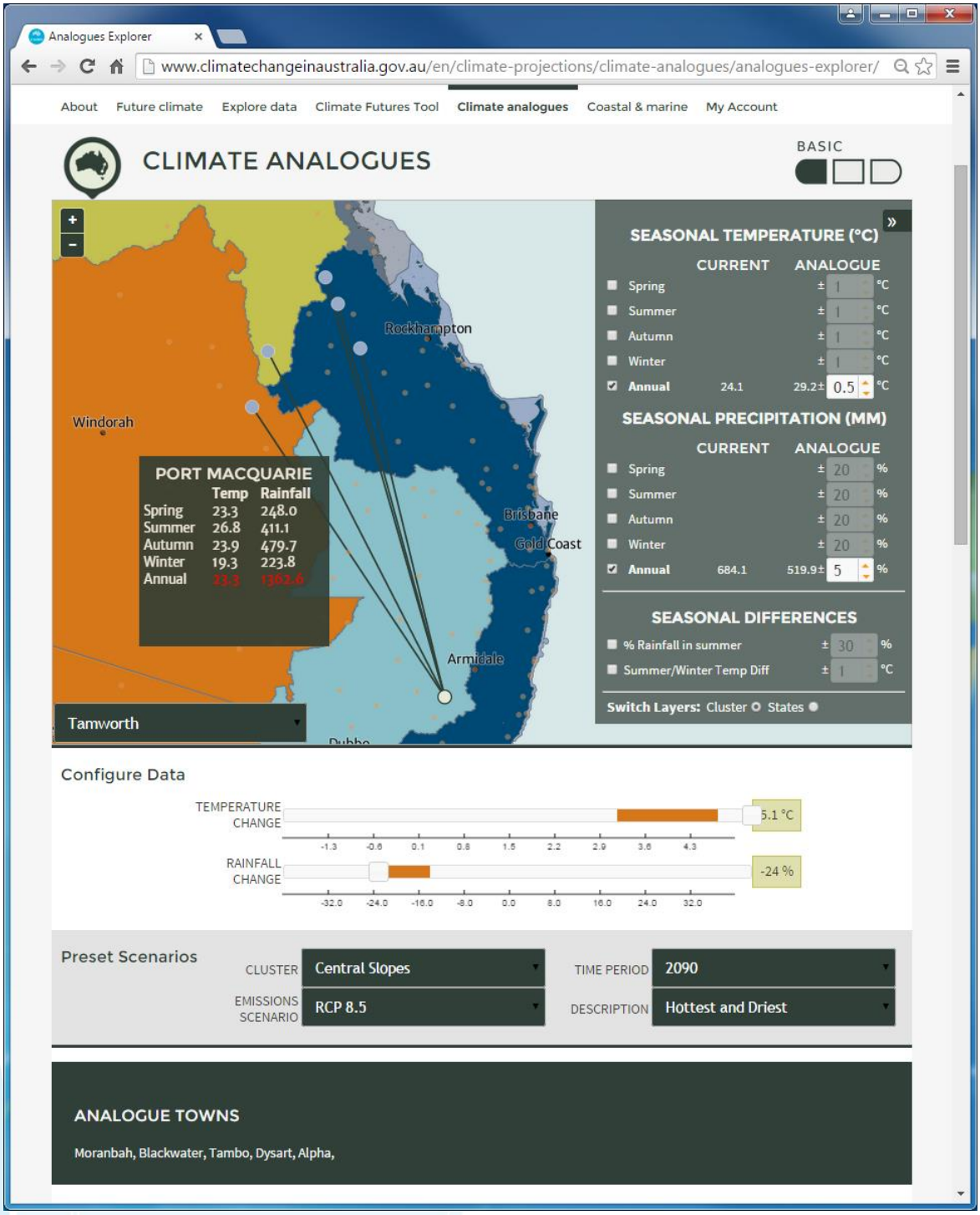
Realisation of climate future for central slopes cluster			Annual Surface Temperature (^{0}C)											
			Slightly Warmer (<+0.5°C)			Warmer (+0.5 to +1.5°C)			Hotter (+1.5 to +3.0°C)			Much Hotter (> +3.0°C)		
			2030	2050	2090	2030	2050	2090	2030	2050	2090	2030	2050	2090
Annual Rainfall (% change)	Much Wetter (>15%)	RCP2.6				1/29								
		RCP4.5								1/40	1/40			
		RCP8.5				1/40	2/42				3/42			3/42
	Wetter (5 to 15%)	RCP2.6			1/29	3/29	5/29	4/29						
		RCP4.5	1/40			5/40	8/40	1/40		1/40	2/40			
		RCP8.5	1/42			6/42	1/42			4/42				5/42
	Little change (-5 to +5%)	RCP2.6	1/29		2/29	16/29	12/29	9/29			1/29			
		RCP4.5				21/40	10/40	4/40		6/40	15/40			
		RCP8.5	1/42			17/42	4/42		2/42	15/42				9/42
	Drier (-15 to -5%)	RCP2.6				7/29	6/29	7/29		3/29				
		RCP4.5				12/40	3/40	2/40		9/40	11/40			
		RCP8.5				11/42			1/42	9/42	1/42			11/42
	Much Drier (< -15%)	RCP2.6				1/29	1/29	4/29		2/29	2/29			
		RCP4.5				1/40				2/40	3/40			1/40
		RCP8.5							2/42	6/42				10/42

Keys	Colour	% of models for that period/RCP	Number of GCM models used for the assessment:	
		33–66%	RCP2.6	29 GCMs
		10–33%	RCP4.5	40 GCMs
		<10% or None	RCP8.5	42 GCMs

Source: http://www.climatechangeinaustralia.gov.au/en/climate-projections/climate-analogues/about-analogues/, accessed on April 2015

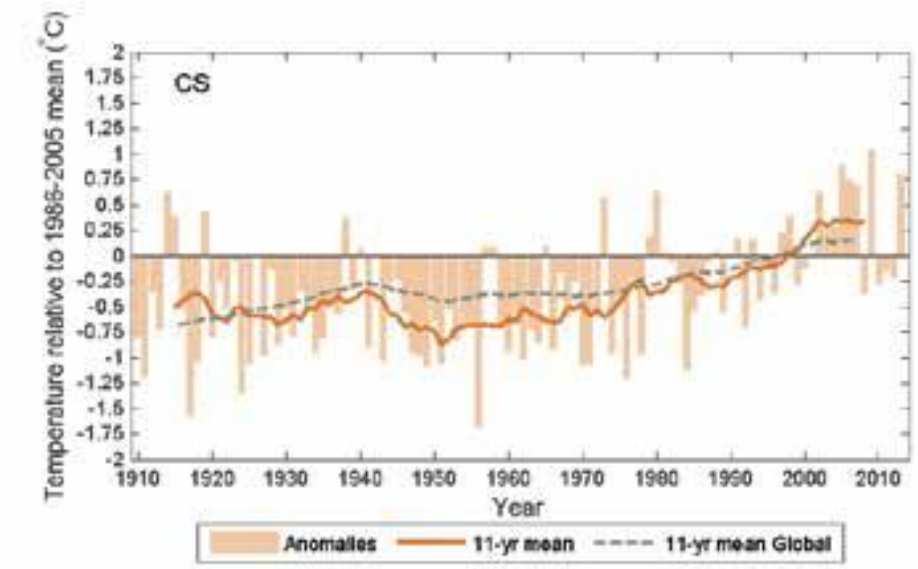
Climate analogues can be used to identify areas that experience similar climatic conditions, but which may be separated in space or time (i.e. with past or future climates). The Australian Climate Change website www.climatechangeinaustrali.gov.au provides the climate analogue tool that matches the proposed future climate of major towns in Australia with the current climate experienced in another town/s using annual average rainfall and maximum temperature within set tolerances. Other potentially important aspects of local climate may not match when using this approach (for example, frost days or and other local climate influences). This approach may have limited application in agriculture as solar radiation and soils are not considered.

Figure 16. Climate analogue of Tamworth city for the hottest and driest climate, future projected for late in century under the high emission scenario (RCP8.5). In this case, Tamworth future climate would be more like the current climate of Moranbah, Blackwater, Tambo, Dysart and Alpha of Queensland



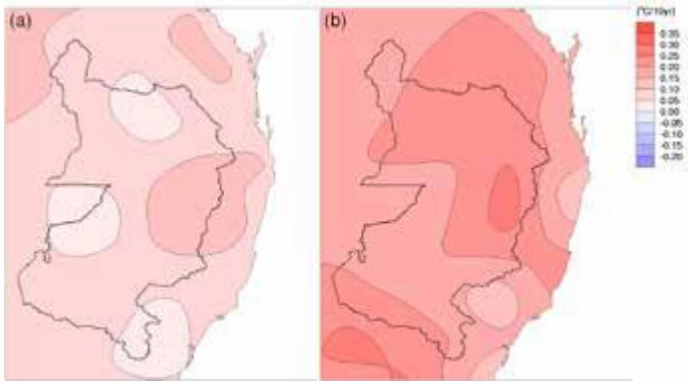
Source: http://www.climatechangeinaustralia.gov.au/en/climate-projections/climate-analogues/about-analogues/, accessed on April 2015.

Figure 17. Observed annual mean temperature anomalies (°C) for 1910–2013 compared to the baseline 1986–2005 for central slopes



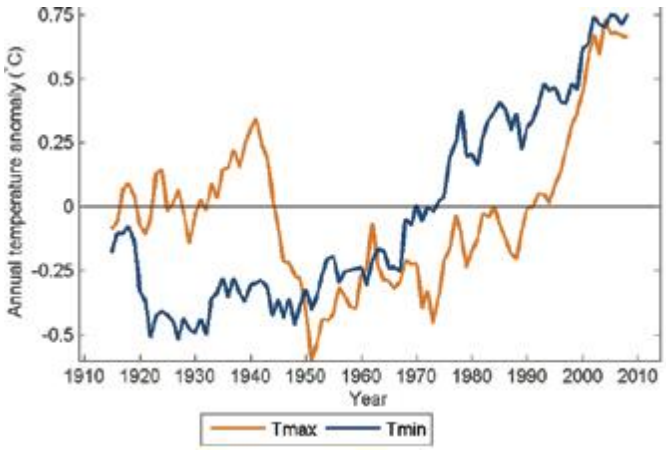
Adapted from Ekström, M. et al. 2015.

Figure 18. Maps of trend in mean temperature (°C/10 years) for (a) 1910–2013 (b) 1960–2013 (ACORN-SAT)



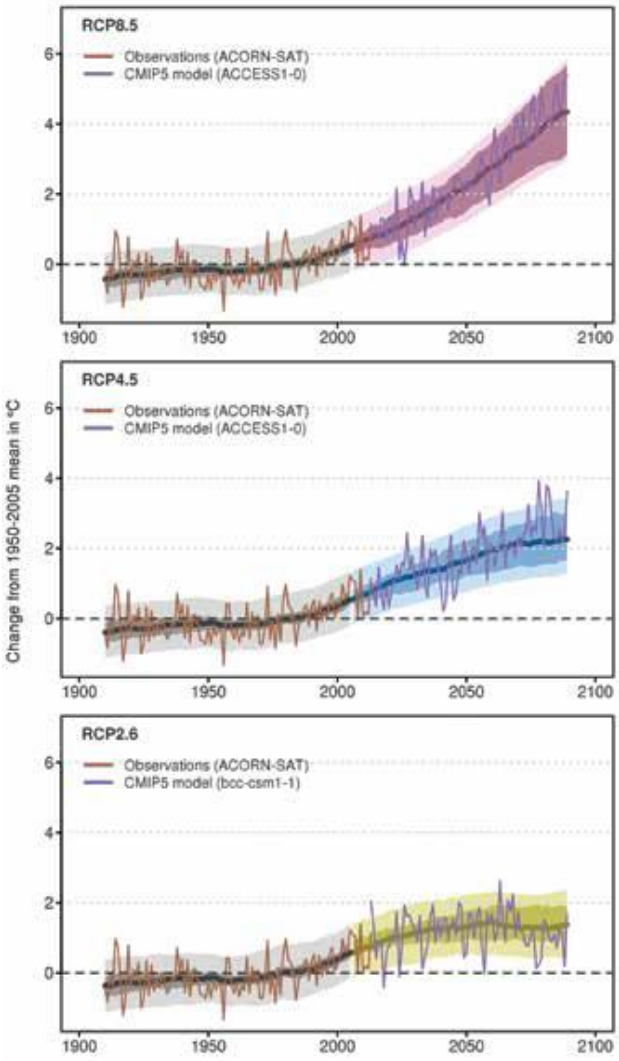
Adapted from Ekström, M. et al. 2015.

Figure 19. Observed annual mean of daily maximum (orange line) and minimum (blue line) temperature (°C , 11-year running mean), presented as anomalies relative to their respective 1910–2013 mean value (ACRON-SAT)



Adapted from Ekström, M. et al. 2015.

Figure 20. Time series for Central Slopes



Annual average surface air temperature (°C) for 1910–2090, as simulated in CMIP5 relative to the 1950–2005 mean. The central line is the median value, and the shading is the 10th and 90th percentile range of 20-year means (inner) and single year values (outer). The grey shading indicates the period of the historical simulation, while three future scenarios are shown with colour-coded shading: RCP8.5 (purple), RCP4.5 (blue) and RCP2.6 (green). ACORN-SAT observations and projected values from a typical model are also shown. (Further explanation of time series plot refers to Box 4.2 of Ekström, M. et al. 2015).

Adapted from Ekström, M. et al. 2015.

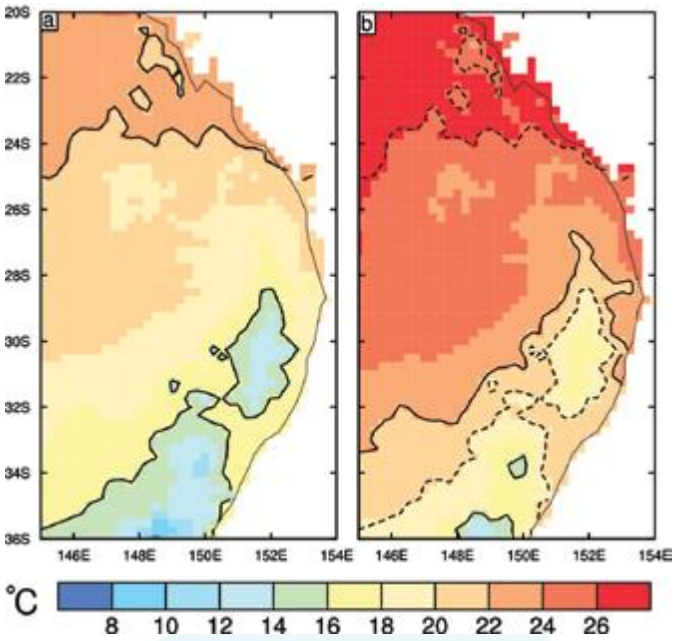
Table 5. Projected temperature change (°C) compared to 1986–2005, for 20-year period (centred on 2030 and 2090) and three RCPs

	RCP2.6 Low emissions	RCP4.5 Intermediate emissions	RCP8.5 High emissions
2030	0.9 (0.6 to 1.2)	1.0 (0.6 to 1.3)	1.1 (0.7 to 1.5)
2090	1.1 (0.6 to 1.8)	2.1 (1.4 to 2.7)	4.2 (3.0 to 5.4)

The median projection across the models is shown, with the 10th to 90th percentile range of model results in brackets.

Adapted from CSIRO and Bureau of Meteorology 2015, Central Slopes Cluster brochure.

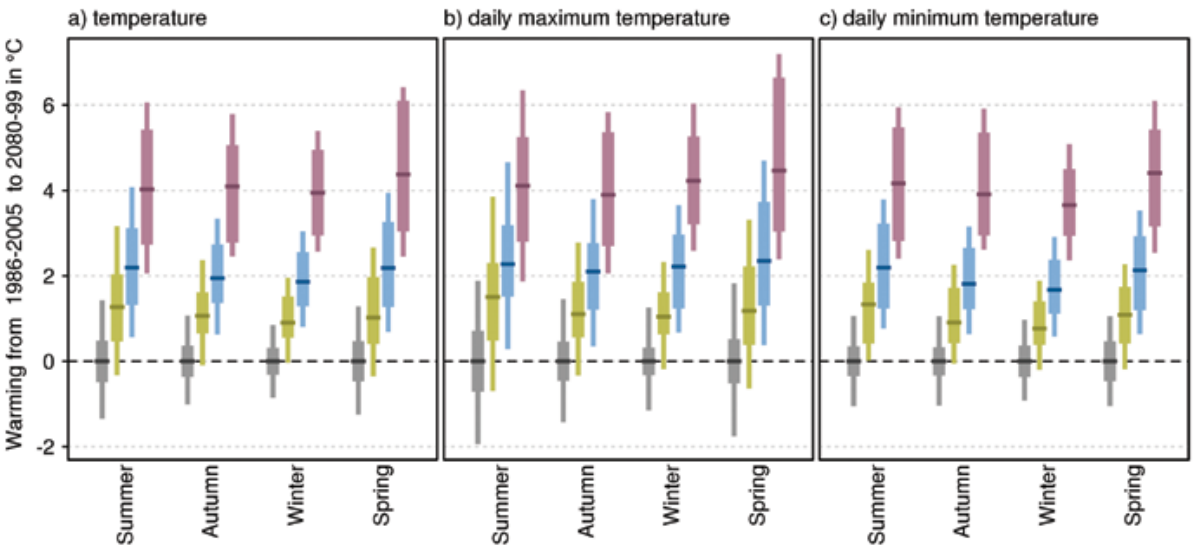
Figure 21. Annual mean surface air temperature (°C), for the present climate (a), and for median warming in 2090 under RCP8.5 (b)



The present is using data from Australian Water Availability Project (AWAP) for 1986–2005, on a 0.25 degree grid. For clarity, the 16° and 22° contours are shown with solid black lines. In (b) the same contours from the present climate are plotted as dotted lines.

Adapted from Ekström, M. et al. 2015.

Figure 22. Projected seasonal surface air temperature changes for 2090



Graphs show changes to the (a) mean, (b) daily maximum and (c) daily minimum temperature. Temperature anomaly is given in °C with respect to 1986–2005 under RCP2.6 (green), RCP4.5 (blue) and RCP8.5 (purple). Natural climate variability is presented by the grey bar.

Adapted from Ekström, M. et al. 2015.

Table 6. GCM simulated changes in a mean temperature (°C) and rainfall (%) for the 2020–2039 (2030) and 2080–2099 (2090) period relative to the 1986–2005 period for the Central Slopes cluster

The table gives the median (50th percentile) change, as projected by the CMIP5 model archives, with 10th to 90th percentile range given within brackets.

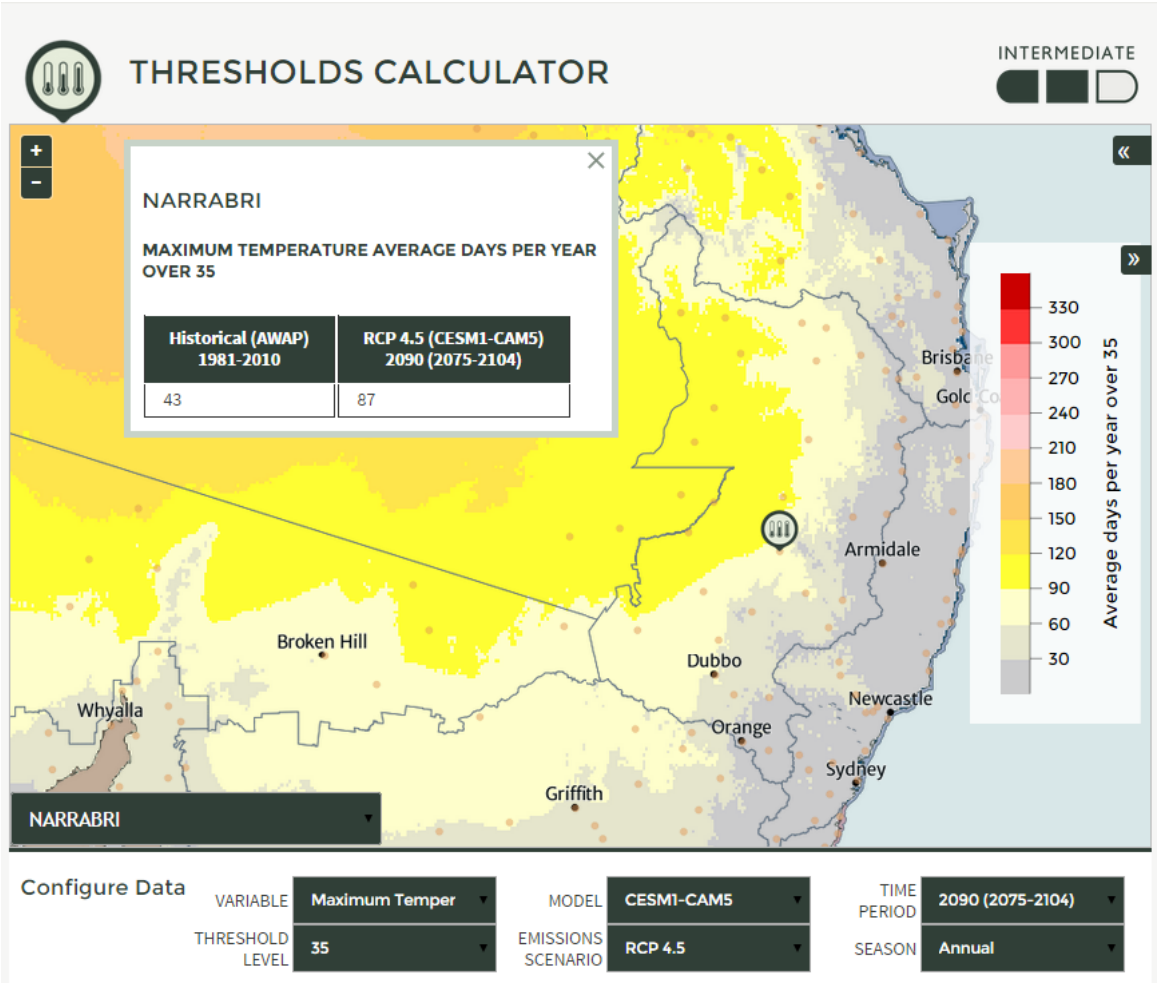
VARIABLE	SEASON	2030, RCP2.6	2030, RCP4.5	2030, RCP8.5	2090, RCP2.6	2090, RCP4.5	2090, RCP8.5
Temperature mean (°C)	Annual	0.9 (0.6 to 1.2)	1 (0.6 to 1.3)	1.1 (0.7 to 1.5)	1.1 (0.6 to 1.8)	2.1 (1.4 to 2.7)	4.2 (3 to 5.4)
	DJF	0.8 (0.5 to 1.5)	1 (0.5 to 1.5)	1 (0.4 to 1.7)	1.3 (0.5 to 2)	2.2 (1.3 to 3.1)	4 (2.7 to 5.4)
	MAM	0.9 (0.5 to 1.2)	0.9 (0.6 to 1.3)	1 (0.5 to 1.5)	1.1 (0.7 to 1.6)	1.9 (1.4 to 2.7)	4.1 (2.8 to 5.1)
	JJA	0.8 (0.5 to 1.2)	0.9 (0.5 to 1.2)	1 (0.7 to 1.4)	0.9 (0.6 to 1.5)	1.9 (1.3 to 2.6)	3.9 (2.9 to 4.9)
	SON	0.9 (0.4 to 1.5)	1 (0.5 to 1.4)	1.1 (0.6 to 1.9)	1 (0.4 to 2)	2.2 (1.3 to 3.3)	4.4 (3 to 6.1)
Temperature maximum (°C)	Annual	0.9 (0.7 to 1.3)	1.1 (0.6 to 1.4)	1.2 (0.5 to 1.6)	1.3 (0.6 to 1.9)	2.2 (1.5 to 3)	4.2 (3.2 to 5.5)
	DJF	0.9 (0.6 to 1.6)	0.9 (0.5 to 1.7)	1.1 (0.4 to 1.8)	1.5 (0.5 to 2.3)	2.3 (1.5 to 3.2)	4.1 (2.8 to 5.3)
	MAM	0.9 (0.3 to 1.3)	1 (0.5 to 1.4)	1.1 (0.4 to 1.5)	1.1 (0.6 to 1.9)	2.1 (1.2 to 2.8)	3.9 (2.7 to 5.4)
	JJA	0.9 (0.5-1.3)	1.1 (0.6 to 1.5)	1.1 (0.6 to 1.7)	1 (0.6 to 1.6)	2.2 (1.2 to 3)	4.2 (3.2 to 5.3)
	SON	1 (0.4 to 1.8)	1.1 (0.5 to 1.7)	1.2 (0.5 to 2.1)	1.2 (0.4 to 2.2)	2.3 (1.3 to 3.7)	4.5 (3 to 6.6)
Temperature minimum (°C)	Annual	0.9 (0.5 to 1.1)	1 (0.6 to 1.1)	1 (0.7 to 1.4)	1 (0.6 to 1.6)	1.9 (1.3 to 2.7)	4.1 (3 to 5.3)
	DJF	0.9 (0.5 to 1.3)	1 (0.7 to 1.4)	1 (0.6 to 1.6)	1.3 (0.4 to 1.8)	2.2 (1.2 to 3.2)	4.2 (2.8 to 5.5)
	MAM	0.8 (0.4 to 1.1)	0.9 (0.6 to 1.3)	1 (0.5 to 1.5)	0.9 (0.4 to 1.7)	1.8 (1.2 to 2.7)	3.9 (2.9 to 5.4)
	JJA	0.6 (0.3 to 1)	0.8 (0.3 to 1.1)	0.9 (0.6 to 1.3)	0.8 (0.4 to 1.4)	1.7 (1.1 to 2.4)	3.7 (2.9 to 4.5)
	SON	0.8 (0.4 to 1.4)	1 (0.6 to 1.3)	1.1 (0.6 to 1.6)	1.1 (0.4 to 1.7)	2.1 (1.2 to 2.9)	4.4 (3.2 to 5.4)
Rainfall (%)	Annual	-1 (-11 to 8)	-2 (-11 to 7)	-1 (-13 to 8)	-3 (-18 to 8)	-4 (-16 to 6)	-6 (-23 to 18)
	DJF	2 (-13 to 17)	1 (-9 to 16)	2 (-12 to 23)	-5 (-23 to 13)	0 (-14 to 17)	10 (-14 to 29)
	MAM	-2 (-25 to 19)	-5 (-22 to 19)	-2 (-17 to 14)	-10 (-26 to 17)	-4 (-28 to 23)	-4 (-35 to 27)
	JJA	-3 (-18 to 14)	-3 (-20 to 11)	-2 (-27 to 15)	-4 (-24 to 11)	-10 (-24 to 9)	-17 (-39 to 15)
	SON	-2 (-21 to 19)	-2 (-18 to 12)	-1 (-23 to 12)	-1 (-25 to 12)	-8 (-26 to 12)	-14 (-40 to 11)

LEGEND TO TABLE 1

Very high model agreement on substantial increase
High model agreement on substantial increase
Medium model agreement on substantial increase
High model agreement on increase
Medium model agreement on increase
High model agreement on little change
Medium model agreement on little change
High model agreement on substantial decrease
Medium model agreement on substantial decrease
High model agreement on decrease
Medium model agreement on decrease

Adapted from Ekström, M. et al. 2015.

Figure 23. Average number of hot days (temperature above 35°C) across central slope region at Narrabri for the projected climate for 2090 with emission scenario RCP8.5

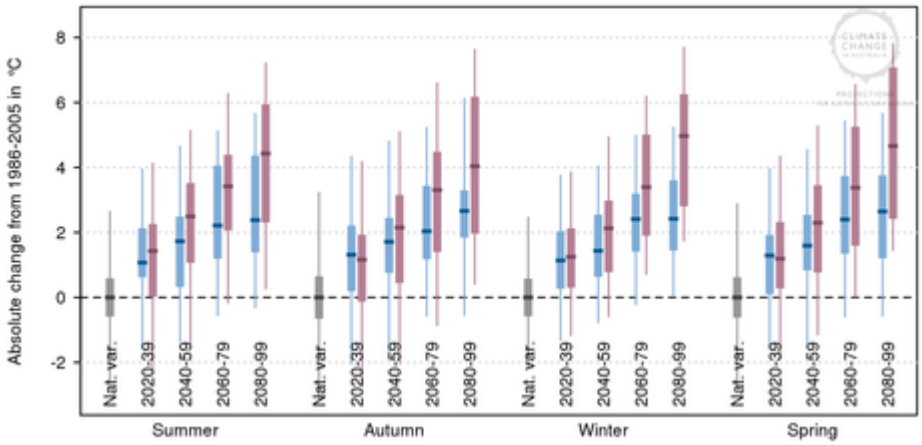


Projected climate data by the CEM1–CAM5 model under an intermediate emission scenario (RCP4.5) by late in century (2090: 2075–2104) as projected by CESM1–CAM5 model. The inset box provides comparison of average days per year over 35°C between historical climate and projected climate at Narrabri station.

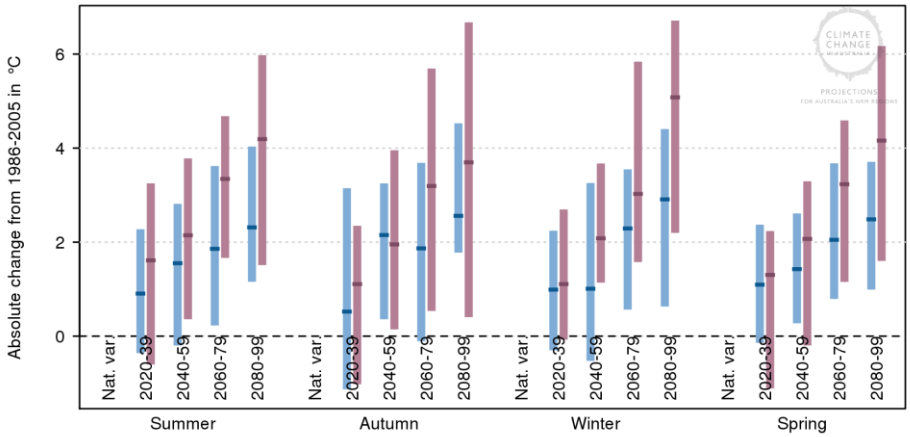
Source: http://www.climatechangeinaustralia.gov.au/, accessed on April 2015.

Figure 24. Projected change in seasonal hottest day (a) and 1-in-20-year hottest night (b)

(a)



(b)

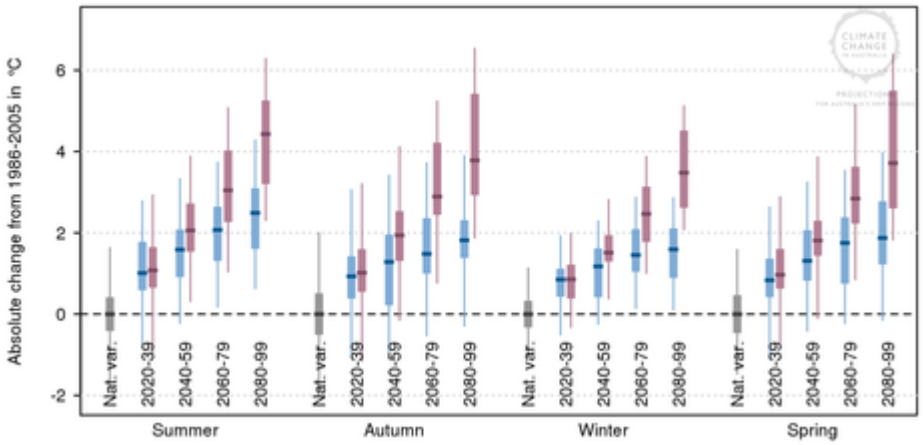


Graphs show change in (from left) summer, autumn, winter and spring. Anomalies are given in °C relative to 1995(1986–2005) under RCP4.5 (blue) and RCP8.5 (purple). Natural climate variability is represented by the grey bar.

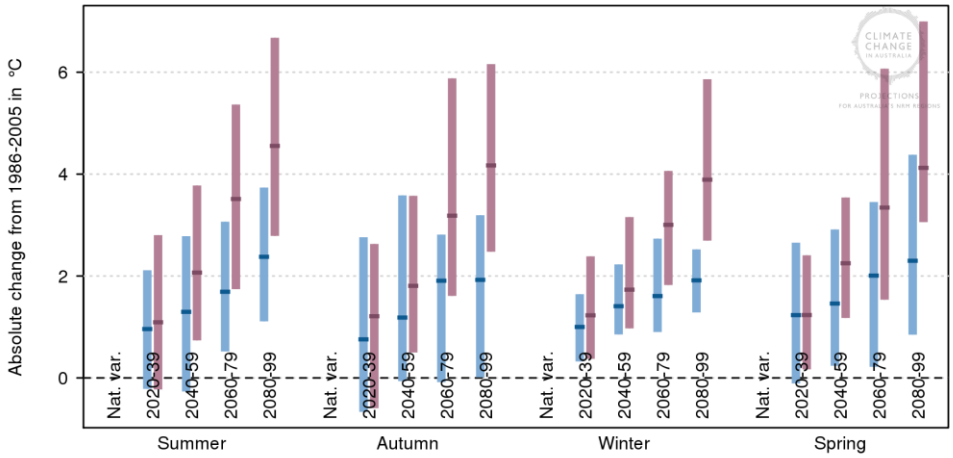
Source: http://www.climatechangeinaustralia.gov.au/, accessed on April 2015.

Figure 25. Projected change in seasonal coldest night (a) and 1-in-20-year coldest night (b)

(a)



(b)



Graphs show change in (from left) summer, autumn, winter and spring. Anomalies are given in °C relative to 1995(1986–2005) under RCP4.5 (blue) and RCP8.5 (purple). Natural climate variability is represented by the grey bar.

Source: http://www.climatechangeinaustralia.gov.au/, accessed on April 2015.

Table 4. Average annual number of days above 35°C for the 30-year period centred on 1995 (1981–2010) and for future 30-year periods (centred on 2030, 2050 and 2090)

Location	Historical: 1995 (1981-2010)	2030 (2016-2045)						2050 (2036-2065)						2090 (2075-2104)					
		RCP4.5			RCP8.5			RCP4.5			RCP8.5			RCP4.5			RCP8.5		
		CES1-CAM5	GFDL-ESM2M	NorESM1-M	CES1-CAM5	GFDL-ESM2M	NorESM1-M	CES1-CAM5	GFDL-ESM2M	NorESM1-M	CES1-CAM5	GFDL-ESM2M	NorESM1-M	CES1-CAM5	GFDL-ESM2M	NorESM1-M	CES1-CAM5	GFDL-ESM2M	NorESM1-M
Tamworth	13	19	22	19	23	23	19	24	25	24	29	38	25	38	35	26	73	59	43
Gunnedah	21	29	33	29	35	33	29	37	38	36	43	55	37	54	38	38	92	55	59
Narrabri	43	54	59	56	63	61	54	65	66	63	73	89	65	87	83	65	130	127	91
Moree	41	55	59	55	65	63	52	69	67	64	78	92	66	90	84	66	134	132	90
Walgett	60	70	78	73	78	80	71	85	88	81	92	112	84	104	104	83	142	151	104

Table 5. Average Annual Number of days above 40°C for the 30-year period centred on 1995 (1981–2010) and for future 30-year periods (centred on 2030, 2050 and 2090)

Location	Historical: 1995 (1981-2010)	2030 (2016-2045)						2050 (2036-2065)						2090 (2075-2104)					
		RCP4.5			RCP8.5			RCP4.5			RCP8.5			RCP4.5			RCP8.5		
		CES1-CAM5	GFDL-ESM2M	NorESM1-M	CES1-CAM5	GFDL-ESM2M	NorESM1-M	CES1-CAM5	GFDL-ESM2M	NorESM1-M	CES1-CAM5	GFDL-ESM2M	NorESM1-M	CES1-CAM5	GFDL-ESM2M	NorESM1-M	CES1-CAM5	GFDL-ESM2M	NorESM1-M
Tamworth	0	1	1	1	1	1	1	2	2	1	2	4	1	3	3	1	13	8	4
Gunnedah	1	2	3	2	2	3	2	3	4	3	4	7	3	6	5	4	22	15	8
Narrabri	4	6	9	6	6	9	6	10	10	9	12	18	9	18	14	9	43	35	18
Moree	4	6	8	6	6	8	6	10	9	8	12	16	8	16	13	8	42	35	15
Walgett	10	15	19	16	15	19	14	21	23	20	25	36	20	31	28	19	58	60	30

Table 6. Average annual number of days less than 2°C for the 30 years period centred on 1995 (1981–2010) and for future 30-year periods (centred on 2030, 2050 and 2090)

Location	Historical: 1995 (1981-2010)	2030 (2016-2045)						2050 (2036-2065)						2090 (2075-2104)					
		RCP4.5			RCP8.5			RCP4.5			RCP8.5			RCP4.5			RCP8.5		
		CES1-CAM5	GFDL-ESM2M	NorESM1-M	CES1-CAM5	GFDL-ESM2M	NorESM1-M	CES1-CAM5	GFDL-ESM2M	NorESM1-M	CES1-CAM5	GFDL-ESM2M	NorESM1-M	CES1-CAM5	GFDL-ESM2M	NorESM1-M	CES1-CAM5	GFDL-ESM2M	NorESM1-M
Tamworth	47	36	38	37	29	39	35	29	37	33	25	33	28	20	31	26	6	19	13
Gunnedah	26	18	19	18	12	19	18	13	18	16	11	16	11	5	14	10	1	5	3
Narrabri	26	17	19	19	12	18	20	13	17	17	12	15	13	6	12	10	1	4	4
Moree	26	17	19	19	12	18	21	13	16	17	12	14	13	6	12	11	1	3	4
Walgett	26	16	17	19	11	18	19	11	15	17	10	13	13	5	12	10	1	2	4

Table 7. Projected climate futures represented by three GCMs under high emission scenarios (RCP8.5)

Period	Projected by		
	CES1-CAM5	GFDL-ESM2M	NorESM1-M
2030 (2016–2045)	Warmer (0.5 to 1.5°C) with litter change in rainfall (±5%)	Hotter (1.5 to 3°C) and much drier (<-15%)	Warmer (0.5 to 1.5^{0}C), but wetter (+5% to +15%)
2050 (2036–2065)	Hotter (1.5 to 3°C) with litter change in rainfall (±5%)	Hotter (1.5 to 3°C) and much drier (<-15%)	Warmer (0.5 to 1.5^{0}C) with little change in rainfall (±5%)
2090 (2075–2104)	Much hotter (> 3°C) with little change in rainfall (±5%)	Much hotter (> 3°C) and much drier (< -15%)	Hotter (1.5 to 3^{0}C), but much wetter (> +15%)

Note: The same three GCMs were used for threshold analysis presented as Table 7.

Source: http://www.climatechangeinaustralia.gov.au/, accessed on April 2015

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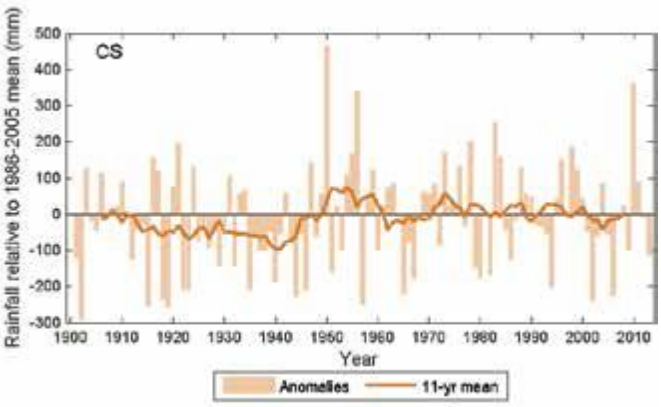
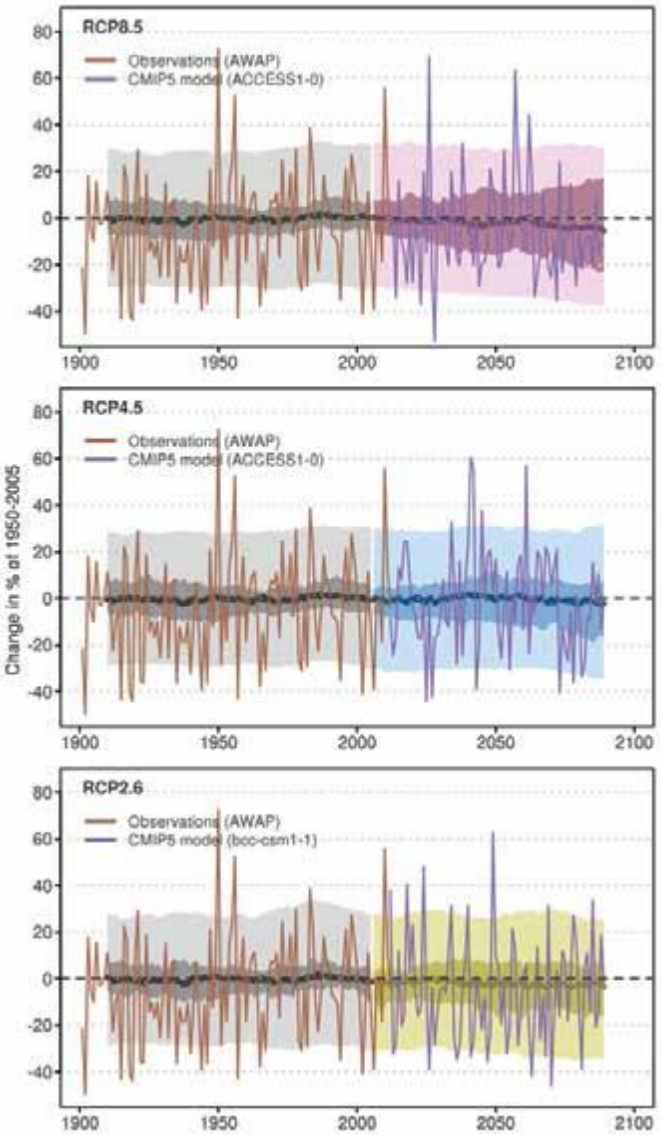
Figure 26. Observed annual rainfall anomalies (mm) for 1901–2013, compared to the baseline 1986–2005 for Central Slopes region



Adapted from Ekström, M. et al. 2015.

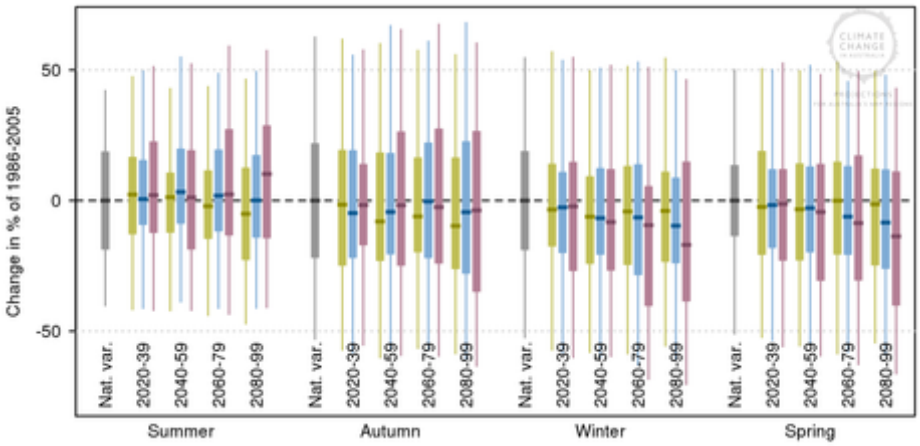
Figure 27. Time series for central slopes annual rainfall for 1910–2090, as simulated in CMIP5 expressed as a percentage relative to the 1950–2005 mean



The central line is the median value, and the shading is the 10th and 90th percentile range of 20-year means (inner) and single-year values (outer). The grey shading indicates the period of the historical simulation, while three future scenarios are shown with colour-coded shading: RCP8.5 (purple), RCP4.5 (blue) and RCP2.6 (green).

Adapted from Ekström, M. et al. 2015.

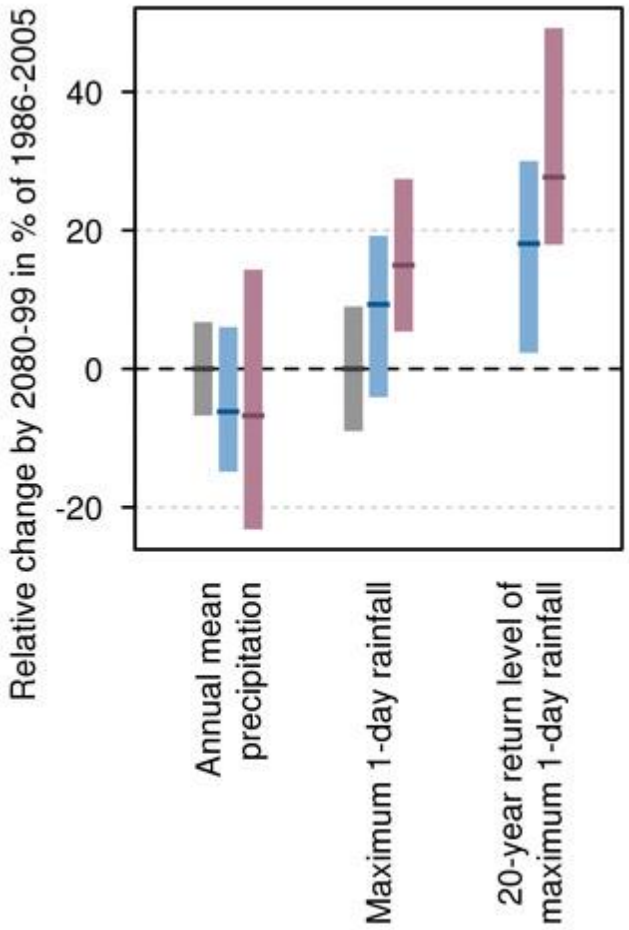
Figure 28. Projected change in seasonal precipitation for central slopes



Graphs show change in (from left) summer, autumn, winter and spring. Anomalies are given in % relative to 1995(1986–2005) under RCP2.6 (green), RCP4.5 (blue) and RCP8.5 (purple). Natural climate variability is represented by the grey bar.

Source: http://www.climatechangeinaustralia.gov.au/, accessed on April 2015.

Figure 29. Projected changes in central slopes mean rainfall, magnitude of annual maximum 1-day rainfall and magnitude of the 20-year return value for the 1-day rainfall for 2090

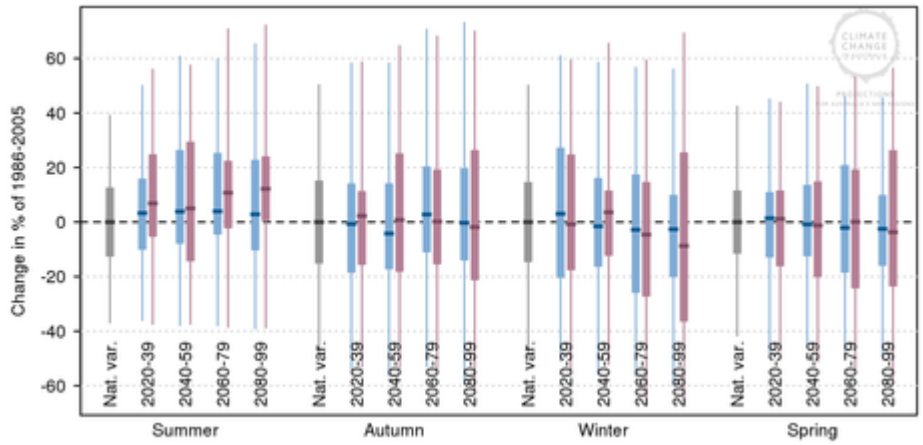


Change is given in percentage with respect to the 1986–2005 mean for RCP4.5 (blue) and RCP8.5 (purple). Natural climate variability is presented by the grey bar.

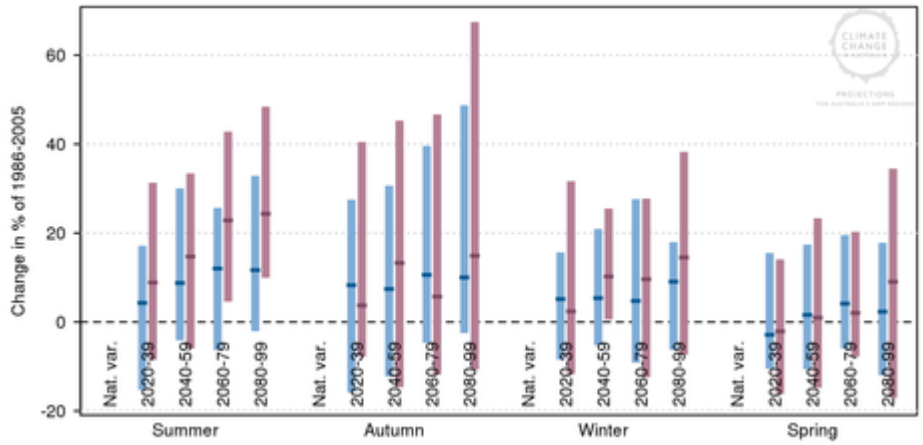
Adapted from Ekström, M. et al. 2015.

Figure 30. Projected change in seasonal wettest day (a) and 1-in-20-year wettest day (b)

(a)



(b)

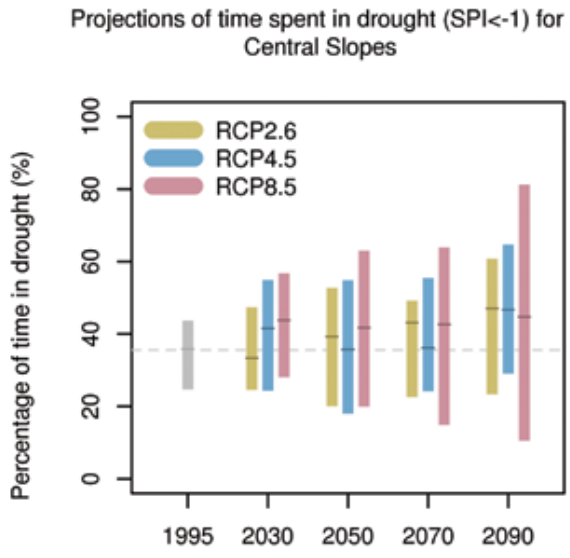


Graphs show change in (from left) summer, autumn, winter and spring. Anomalies are given in % relative to 1995 (1986–2005) under RCP4.5 (blue) and RCP8.5 (purple). Natural climate variability is represented by the grey bar.

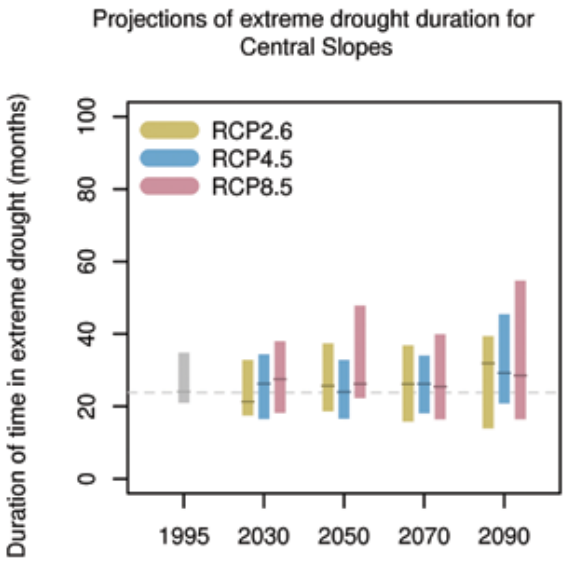
Source: http://www.climatechangeinaustralia.gov.au/, accessed on April 2015.

Figure 31. Simulated changes in drought based on the standardised precipitation index (SPI)

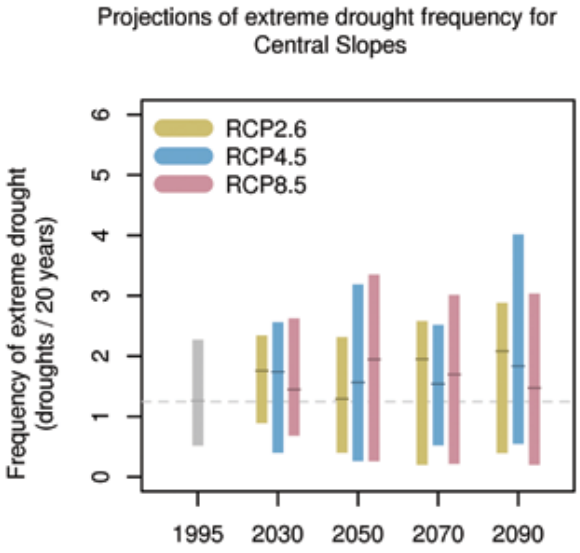
(a)



(b)



(c)



The figure shows (a) the percentage of time in drought (SPI < -1), (b) duration of extreme drought and (c) frequency of extreme drought for each 20-year period centred on 1995, 2030, 2050, 2070 and 2090 under RCP2.6 (green), RCP4.5 (blue) and RCP8.5 (purple). Natural climate variability is represented by the grey bar.

Adapted from Ekström, M. et al. 2015.

Box 1. Standardised Precipitaiton Index (SPI)

The standardised precipitation index (SPI, McKee et al. 1993, Lloyd-Hughes and Saunders, 2002) was used by CSIRO for drought analysis for the technical report on Climate Change in Australia (CSIRO 2015). SPI is solely based on rainfall and is calculated by fitting a probability density function to the frequency distribution of a long-term (e.g., 1900–2005 for this Central Slopes cluster report) series of rainfall values, summed over the timescale of interest. CSIRO (2015) drought analysis uses monthly data with 12 months timescale of interest, which is considered as the time required for water deficit conditions to affect various agricultural and hydrological systems (e.g., Szalai and Sziness, 2000, Zargar et al. 2011). Thus, each monthly value is the total rainfall for the previous 12 months. Subsequently, the probability distribution is transformed to a standardised normal distribution. Negative SPI values are indicative of dryness while positive values are indicative of wetness.

Table 8. Drought category based on standardised precipitation index (SPI)

SPI Value	Drought category
0 to -0.99	Near normal
-1.00 to -1.49	Moderate
-1.50 to -1.99	Severe
-2 or less	Extreme

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

Table 9. Cluster mean annual values of maximum temperature (°C), rainfall (mm), drought factor (no units), the number of severe fire danger days (SEV: FFDI greater than 50 days per year) and cumulative FFDI (ΣFFDI; no units) for the 1995 baseline and projections for 2030 and 2090 under RCP4.5 and RCP8.5

Variable	1995 Baseline	2030 RCP4.5	2030 RCP8.5	2090 RCP4.5	2090 RCP8.5
Maximum temperature (°C)	25.2	26.5	26.8	27.8	29.6
Rainfall (mm)	586	541	526	519	504
Drought factor (no unit)	6.8	7.2	7.3	7.5	7.8
Severe fire danger days (FFDI greater than 50 days per year)	2.2	3.0	3.7	4.1	7.2
Cumulative FFDI (no unit)	3857	4183	4446	4600	5357

* FFDI McArthur Forest Fire Danger Index (McArthur, 1967)

Adapted from Ekström, M. et al. 2015.

Table 10. GCM simulated changes in potential evapotranspiration for 20-year period centred on 2030 and 2090 relative to the baseline period 1986–2005 for the Central Slopes cluster. The value represents median change (50th percentile), as projected by the CMIP5 models, with 10th and 90th percentile range given within brackets

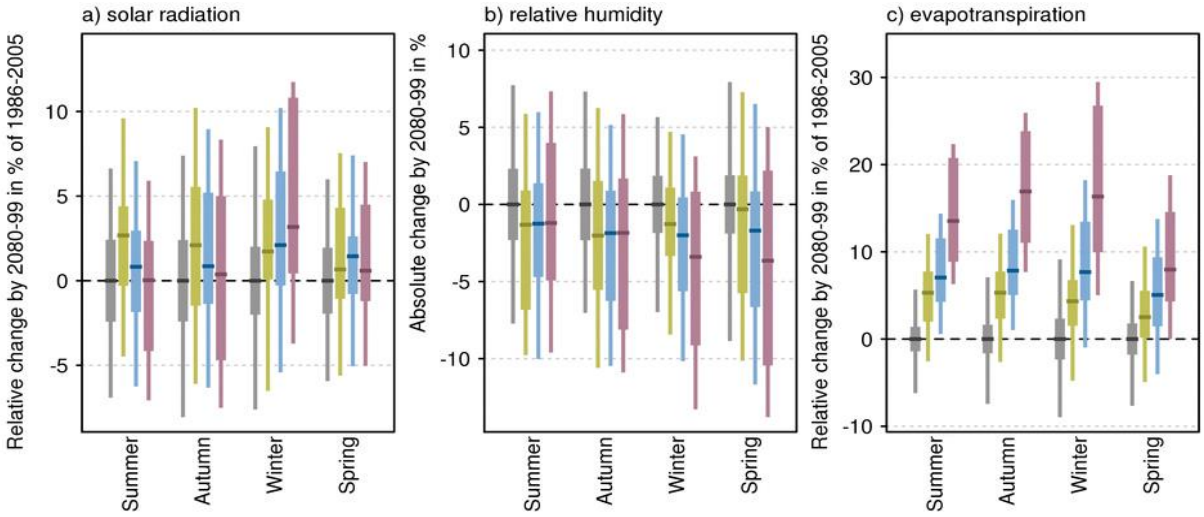
VARIABLE	SEASON	2030, RCP2.6	2030, RCP4.5	2030, RCP8.5	2090, RCP2.6	2090, RCP4.5	2090, RCP8.5
Evapo-transpiration (%)	Annual	3.6 (2.5 to 4.8)	3.3 (1.6 to 4.8)	3.6 (1.8 to 5.8)	4.2 (2.3 to 6.9)	6.8 (4.2 to 10.8)	12.5 (9.8 to 18.1)
	DJF	3.9 (1.7 to 5.1)	2.8 (1.3 to 6.2)	3.1 (1.2 to 6.6)	5.3 (2 to 7.7)	7.1 (4.3 to 11.5)	13.5 (8.9 to 20.8)
	MAM	4.6 (-0.9 to 6.6)	3.2 (1 to 7.2)	4.7 (2.3 to 7.2)	5.3 (2.3 to 7.7)	7.8 (5 to 12.5)	16.9 (11 to 23.8)
	JJA	4 (1.5 to 8.2)	3.7 (0.5 to 8)	4.5 (1.1 to 7.4)	4.3 (1.5 to 6.8)	7.7 (4.4 to 13.5)	16.3 (9.9 to 26.8)
	SON	3.3 (0.5 to 5.6)	3 (0.8 to 4.6)	2.2 (0.5 to 4.9)	2.5 (0.2 to 5.5)	5.1 (1.5 to 9.4)	8 (4.3 to 14.6)

LEGEND TO TABLE 1

	Very high model agreement on substantial increase
	High model agreement on substantial increase
	Medium model agreement on substantial increase
	High model agreement on increase
	Medium model agreement on increase
	High model agreement on little change
	Medium model agreement on little change
	High model agreement on substantial decrease
	Medium model agreement on substantial decrease
	High model agreement on decrease
	Medium model agreement on decrease

Adapted from Ekström, M. et al. 2015.

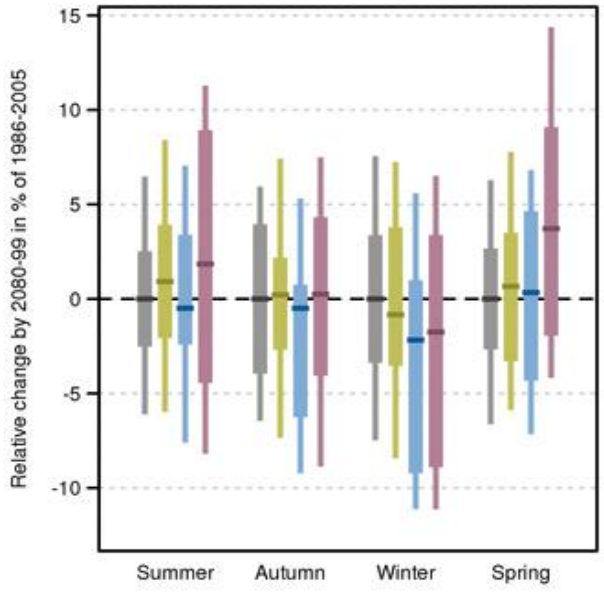
Figure 32. Projected changes in (a) solar radiation (%), (b) relative humidity (% absolute change) and (c) potential evapotranspiration (%) for Central Slopes in 2090



The bar plots show seasonal projections with respect to the 1986–2005 mean for RCP2.6 (green), RCP4.5 (blue) and RCP8.5 (purple) and the extent of natural climate variability is showing in grey.

Adapted from Ekström, M. et al. 2015.

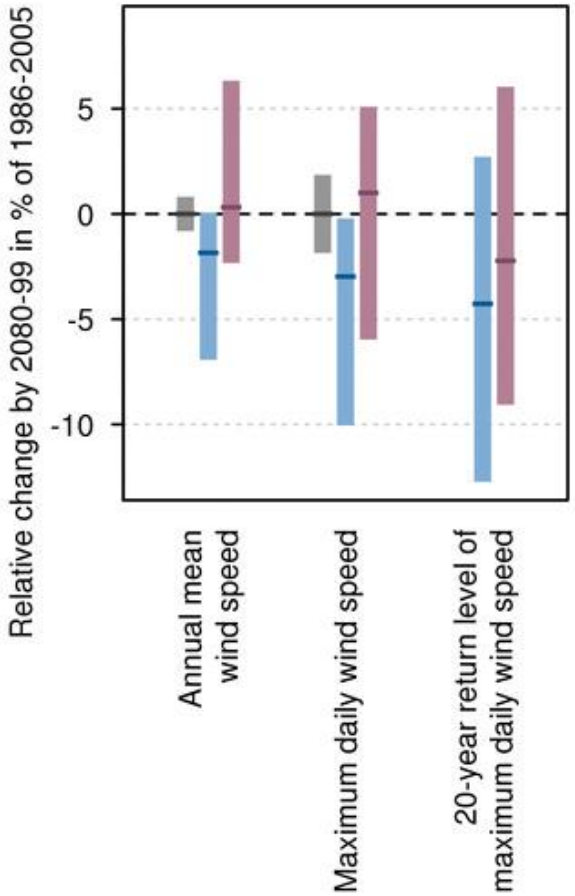
Figure 33. Projected near-surface wind speed changes for 2090 for Central Slopes cluster



Anomalies are given in percent with respect to the baseline period (1986–2005) mean for RCP2.6 (green), RCP4.5 (blue), RCP8.5 (purple) and natural variability as grey bars.

Adapted from Ekström, M. et al. 2015.

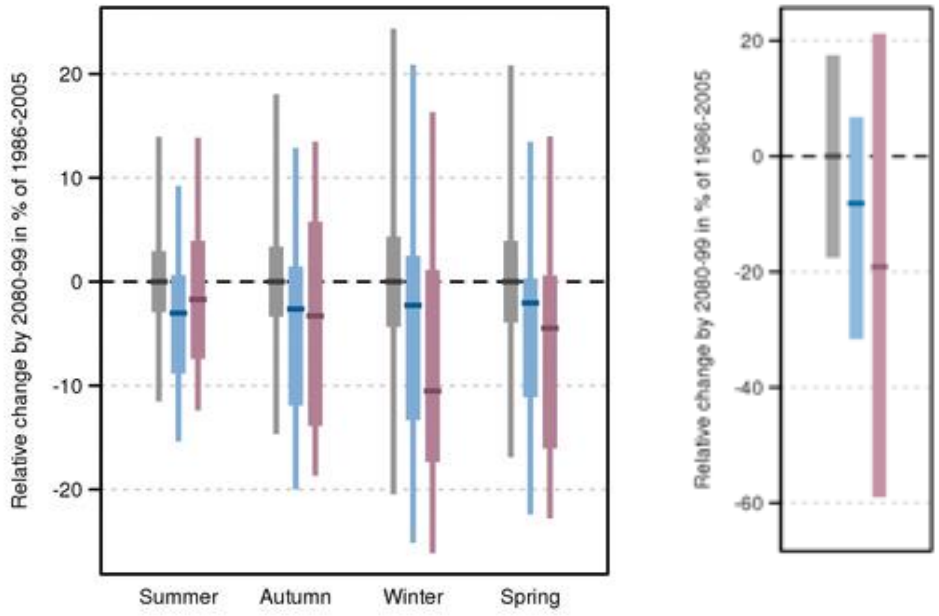
Figure 34. Projected near-surface annual mean wind speed, annual maximum daily wind speed and the 20-year return value for the annual maximum daily wind speed for 2090 for central slopes cluster



Anomalies are given in percentage with respect to the 1986–2005 mean for RCP2.6 (green), RCP4.5 (blue), RCP8.5 (purple) and natural variability as grey bars.

Adapted from Ekström, M. et al. 2015.

Figure 35. Projected change in seasonal soil moisture (left) and annual runoff (right) in Central Slopes for 2090



Anomalies are given in percentage with respect to the 1986–2005 mean for RCP4.5 (blue), RCP8.5 (purple) and natural variability as grey bars.

Adapted from Ekström, M. et al. 2015.

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Appendix 2. Responses to climate change

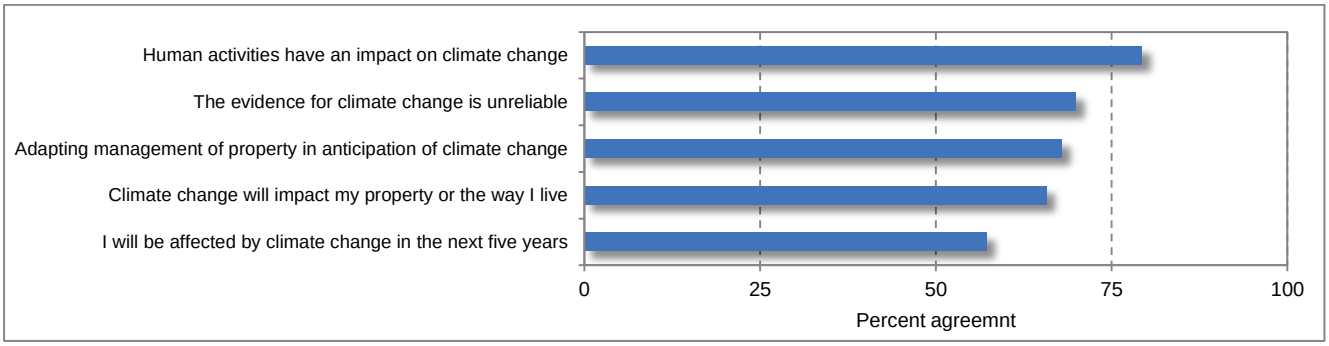
Table 1. Beliefs about climate change

Belief statements	Agreement		Total	
	Count	Percent	Count	Percent
Human activities have a significant impact on climate change	752	79.4	947	100.0
The evidence for climate change is unreliable	660	70.0	943	100.0
I am adapting the way I manage my property in anticipation of long term climate change	675	68.0	992	100.0
Long-term climate change is going to impact my property or the way I live	636	65.8	967	100.0
I will be personally affected by climate change in the next five years	503	57.3	879	100.0

Note: Landholders who indicated 'don't know' have been excluded from the analysis.
Values in the table show the percentage of landholders who indicated agreement with the statement.
Source: EBC (2015).

Adapted from NWLLS 2014.

Figure 1. North West LLS landholders' personal perspective on climate change



Adapted from NWLLS 2014.

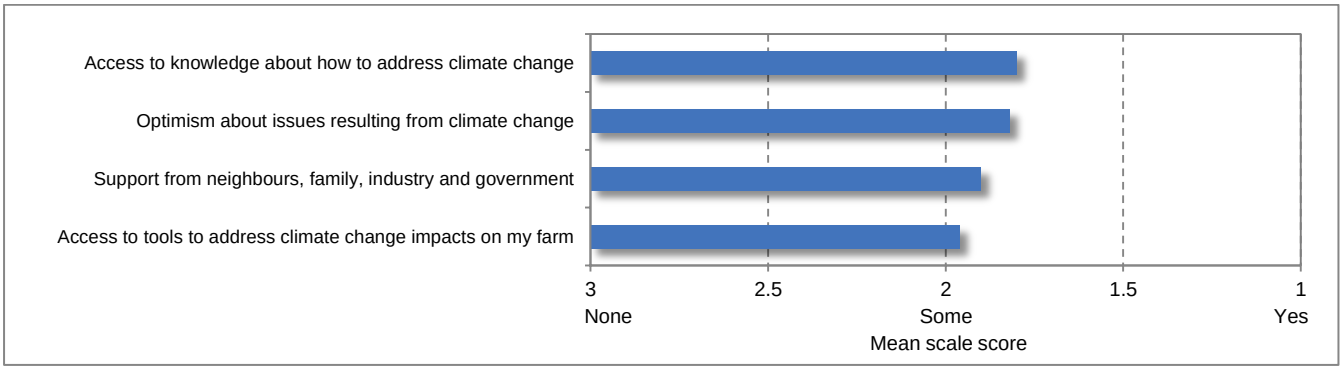
Table 2. North West LLS landholders' personal perspective on capacity to adapt to climate change

Belief statements	Yes (1)	Some (2)	None (3)	Mean score	Total count
Access to knowledge about how to address climate change	34.3	51.6	14.0	1.80	1,026
Optimism about issues resulting from climate change	34.4	49.0	16.6	1.82	1,031
Support from neighbours, family, industry and government	27.2	55.6	17.2	1.90	1,018
Access to tools to address climate change impacts on my farm	26.8	50.8	22.5	1.96	1,025

Note: Values in the table are row percentages.
Source: EBC (2015).

Adapted from NWLLS 2014.

Figure 2. North West LLS landholders' personal perspective on capacity to adapt to climate change



Adapted from NWLLS 2014.

Table 3. Anticipated practice change in response to climate change

Response	Count	Percent
Destock or have less stock	152	14.5
Improve water management, conservation or efficiency	93	8.9
More on-farm water storage	88	8.4
Improve or change crops	34	3.2
Change pasture species	33	3.2
Preserve or plant trees or vegetation	26	2.5
Install or develop bore water	24	2.2
Adopt minimum or zero tillage practices	20	1.9
Develop more on farm dams	19	1.8
Import feed for livestock	18	1.7
Improve pasture management *(general)*	17	1.7
Improve groundcover	17	1.6
Develop or improve irrigation	14	1.4
Conserve soil moisture levels	14	1.3
Don't farm or use the land	14	1.3
Improve livestock management *(general)*	13	1.2
Change livestock rotation practices	10	1.0
Create more shelter for livestock	10	1.0
Install solar power	10	1.0
Fewer crops	9	0.8
Adopt conservation farming methods	8	0.8
Become more self sufficient	8	0.7
Build new fences	7	0.7
Financial impact/less income	7	0.6
Too expensive to farm or keep animals	6	0.6
Change stock from sheep to cattle	6	0.6
Grow feed for livestock	5	0.5
Improve soil condition	5	0.5
Retire from farming	5	0.5
Make property more drought resistant	5	0.5
Improve crop rotation	5	0.5
Change cattle breeds	5	0.5
More erosion mitigation	5	0.4
More or better farm storage (i.e., grains, hay)	4	0.4
Adjust stocking rates to weather conditions	3	0.2
Undertaken off farm employment	3	0.2
Develop on farm feed storage	2	0.2
Recognition of the need for change *(general statements)*	252	24.0
No need for change or denial of climate change	217	20.7
Don’t know or unsure	144	13.7
No need as change as climate change won’t occur their lifetime	71	6.8
Move off the land	40	3.8
Unlikely to continue farming	20	1.9
Total landholders	1,050	100.0

Note: This is a multiple response table in which a respondent may be included in multiple rows.

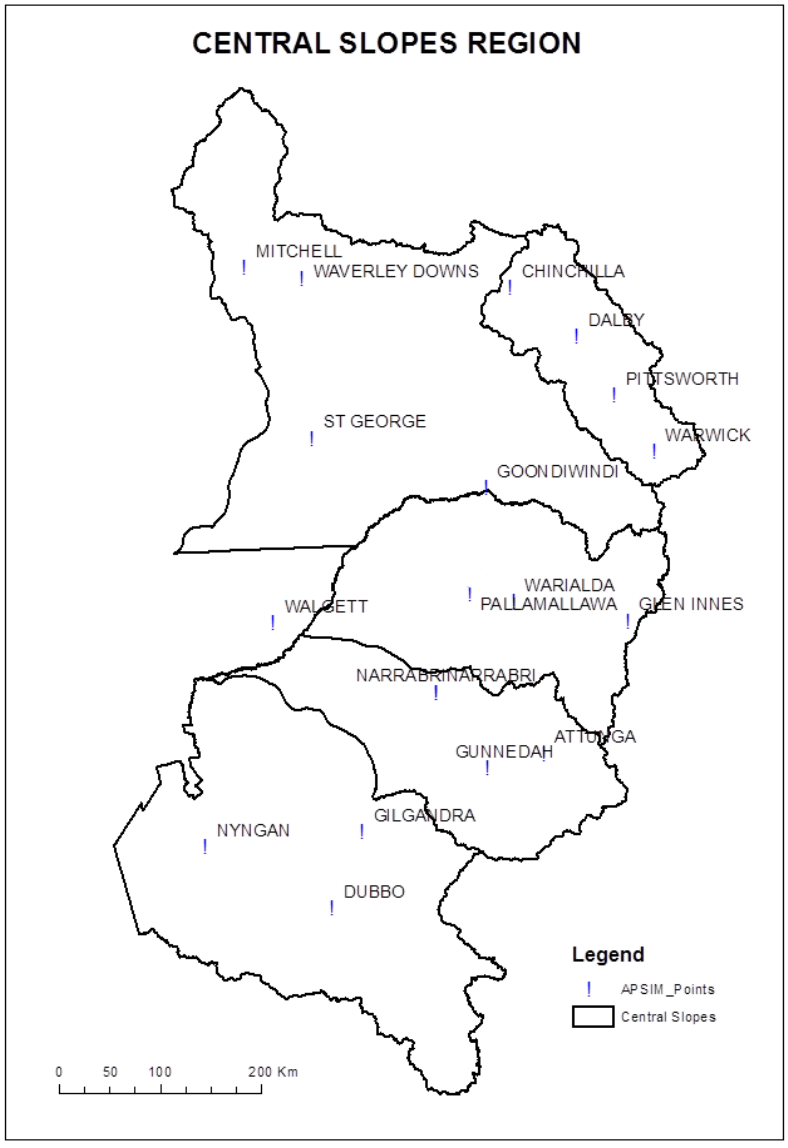
Adapted from NWLLS 2014.

Table 4. Representative GCMs and associated indicative future climate for 2030 under a high emissions scenario used for APSIM modelling in Central Slopes cluster

Representative model from CMIP3	Indicative climate future
MIROC-H and EACHAM5	Warmer future (HI)
CSIRO Mk3.5 and HADGEM1	Much warmer and drier (HP)
NCAR-CCSM and GFDL-21	Warmer and drier (WP)

Source: Williams, A. 2014.

Figure 3. Map of Central Slopes region showing APSIM simulation sites



Adapted from: Power B. 2014.

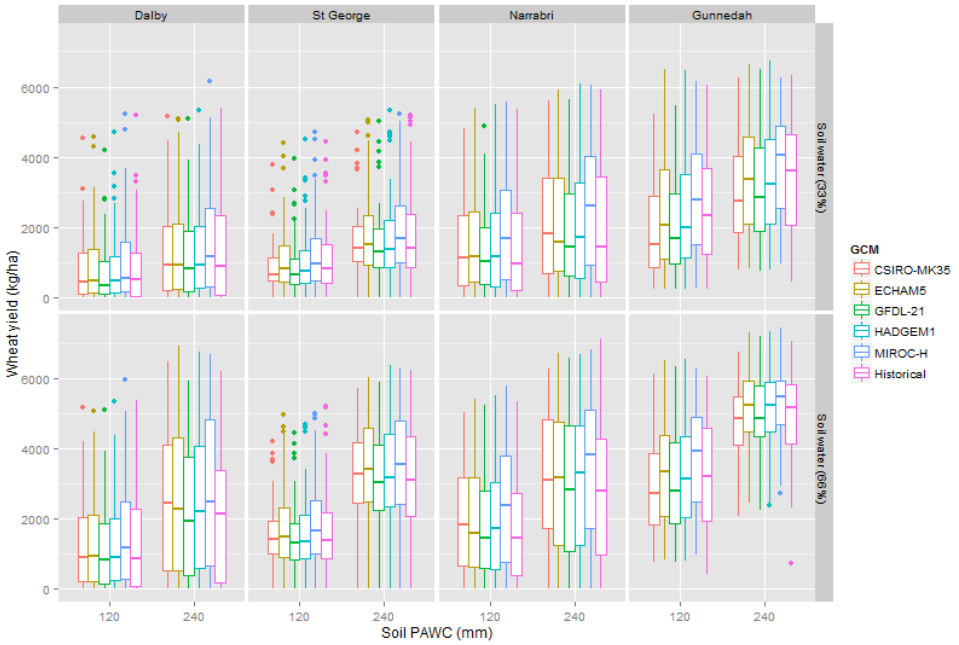
Table 5. General site character such as representative soils (APSoil number), average slopes adapted for APSIM simulation across the Central Slopes region

Simulation sites located within North West LLS region are presented in bold and italics.

Site	Wheat		Sorghum		Cotton		Primary Soil soils (APSoil numbers)	Average paddock slopes
	Start	End	Start	End	Start	End		
Attunga	***1-May***	***30-Jun***	***1-Oct***	***15-Jan***	***1-Oct***	***15-Nov***	***Red Chromosol (Harden No548)***	***0.98***
Chinchilla	1-May	30-Jun	15-Sep	15-Jan	1-Oct	15-Nov	Grey Vertosol-Brigalow (Warra No019)	2.17
Dalby	1-May	30-Jun	15-Sep	15-Jan	1-Oct	15-Nov	Grey Vertosol-Cecilvale (Beverley No010)	0.49
Dubbo	1-Jun	30-Jun	15-Sep	15-Jan	1-Oct	15-Nov	Red Sodosol-Kurrajong Box Duplex (Rocky Crossing No043)	0.66
Gilgandra	1-Jun	30-Jun	1-Oct	15-Jan	1-Oct	15-Nov	Red Kandasol (Boolba No 13)	1.32
Glen Innes	1-Jun	15-Jul	1-Nov	15-Jan	1-Oct	15-Nov	Black Vertosol (Biniguy No061)	0.97
Goondiwindi	1-May	30-Jun	15-Sep	15-Jan	1-Oct	15-Nov	Grey Vertosol (Goondiwindi No219)	1
Gunnedah	***1-May***	***30-Jun***	***1-Oct***	***15-Jan***	***1-Oct***	***15-Nov***	***Black Vertosol (Breeza No119)***	***1.25***
Mitchell	1-May	30-Jun	15-Sep	15-Jan	1-Oct	15-Nov	Brown Vertosol (Roma No063)	1.38
Moree	***1-May***	***30-Jun***	***15-Sep***	***15-Jan***	***1-Oct***	***15-Nov***	***Black Vertosol (Moree No235)***	***0.58***
Narrabri	***1-May***	***30-Jun***	***15-Sep***	***15-Jan***	***1-Oct***	***15-Nov***	***Grey Vertosol (Narrabri No124)***	***1.23***
Nyngan	1-May	30-Jun	1-Oct	15-Jan	1-Oct	15-Nov	Grey Vertosol (Myall Vale No097)	0.55
Pallamallawa	1-May	30-Jun	15-Sep	15-Jan	1-Oct	15-Nov	Grey Vertosol (Terry Hie Hie No079)	1.13
Pittsworth	1-May	30-Jun	15-Sep	15-Jan	1-Oct	15-Nov	Black Vertosol-Irving (Greenmount No067)	1.21
St George	1-May	30-Jun	15-Sep	15-Jan	1-Oct	15-Nov	Red Kandasol (Boolba No 13)	0.9
Walgett	***1-May***	***30-Jun***	***15-Sep***	***15-Jan***	***1-Oct***	***15-Nov***	***Grey Vertosol (Merrywinebone No126)***	***0.69***
Warialda	***1-May***	***30-Jun***	***15-Sep***	***15-Jan***	***1-Oct***	***15-Nov***	***Black Vertosol (Biniguy No061)***	***1.3***
Warwick	1-May	30-Jun	15-Sep	15-Jan	1-Oct	15-Nov	Brown Vertosol-Talgai-shallow phase (Hermitage No033)	2.87
Waverly Downs	1-May	30-Jun	15-Sep	15-Jan	1-Oct	15-Nov	Brown Vertosol (Roma No063)	1.83

Source: Power B. 2014.

Figure 4. Variation of wheat yields for the historical climate (right – purple) and projected future climate at Dalby, St George, Narrabri and Gunnedah stations (left to right)

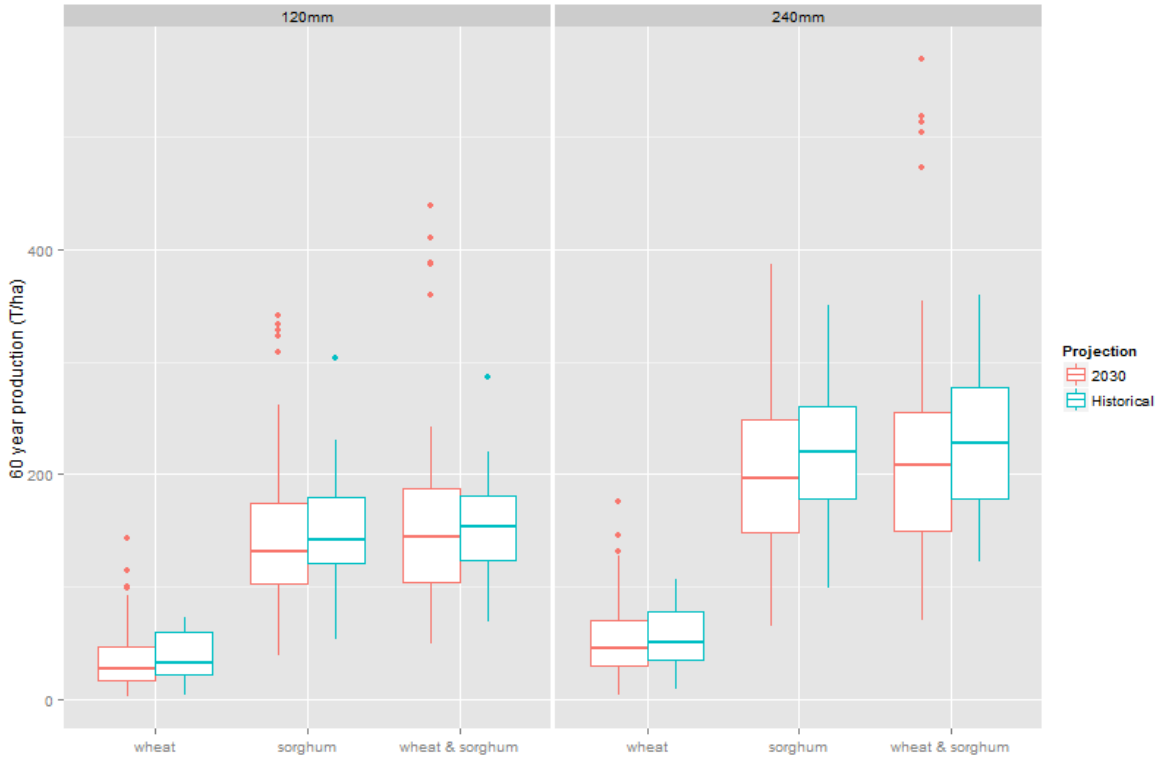


Source: Power B. 2014.

The upper series provides yield with soil water holding capacity at 33% and the lower series for 66%.

Cobon and McRae (2014) anticipated that cropping zones with soils of lower fertility and water holding capacity were likely to be the most vulnerable to future climate risk.

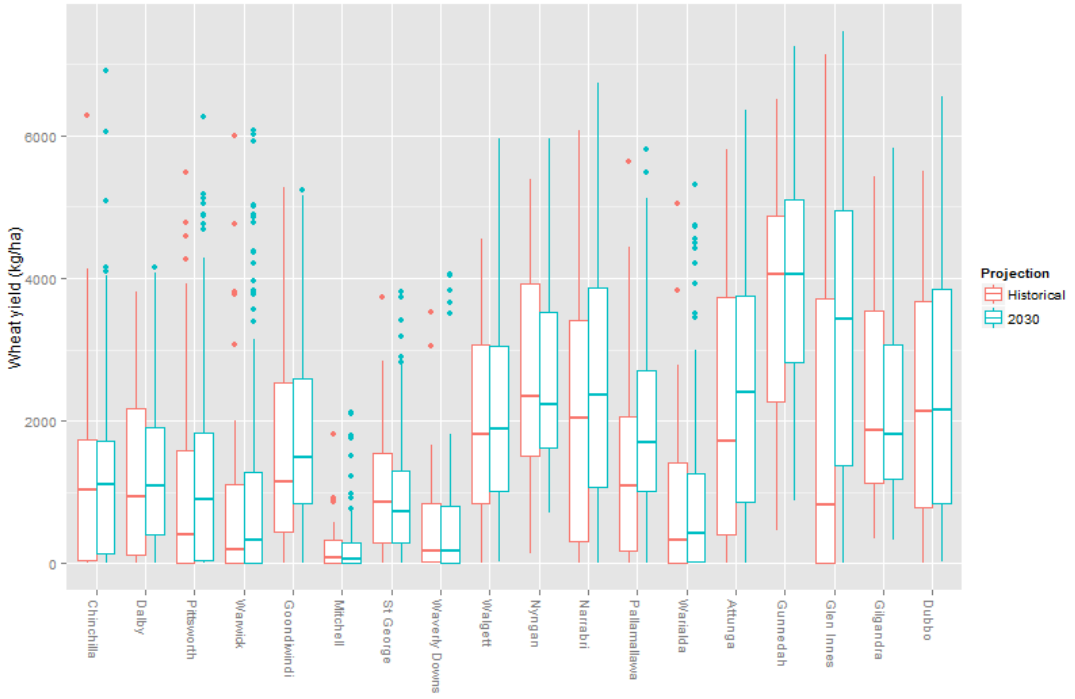
Figure 5. Sixty years production of wheat, sorghum, and wheat and sorghum cropping across Central Slopes region simulated by APSIM under the historical climate and projected future climate for 2030



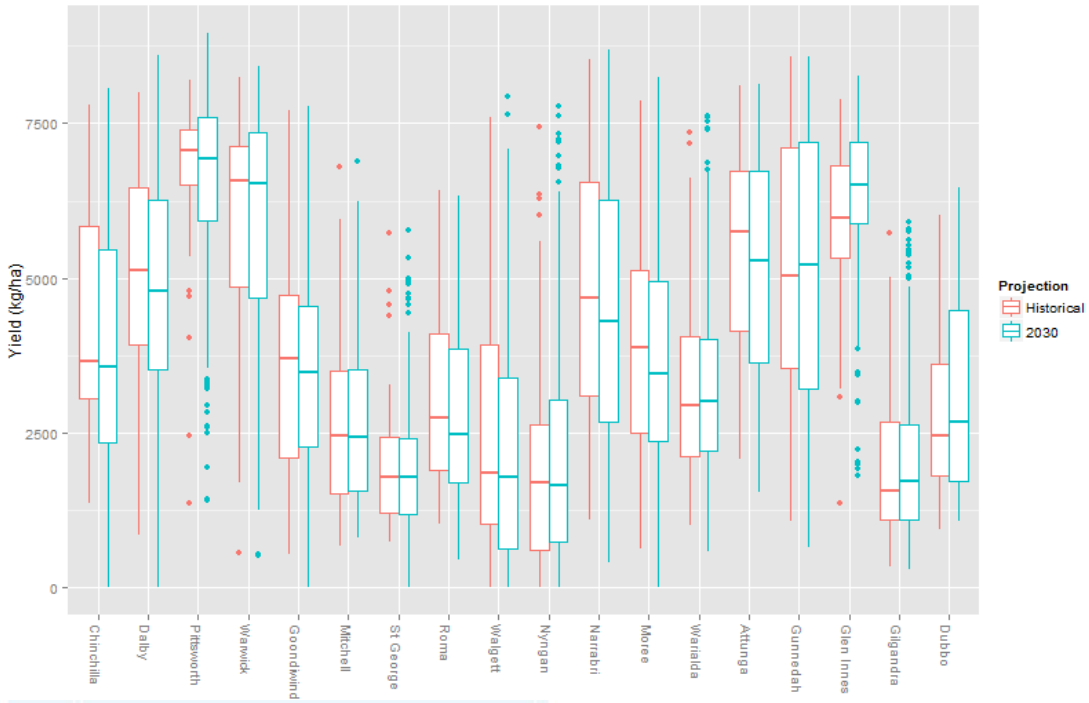
Source: Power B. 2014.

Figure 6. Wheat (a) and sorghum (b) yields (kg/ha) across the Central Slopes region

(a)



(b)

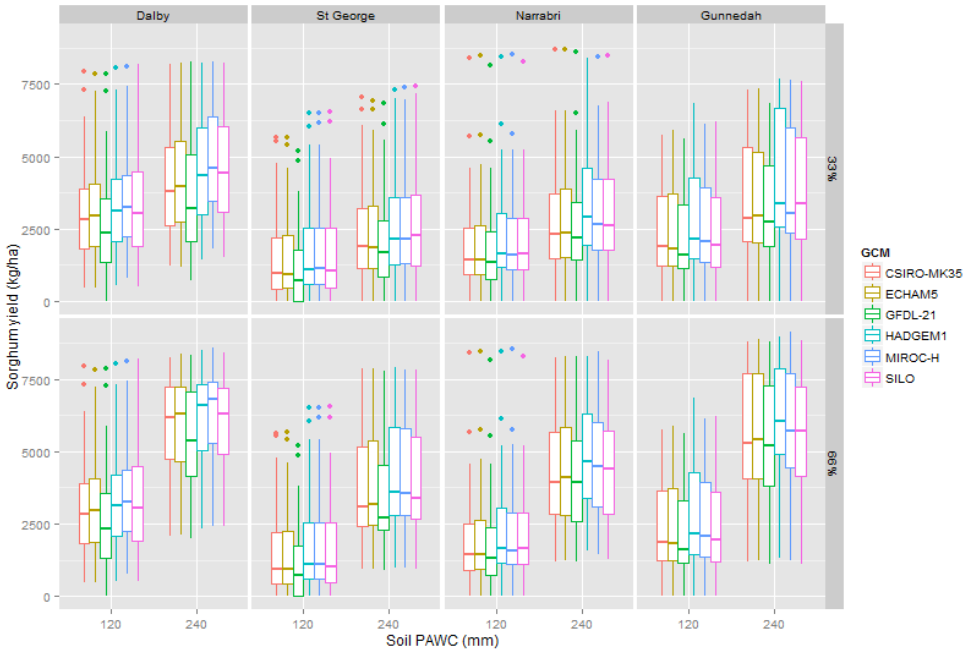


Yields are simulated by APSIM model for 18 climatic stations across the central slopes region using historical (red) and projected 2030 climate (blue).

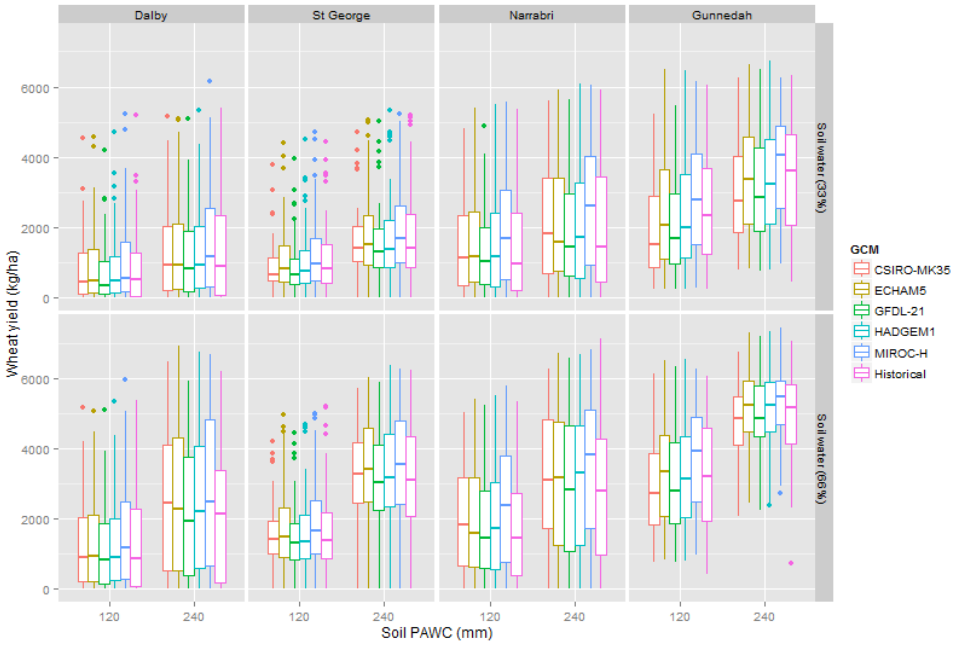
Source: Power B. 2014.

Figure 7. Variation of wheat (a) and sorghum (b) yields at four selected stations of the Central Slopes region for the historical climate (right – purple) and projected future climates for near future period centred on 2030

(a)



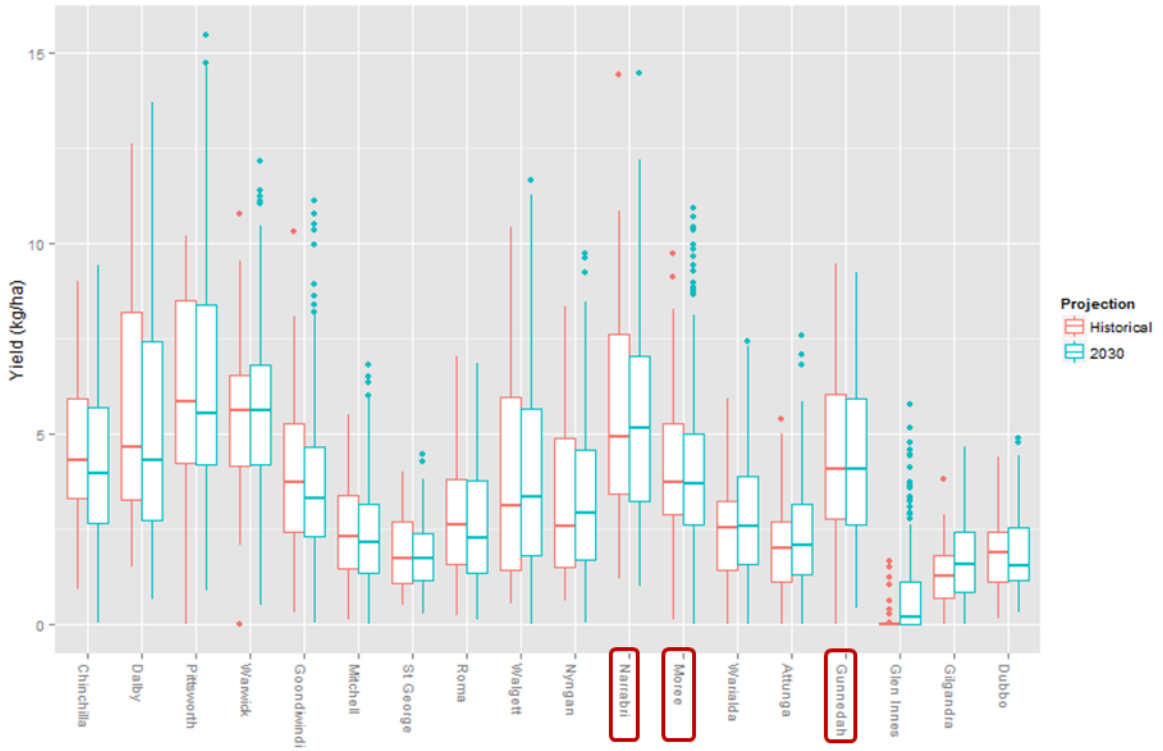
(b)



The upper series provides yield values for soil water holding capacity at 33% and the lower series for 66%. A description of future climate represented by the five GCMs presented in this figure is provided as Table 8.

Source: Power B. 2014.

Figure 8. Climate change influence on cotton (non-irrigated) yields (kg/ha) across the Central Slope region



Climate change influence is simulated by APSIM model under high emission scenario (A1FI, CMIP3) for historical climate (red) and projected future climate 2030 (blue): (a) one irrigation case and (b) two irrigations case. Major irrigated cotton growing areas of North West LLS are highlighted in a dark red box. [Source: Bredan 2014. Report on APSIM modelling for Central Slopes cluster (unpublished) and personal communication with Brendan Power formerly Queensland's Department of Agriculture, Fisheries and Forestry.]

Source: Power B. 2014.

Table 6. Simulation of grazing enterprises for a hypothetical pasture around selected weather stations across North West region for a self-replacing Angus beef cow (Angus) enterprise

Pasture: Native Climate: Historical (1960–2013)

Location	Soil type	Rainfall (mm)	Stocking Rate	NPP (kg/ha)	Ground cover (at p = 0.7)	Gross margin* ($/ha)
Tamworth	Db1.22	679	**0.7**	8306	**76%**	**152**
Warialda	Dr2.21	695	**0.7**	7155	**73%**	**158**
Gunnedah	Dr2.33	627	**0.4**	5509	**71%**	**22**
Narrabri	Dr2.33	678	**0.4**	5155	**70%**	**13**

* Indicative gross margin based on 2013 prices.

Source: Shilpakar and Graham 2015.

Table 7. Assessment of pasture production potential around selected weather stations of North West region

The simulation of potential pasture production from native pasture was carried out using historical climate data (1960–2013) for 0.1 stocking rate for all stations while maintaining an optimum ground cover.

Location	Soil type	Annual Rainfall	Pasture Production (NPP in kg/ha)	Ground cover in % (*p* = 0.7)
Tamworth	Db1.22	679	9168	94
Warialda	Dr2.21	695	7555	94
Gunnedah	Dr2.33	627	5745	84
Narrabri	Dr2.33	678	5282	84

Source: Shilpakar and Graham 2015.

Table 8. Indicative climate change impacts on grazing enterprises for Tamworth station showing relative changes between projected future climate with respect to the historical climate

A hypothetical native pasture was modelled for a self-replacing Angus beef cow (Angus) enterprise at the selected climate stations.

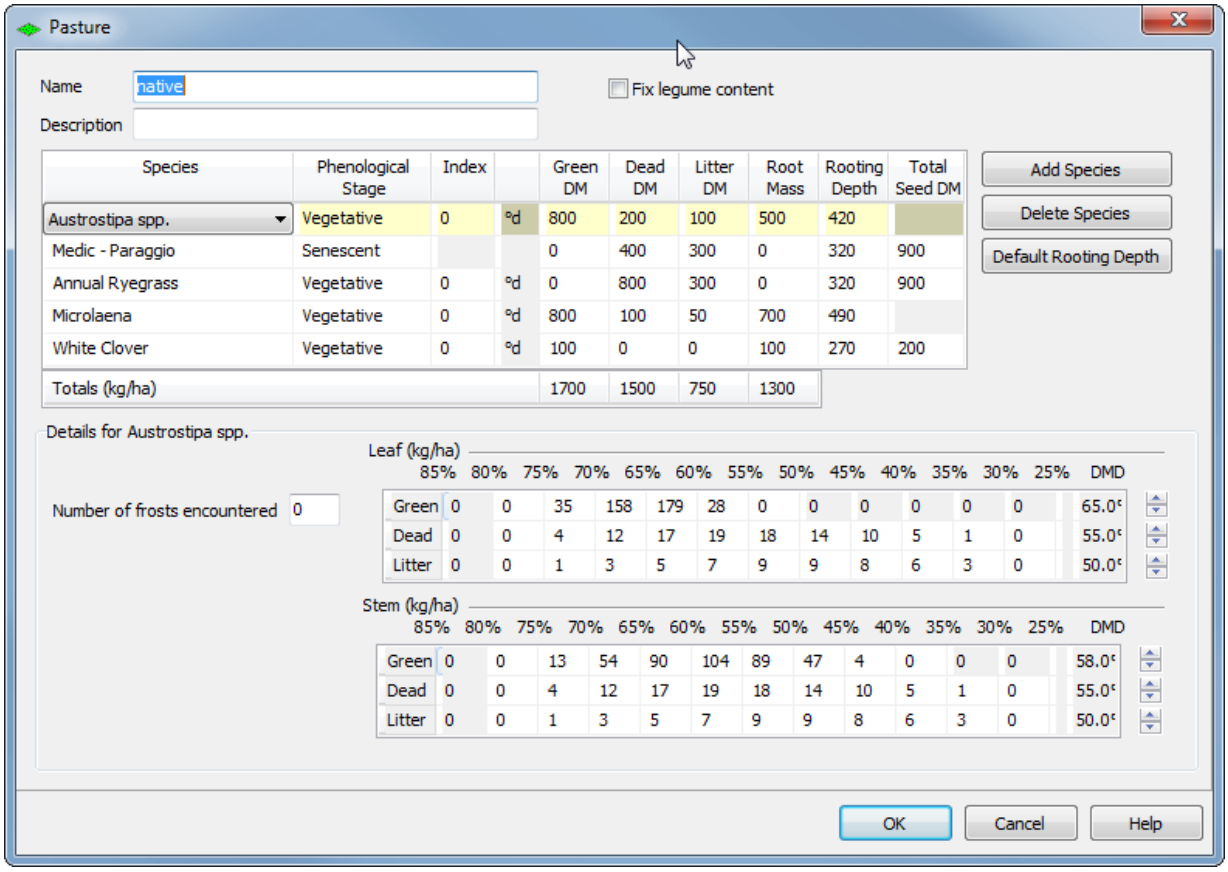
Climate scenario	CO_2 (ppm)	Rainfall (mm)	Ground cover (%)	Stocking Rate	NPP (kg/ha)	Indicative Gross margin ($/ha)*
1. Historic climate (1960–2013)	350	679	**76**	**0.7**	8306	**152**
2. Projected future climate scenarios for 2030 under medium emission scenario (RCP 4.5) (the simulating GCMs are provided in brackets):						
Warmer and drier (HadGEM2)	444	616	**71**	**0.4**	7276	**38**
Warmer and little change in annual rainfall (MPI-ESM)	444	694	**75**	**0.4**	8375	**34**
Warmer and wetter (GFDL-GEM2)	444	727	**72**	**0.6**	7940	**92**

* Indicative gross margin based on 2013 prices.

NPP – Total annual pasture yield.

Source: Shilpakar and Graham 2015.

Figure 9. An example of pasture parameters used in GrassGro model for this rapid assessment



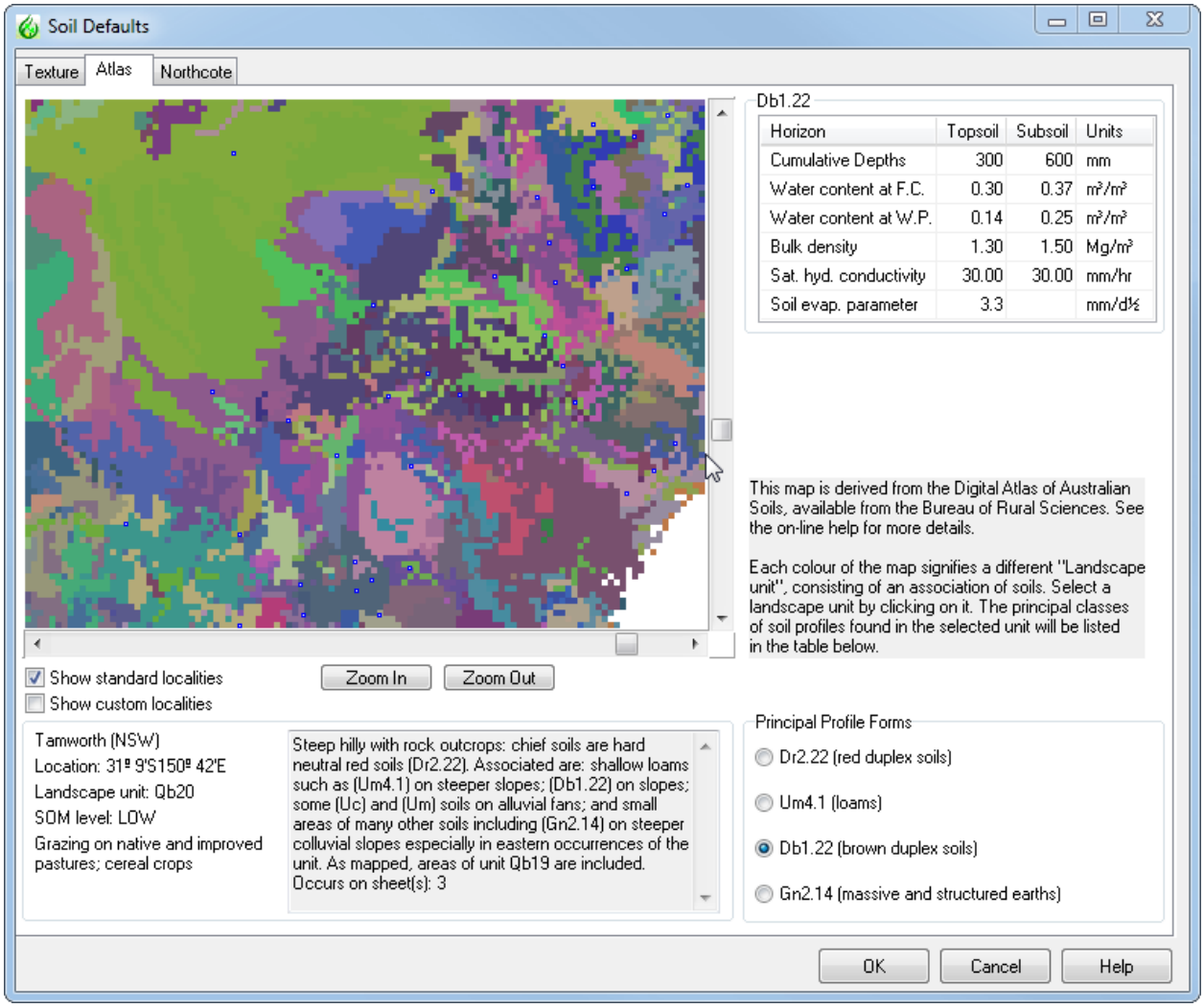
Source: CSIRO (2014), GrassGro 3.

Table 9. Farm system description

Farm system parameter in GrassGro	Initial value
Enterprise type	Beef cow
Initial state	1 Jan 1950
Tested	Over 1 Jan 1950 to 31 Dec 2013
Passed	No
Pasture parameters	Standard, last edited 30 Jan 2013 by Andrew Moore
Animal parameters	Standard, last edited 30 Jan 2013 by Andrew Moore

Note: This table is a summary only. For a detailed description, see Shilpakar and Graham 2015.

Figure 10. Default soil data inbuilt in GrassGro software



Source: CSIRO (2014), GrassGro 3.

Table 10. Long-term average values of key input parameters and associated output variables for a simulation of a notional grazing enterprise under the historical climate scenario at the four sample locations across North West LLS

Variable	Unit	Location				Note
		Tamworth	Gunnedah	Narrabri	Warialda	
Soil type		***Db1.22***	***Dr2.33***	***Dr2.33***	***Dr2.21***	
Stocking rate	***no/ha***	***0.7***	***0.4***	***0.4***	***0.7***	
Annual rainfall (historical average)	mm	679	627	678	695	
Annual pasture yield (NPP)	kg/ha	8306	5509	5155	7155	
DSE	dse/ha	9.7	5.1	4.9	9.4	
Gross margin	$/ha	152	22	13	158	
Ground cover	%	76%	71%	70%	73%	

Pasture: Native; Climate: Historical (1960–2013).
Enterprise: Beef cow (Angus), self-replacing.
Soil type: Based on soil map inbuilt in GrassGro (Figure).
NPP: Net Primary Productivity (or long-term average pasture yield).
Gross margin: Notional figures based on 2013 prices.

Table 11. Projected near future climate of the Central Slopes region (North West LLS is a NRM body within the Central Slopes region created for Stream 1 project) under medium emission scenario (RCP 4.5)

Climate scenario	Description	GCM Model consensus	Selected model*
Warmer and wetter	0.5–1.5°C warmer annual surface temperature with 5.0–15% increase in annual rainfall	5 of 40 GCMs	GFDL-CM3
Warmer with little change in rainfall	0.5–1.5°C warmer annual surface temperature with ±5% change in annual rainfall	21 of 40 GCMs	MPI-ESM-LR
Warmer and Drier	0.5–1.5°C warmer annual surface temperature with 5.0–15% reduction in annual rainfall	12 of 40 GCMs	HadGEM2

Source: CSIRO and Bureau of Meteorology (2015).

Table 12. Relative change in long-term average annual production (NPP) and minimum mass of pasture, water balance and methane production at Tamworth under historical and projected future climate scenarios

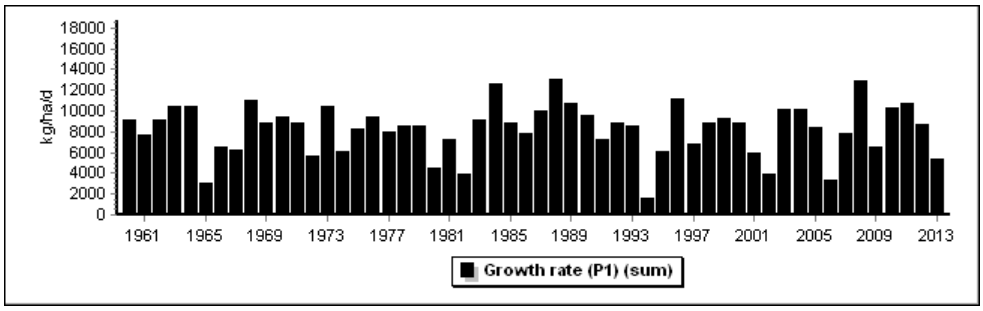
Variables	Unit	Historic Climate (1950-2013)	2030: Warmer & drier (HadGEM2)	2030: Warmer & little change in annual rainfall (MPI-ESM)	2030: Warmer & wetter (GFDL-CM3)
Annual pasture production (P1) (sum)	kg/ha	8234	6706	7340	7922
Minimum total herbage mass (P1) (min)	kg/ha	2016	1438	1584	1802
Ground cover (P1) (min)	m^2/m^2	0.81	0.67	0.69	0.73
Drainage below rooting zone (P1) (sum)	Mm	55	38	76	85
Methane production - main group (sum)	g/head	69670	66003	64917	66304
Methane production - young stock (sum)	g/head	43642	40897	40363	41507

A stocking rate of 0.7 was used to enable comparison of the production parameters between different climate cases.

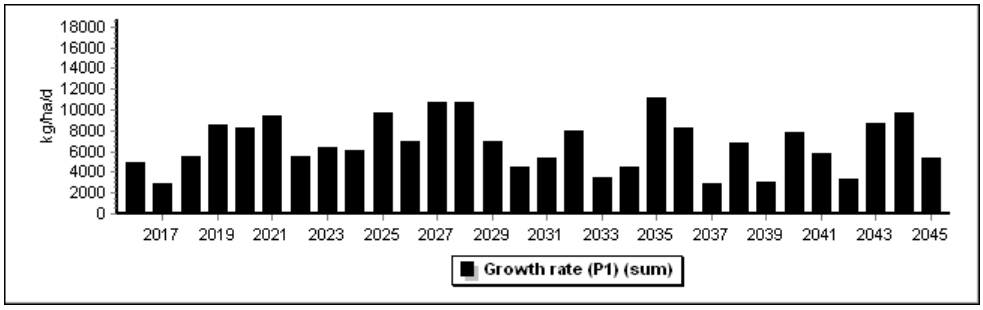
Source: Shilpakar and Graham 2015.

Figure 11. Net primary productivity (NPP) of pasture (total annual shoot growth in kg DM/ha/y) at Tamworth

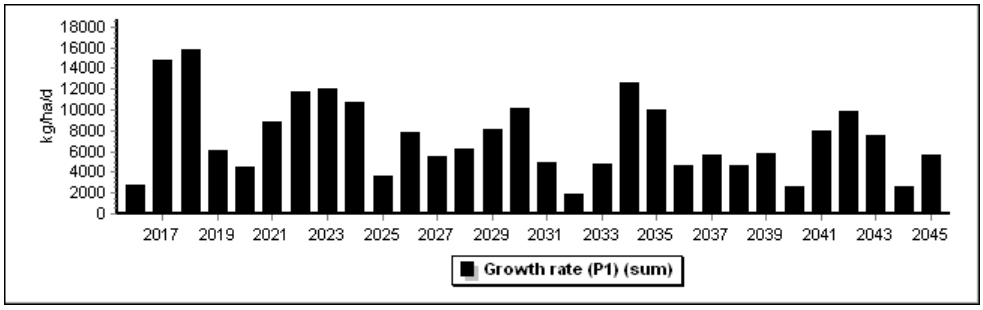
(a)



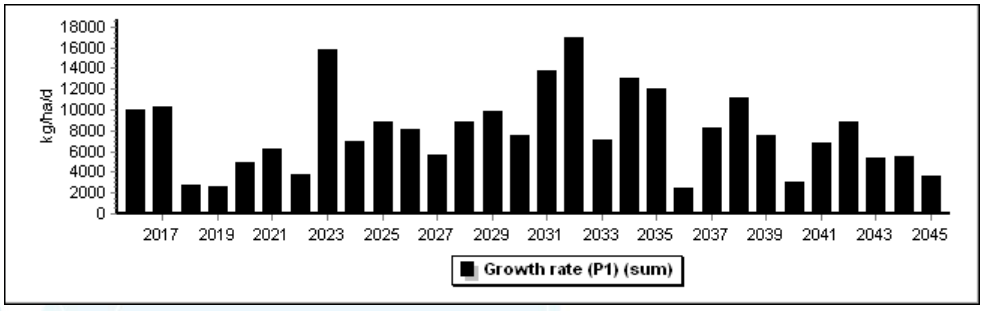
(b)



(c)

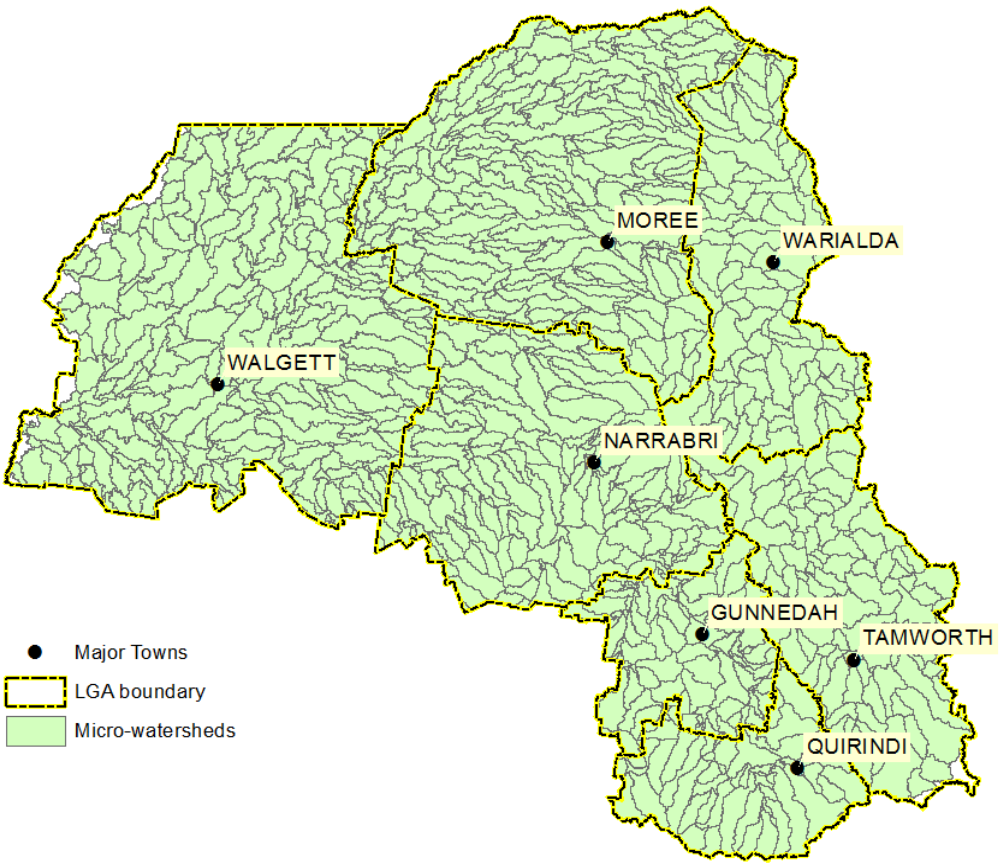


(d)



This figure shows (a) historical climate, (b) 2030: Warmer and drier (HadGEM2), (c) 2030: Warmer and little change in annual rainfall (MPI-ESM), (d) 2030: Warmer and wetter (GFDL-CM3). A stocking rate of 0.7 was used for comparison.

Figure 12. Micro-catchments of North West LLS region



Data credits: Land Management sub-project of Central Slopes cluster project, USQ.

Surface run-off and sediment yields were estimated as each of these micro-catchments using SWAT model.

Source: Apan and Espada 2015.

Table 13. Annual summary of surface run-off and sediment yields across the Central Slopes cluster region under the historical climate (1979–2010) and projected near future climate centre on 2030 under the medium emission scenarios (A1B emission scenario from CMIP3) represented by ECHAN5 global circulation model

Year	Historical climate (1979-2010)		Projected near future climate centre on 2030	
	Surface Run-Off (mm)	Sediment Yield (tons/ha)	Surface Run-Off (mm)	Sediment Yield (tons/ha)
1	9.10	0.09	24.83	0.18
2	7.57	0.03	6.92	0.03
3	12.75	0.06	12.34	0.04
4	21.33	0.09	36.20	0.17
5	16.35	0.07	13.19	0.04
6	4.24	0.02	6.86	0.04
7	14.58	0.04	14.17	0.05
8	32.56	0.14	17.98	0.12
9	24.49	0.06	17.25	0.05
10	105.62	0.32	65.74	0.21
Mean	**24.86**	**0.09**	**21.55**	**0.09**

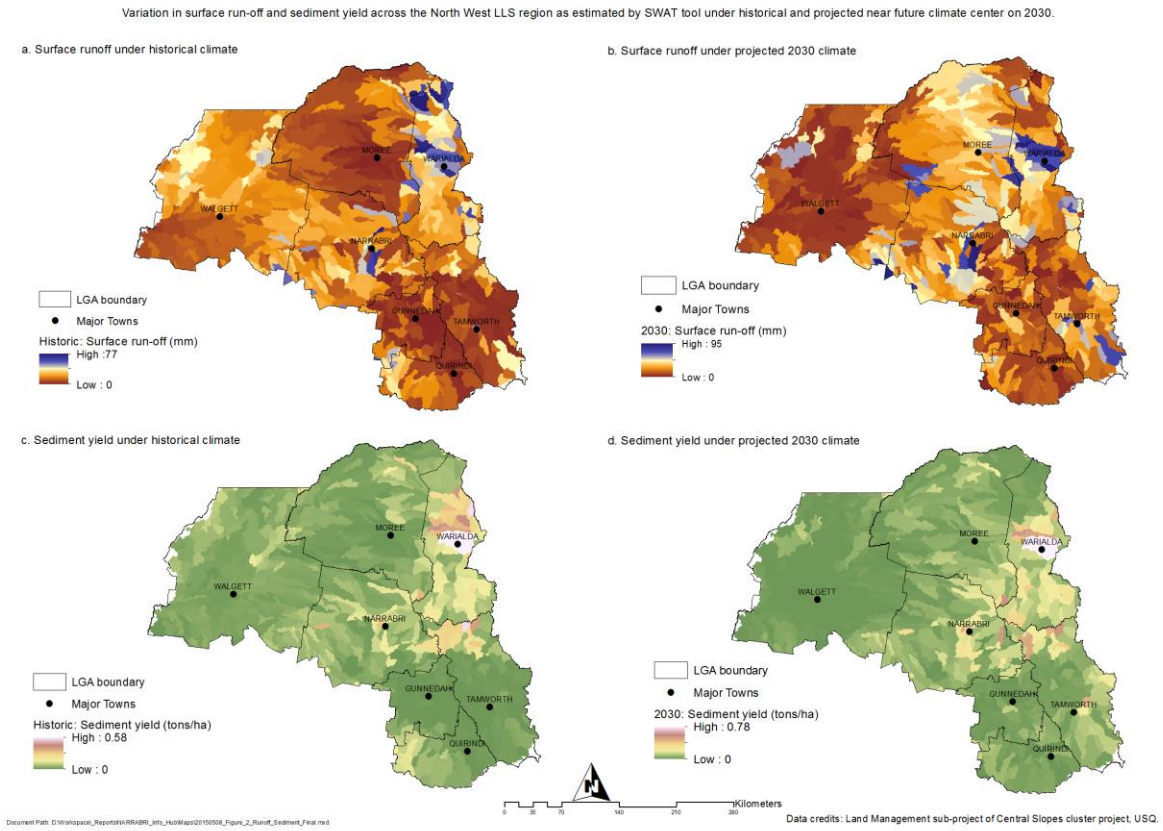
Similarly, indicative impacts of climate change in surface runoff and sediment yields across North West LLS region are presented as Figure 43 and summarised in Table 22. Only long-term average values are presented here for the North West LLS region as individual year results are not compiled at LLS level (personal communication with Prof Armando Apan, USQ).

Table 14. Long-term average annual run-off and sediment yields across the North West LLS region estimated by SWAT tool under the historical climate (1979–2010) and projected near future climate centre on 2030 under the medium emission scenarios (A1B of CMIP3) represented by ECHAN5 global circulation model.

Variable	Historical climate (1979-2010)	Projected near future climate centre on 2030
Surface run-off (mm)	15.4 (0 to 77)	17.6 (0 to 95)
Sediment yield (tons/ha)	0.04 (0 to 0.58)	0.05 (0 to 0.78)

Values inside the brackets represent range across North West region.

Figure 13. Surface run-off and sediment yields across the North West LLS region



Run-off and sediment yields are estimated by SWAT model under the historical climate (1979–2010) and projected near future climate centre on 2030 under the medium emission scenarios (A1B from CMIP3) represented by ECHAN5 global circulation model.

Data credits: Apan and Espada 2015.

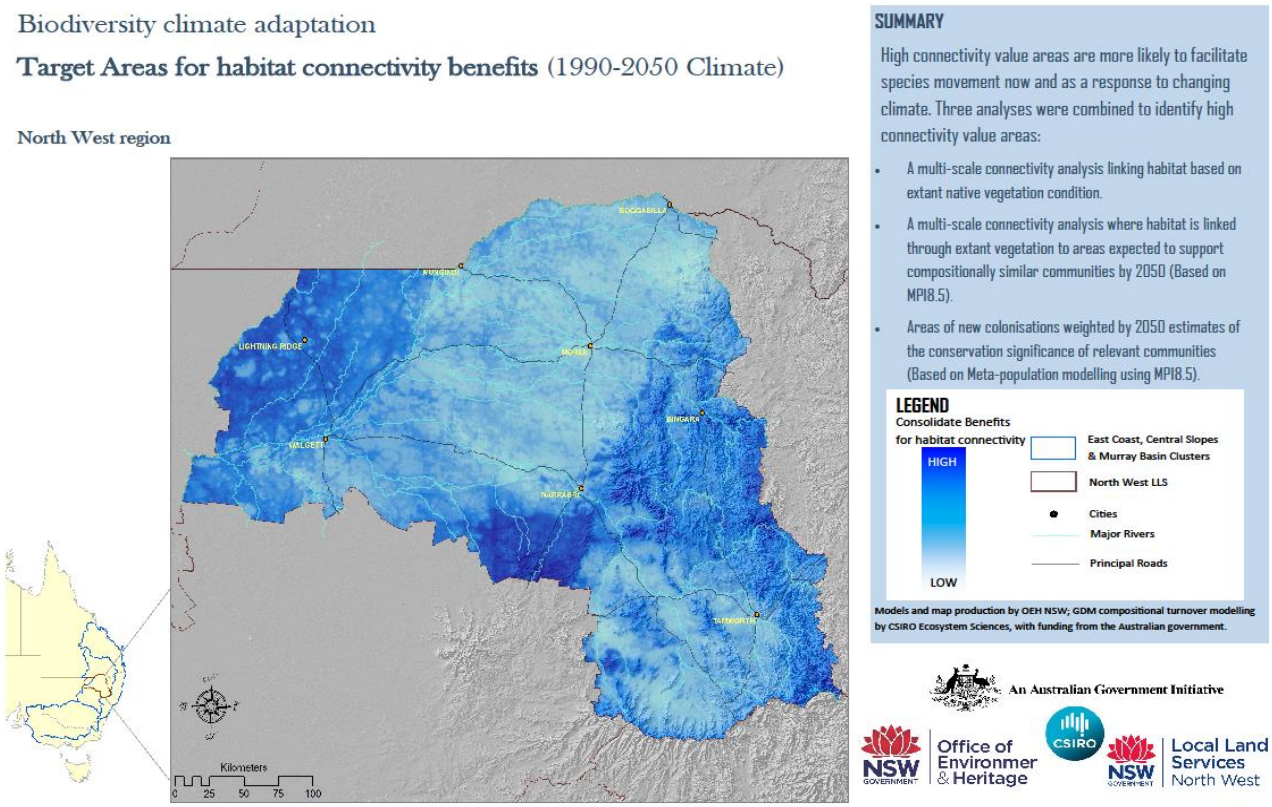
Appendix 3. Effect of climate change on biodiversity

Table 1. Potential ecological change for different biodiversity dimensions

Dimension of biodiversity	Scenarios of ecological change
Species outcomes	• In situ adaptation: Species either unaffected, cope, adapt in situ, adapt locally (within their existing distributions), evolve, possibly with reduced abundance and range • Extinction: Can't adapt, leading to extinctions • Regional shifts: Species disperse and establish at new sites matching their regional bioclimatic habitat, possibly declining in areas of pre-climate change distribution • Coping with new species: Species colonise from elsewhere, some altering habitat and species interactions, altering the realised niche of resident species; possibly contributing to reductions in the abundance and range of resident species.
Ecosystem outcomes	• Change in composition: Loss of species and establishment of new species; potentially reducing local species richness and diversity; structure and function may or may not change significantly • Change in structure: Changes in the relative abundance or dominance of species lead to change in habitat structure; potentially resulting in a simplification of habitat; may or may not include changes in composition and function • Change in function: Changes (loss) in new primary productivity; for example, as a consequence of change in function due to changes in environmental potential or abundance of producer species and food-web interactions; productivity possibly below its potential.
Landscape outcomes	• Change in type of ecosystems and land/water uses: Changes in land, water, sea uses and changes in types and functioning of ecosystem, but not necessarily the net balance; potentially including loss of particular ecosystems or services • Intensification of land/sea use: Less hospitable matrix for species and ecosystems as land uses intensify and agro-ecosystems expand; may happen rapidly in response to technology and climate adaptation opportunities; likely to include loss and degradation of supporting habitat for species and ecosystems • Expansion of land/sea use: Potentially more hospitable matrix and reduction in extent and intensity of land, water and sea uses in response to decreased productivity of fisheries, grazing, cropping systems etc.; reduced water availability, potentially leading to increased habitat availability for native biodiversity, but land abandonment may be preceded by degradation.

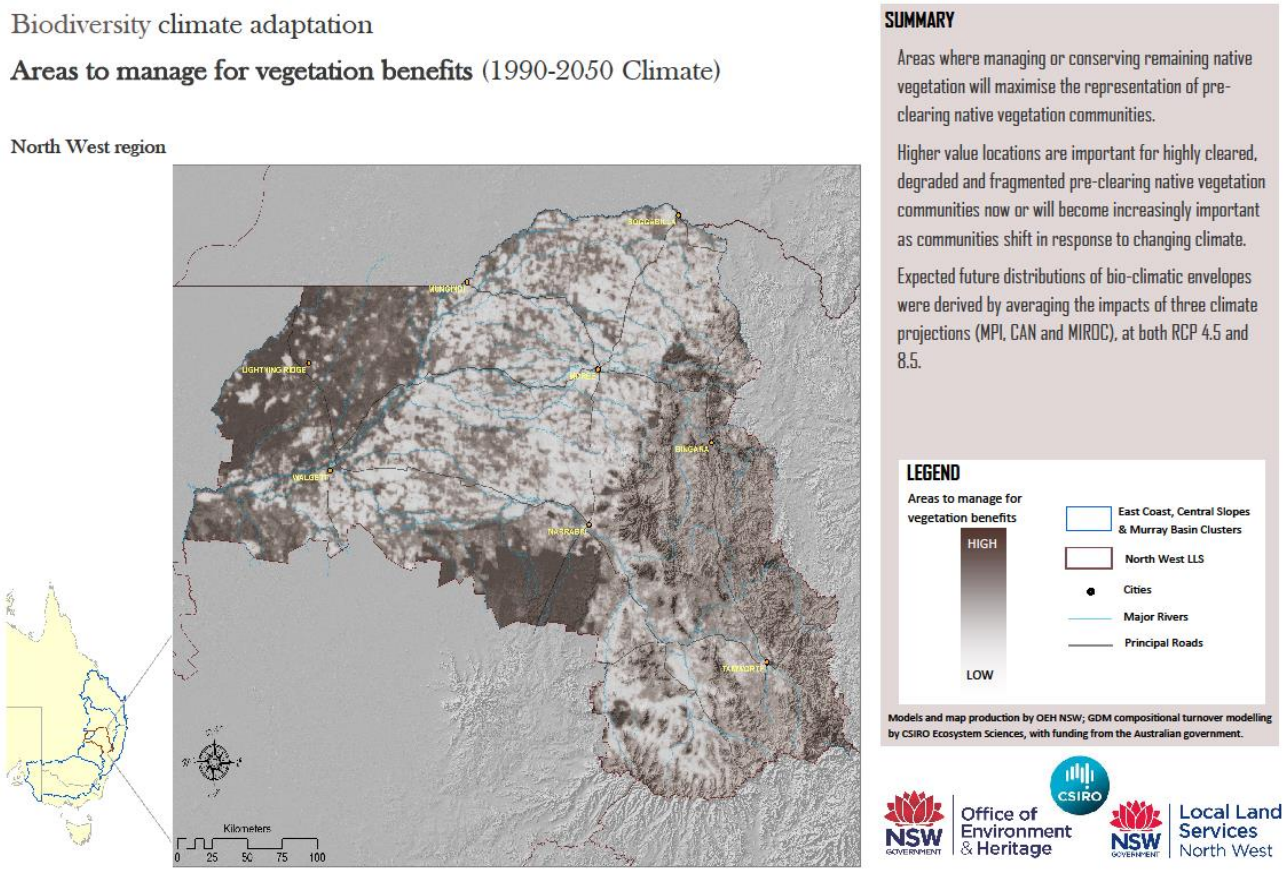
Source: Dunlop et al. 2013.

Figure 1. Target areas for habitat connectivity benefits



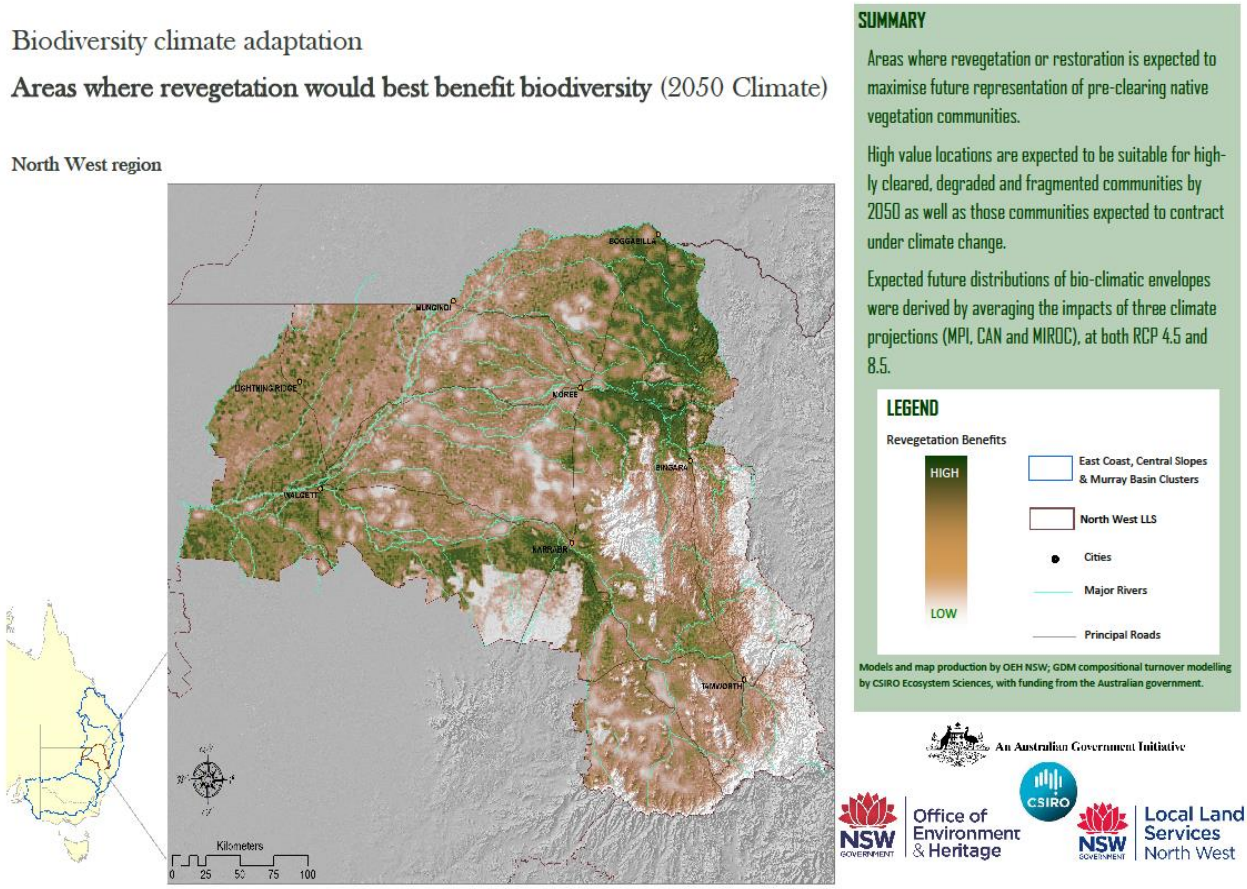
Source: Drielsma et al. 2014.

Figure 2. Areas to manage for vegetation benefits



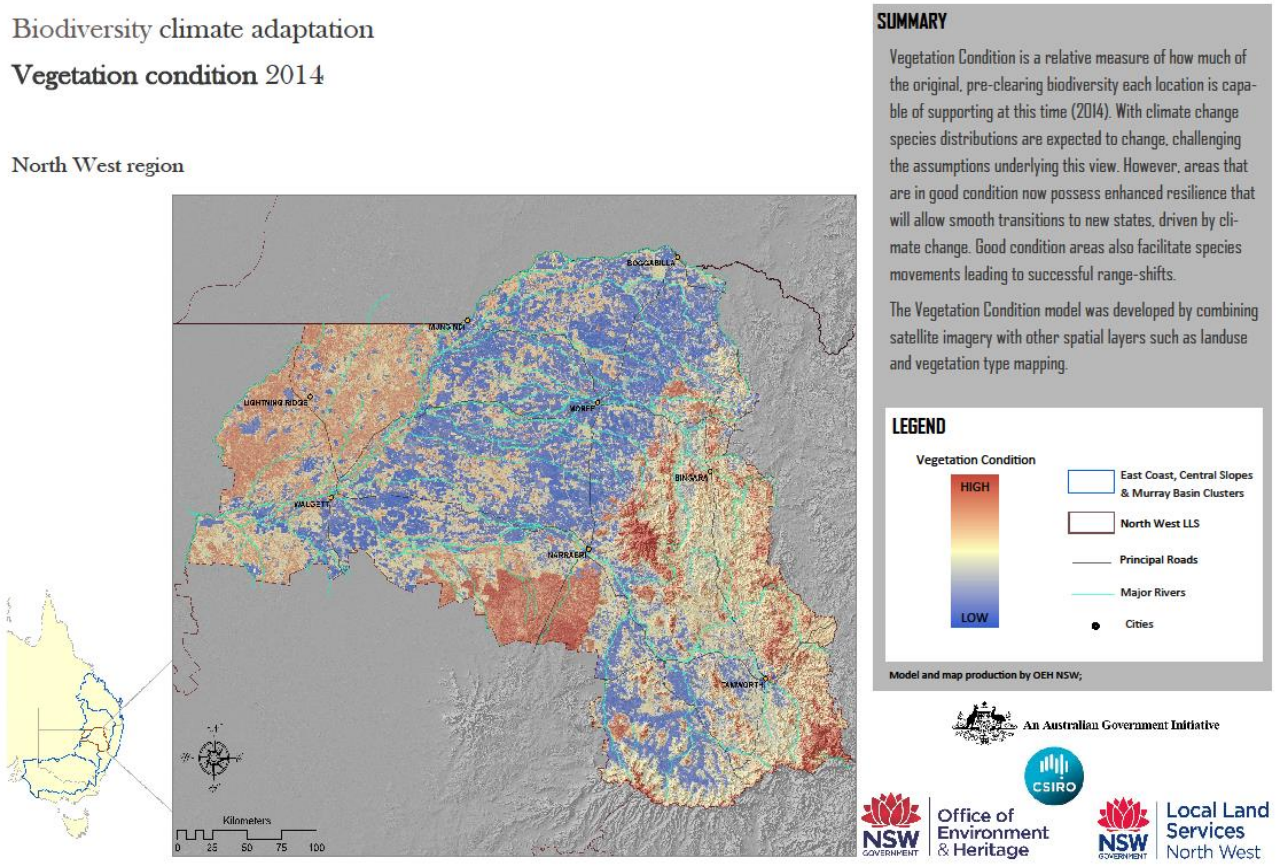
Source: Drielsma et al. 2014.

Figure 3. Areas where vegetation would best benefit biodiversity



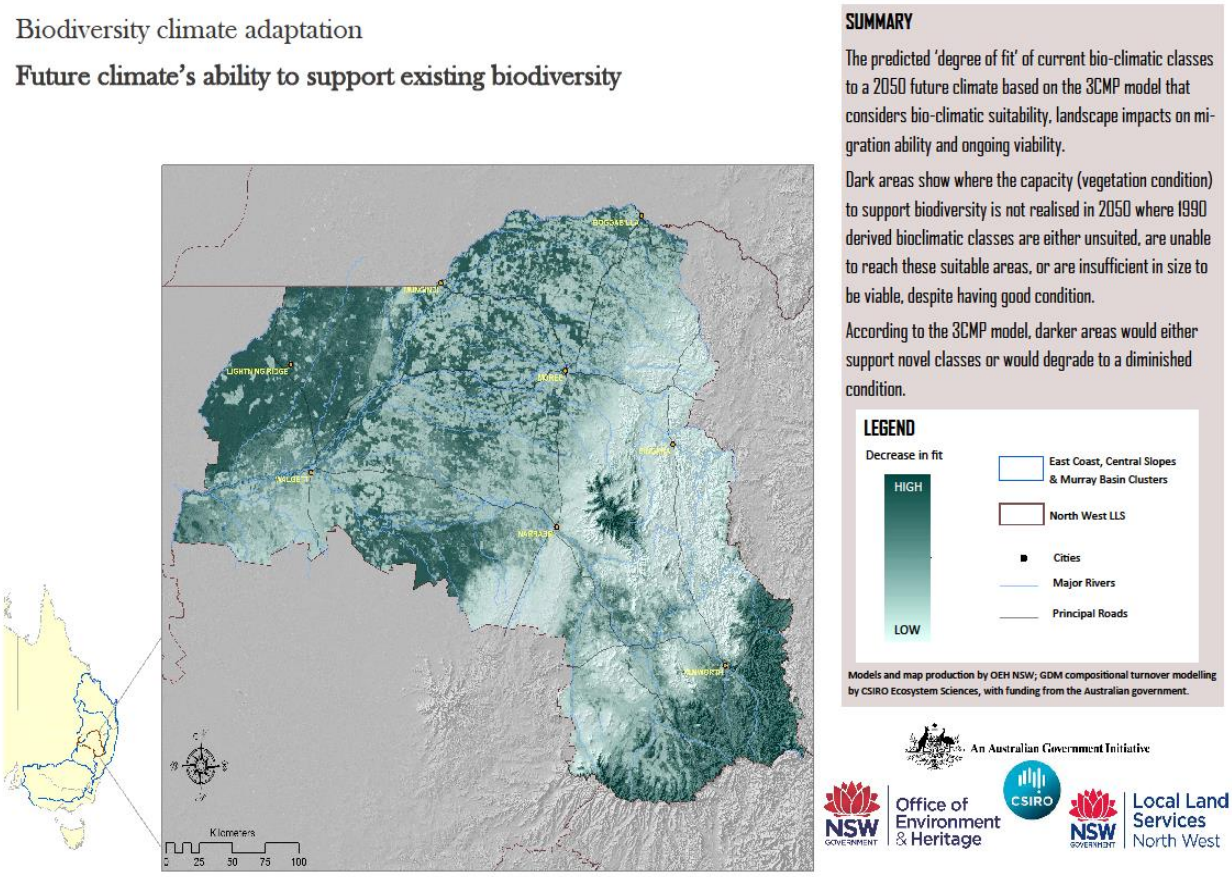
Source: Drielsma et al. 2014.

Figure 4. Vegetation condition 2014



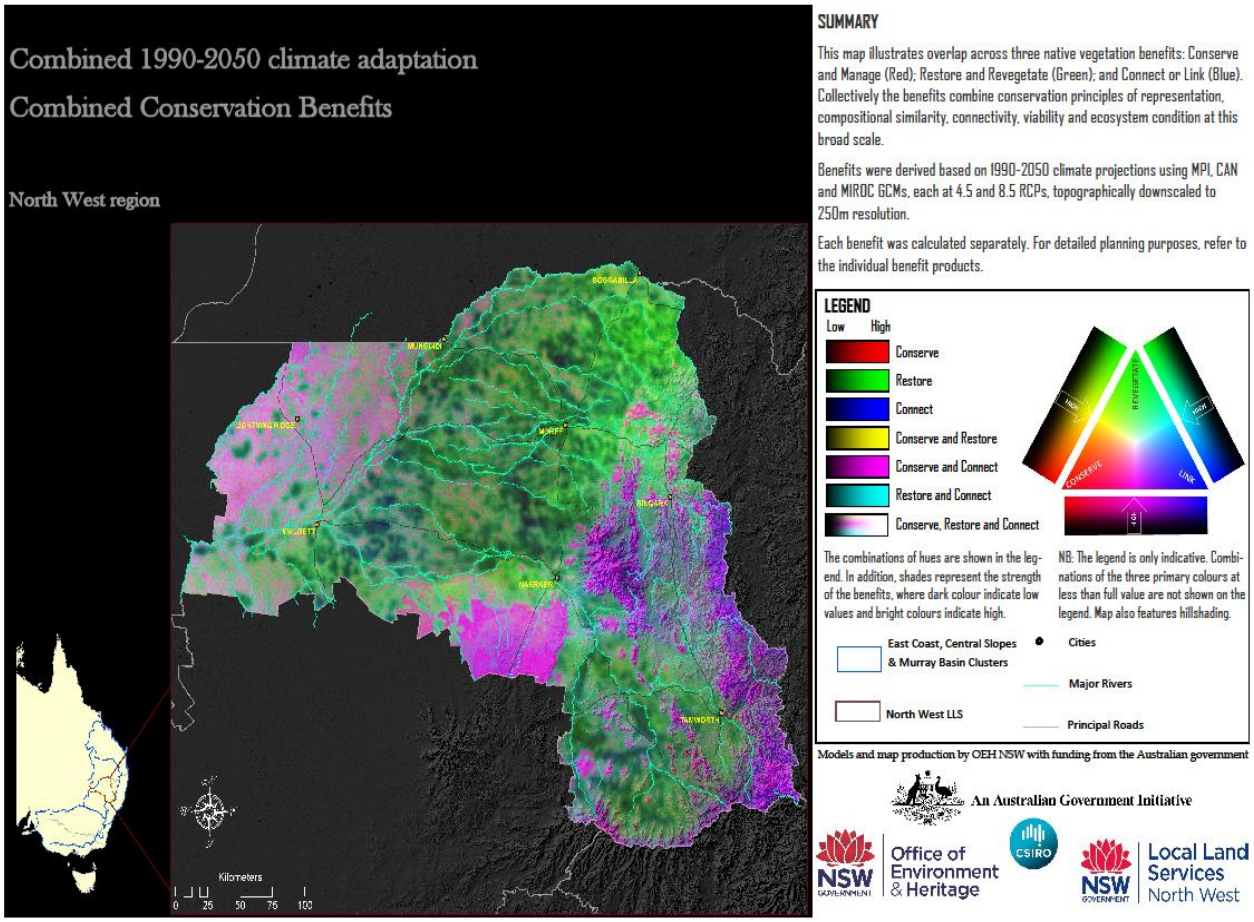
Source: Drielsma et al. 2014.

Figure 5. Future climate's ability to support existing biodiversity



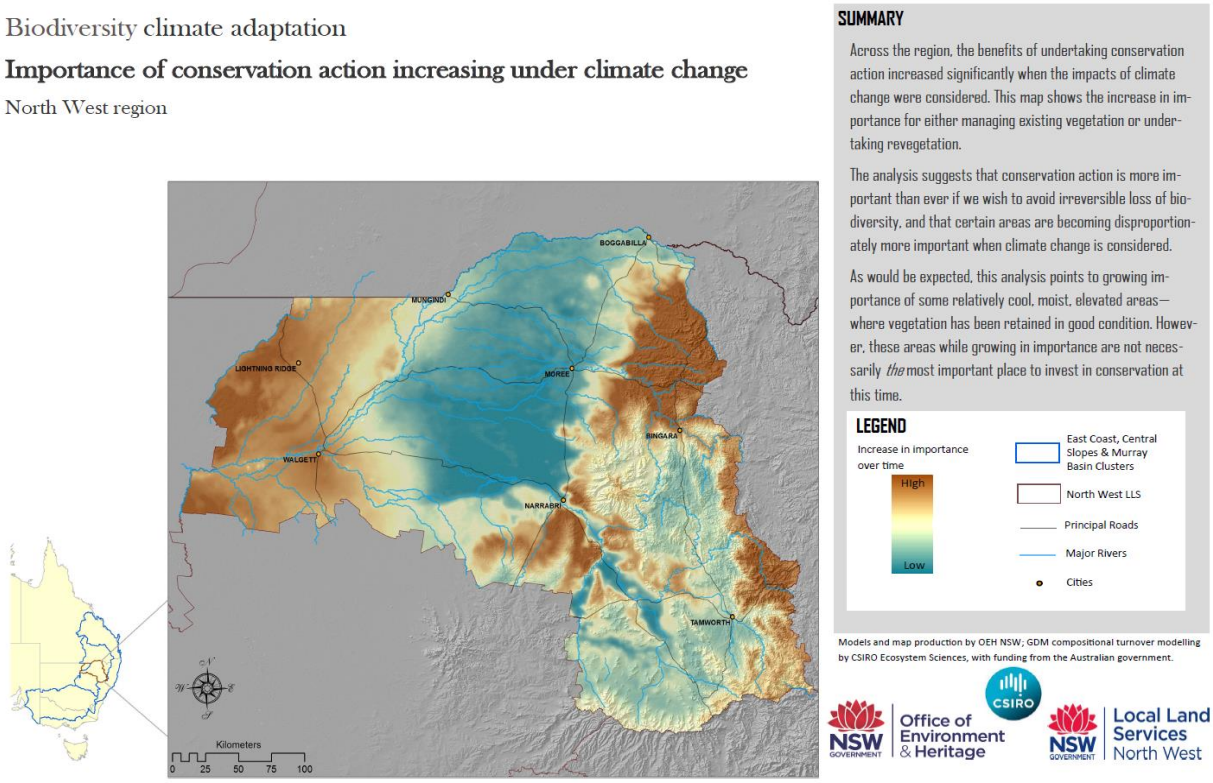
Source: Drielsma et al. 2014.

Figure 6. Combined conservation benefits



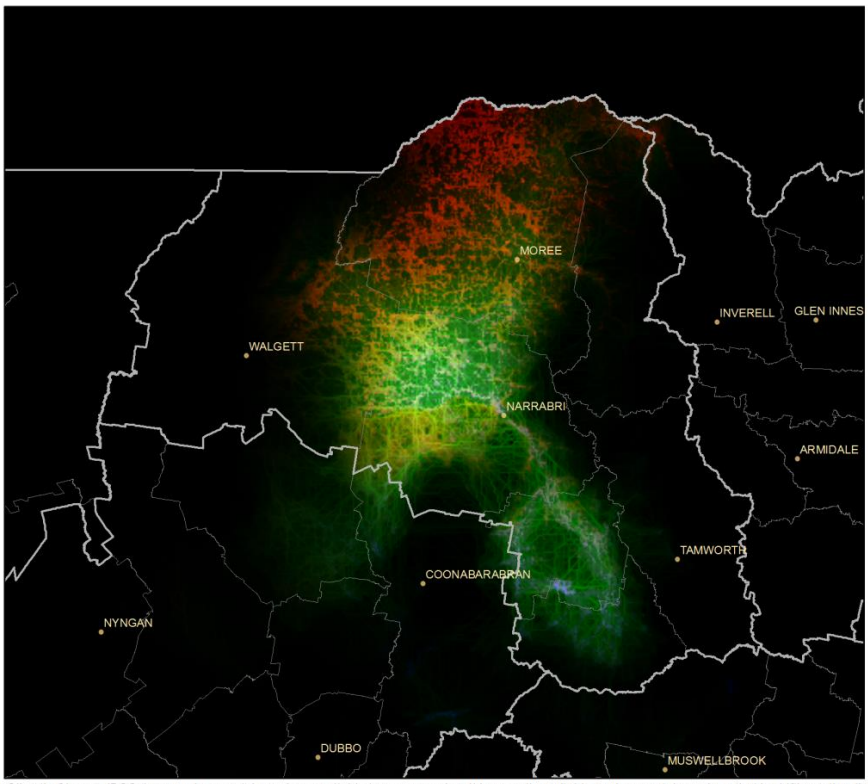
Source: Drielsma et al. 2014.

Figure 7. Importance of conservation action increasing under climate change



Source: Drielsma et al. 2014.

Figure 8. Example of shifting and shrinking bio-climatic classes for North West LLS region



Bio-Climatic Class 16 Distribution Shift

Example output from 3CMP analysis showing predicted distribution shift for one BCC from 1990 to 2050.

The pyramid legend indicates the range of combinations within the combined 1990-2050 envelopes.

Red indicates occupancy in 1990;

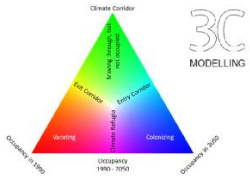
Blue indicates occupancy in 2050;

Green are areas used for migration (but not settled).

Other colours indicate combinations eg:

Pink (red + blue), occupied 1990 and 2050;

White (red + blue + green), occupied throughout and used for migration



3C MODELLING

Local Land Service Regions

Local Government Areas

Major Towns

Bio-Climatic Classes (BCCs) are environmental envelopes suitable to many species. It is more the suitable environmental envelope that is shifting rather than the species themselves. Species may shift in response to changes in bio-climatic envelopes where the ecological capacity to support this is realised. Species are also shared across BCCs, as an areas transitions from one BCC to another it may remain suitable for many existing species. It's those species that are less tolerant to the new climate or those already at the edge of their range that are most likely to shift or disappear.

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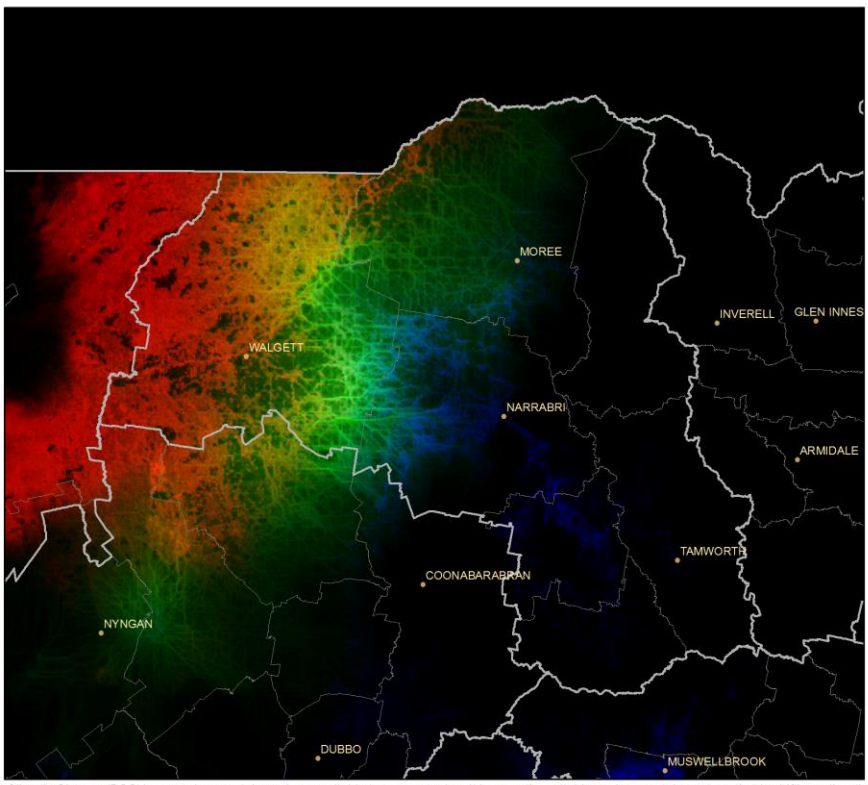

Bio-Climatic Class 61 Distribution Shift

Example output from 3CMP analysis showing predicted distribution shift for one BCC from 1990 to 2050.

The pyramid legend indicates the range of combinations within the combined 1990-2050 envelopes.

Red indicates occupancy in 1990;

Blue indicates occupancy in 2050;

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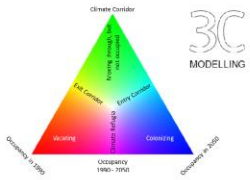

3C MODELLING

Local Land Service Regions

Local Government Areas

Major Towns

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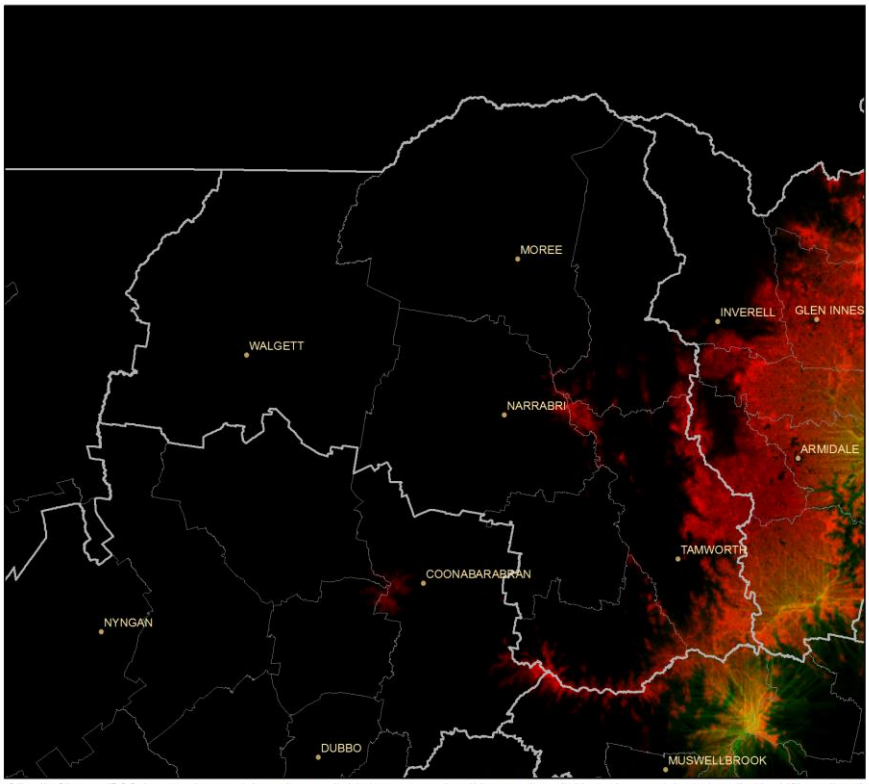
Data credit: Drielsma et al. 2014.

Figure 9. Examples of disappearing bio-climatic classes for North West LLS region



Bio-Climatic Class 21 Distribution Shift

Example output from 3CMP analysis showing predicted distribution shift for one BCC from 1990 to 2050.

The pyramid legend indicates the range of combinations within the combined 1990-2050 envelopes.

Red indicates occupancy in 1990;

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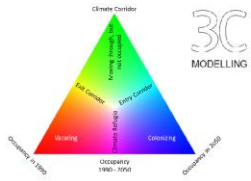

Local Land Service Regions

Local Government Areas

Major Towns

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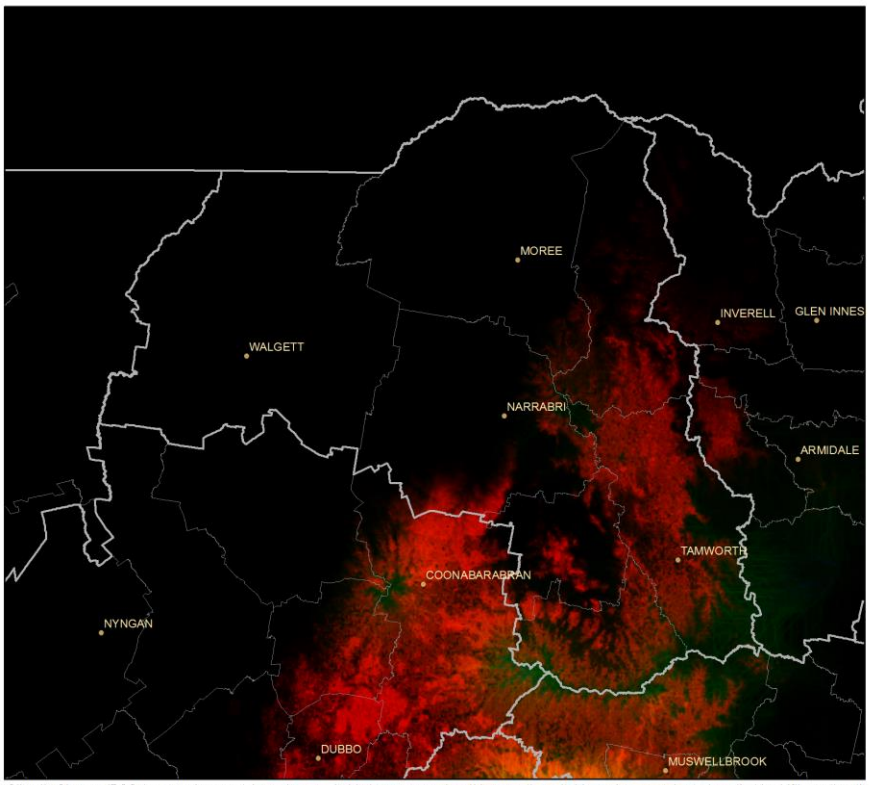

Bio-Climatic Class 25 Distribution Shift

Example output from 3CMP analysis showing predicted distribution shift for one BCC from 1990 to 2050.

The pyramid legend indicates the range of combinations within the combined 1990-2050 envelopes.

Red indicates occupancy in 1990;

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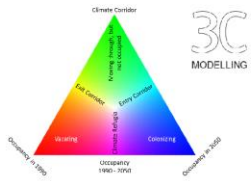

Local Land Service Regions

Local Government Areas

Major Towns

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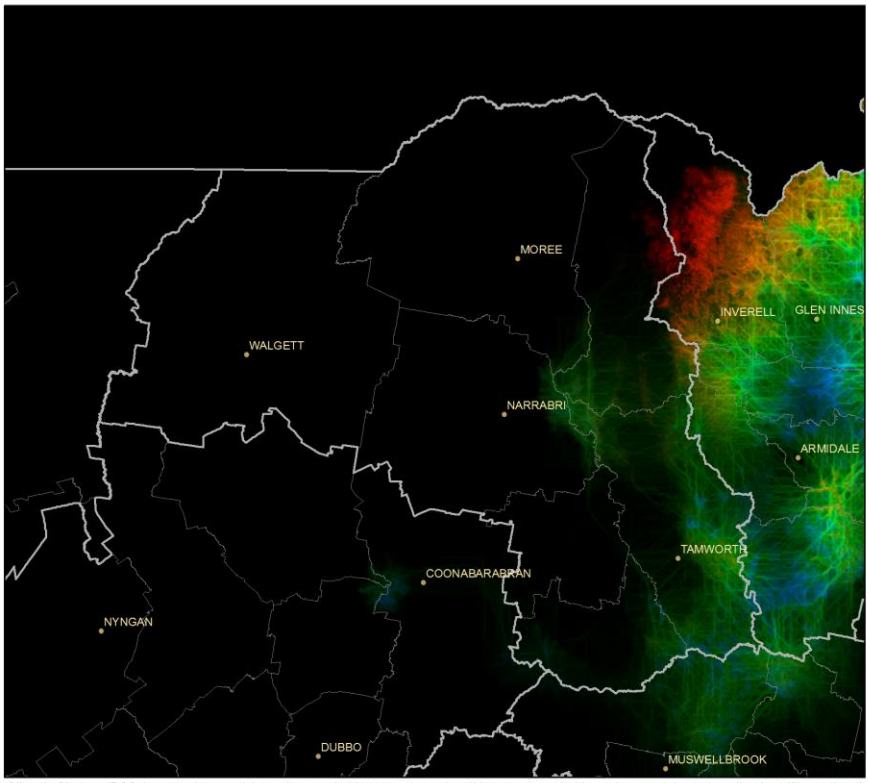

Bio-Climatic Class 28 Distribution Shift

Example output from 3CMP analysis showing predicted distribution shift for one BCC from 1990 to 2050.

The pyramid legend indicates the range of combinations within the combined 1990-2050 envelopes.

Red indicates occupancy in 1990;

Blue indicates occupancy in 2050;

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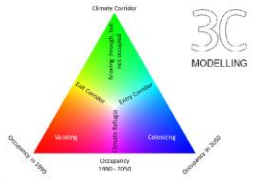

Local Land Service Regions

Local Government Areas

Major Towns

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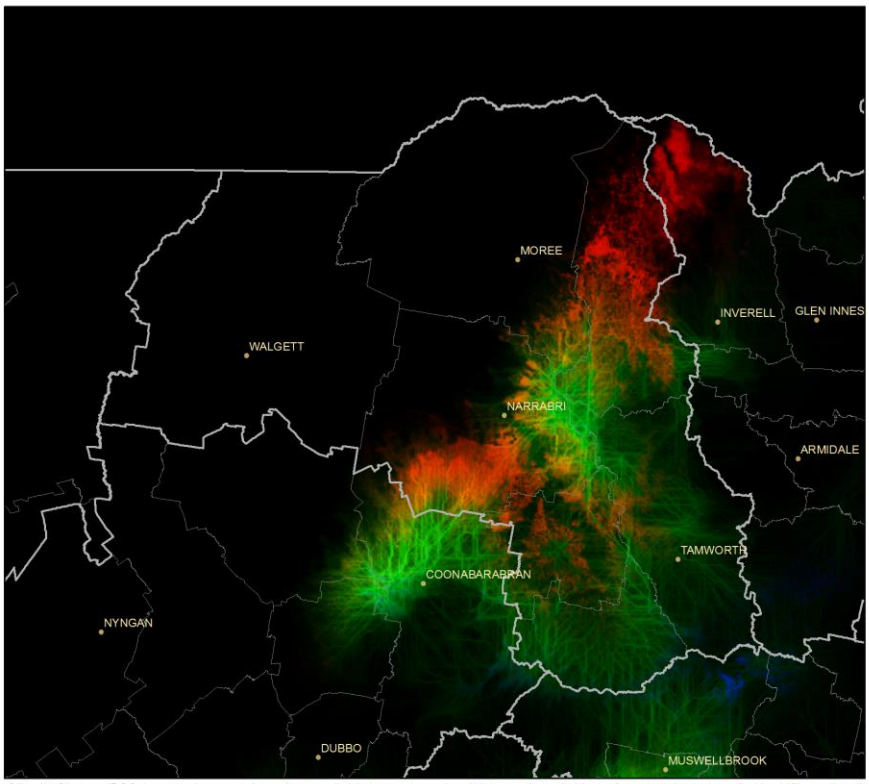

Bio-Climatic Class 71 Distribution Shift

Example output from 3CMP analysis showing predicted distribution shift for one BCC from 1990 to 2050.

The pyramid legend indicates the range of combinations within the combined 1990-2050 envelopes.

Red indicates occupancy in 1990;

Blue indicates occupancy in 2050;

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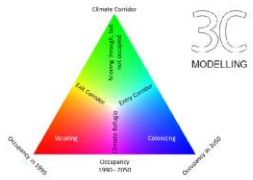

Local Land Service Regions

Local Government Areas

Major Towns

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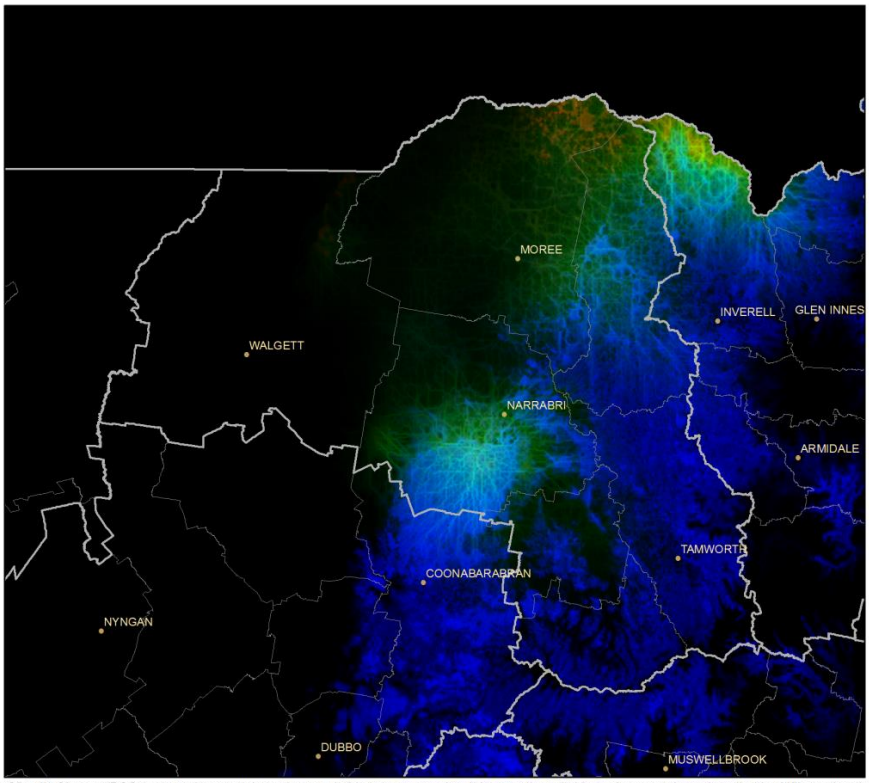
Data credit: Drielsma et al. 2014.

Figure 10. Examples of emerging bio-climatic class for North West LLS region



Bio-Climatic Class 18 Distribution Shift

Example output from 3CMP analysis showing predicted distribution shift for one BCC from 1990 to 2050.

The pyramid legend indicates the range of combinations within the combined 1990-2050 envelopes.

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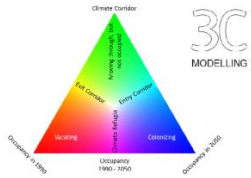

Local Land Service Regions

Local Government Areas

Major Towns

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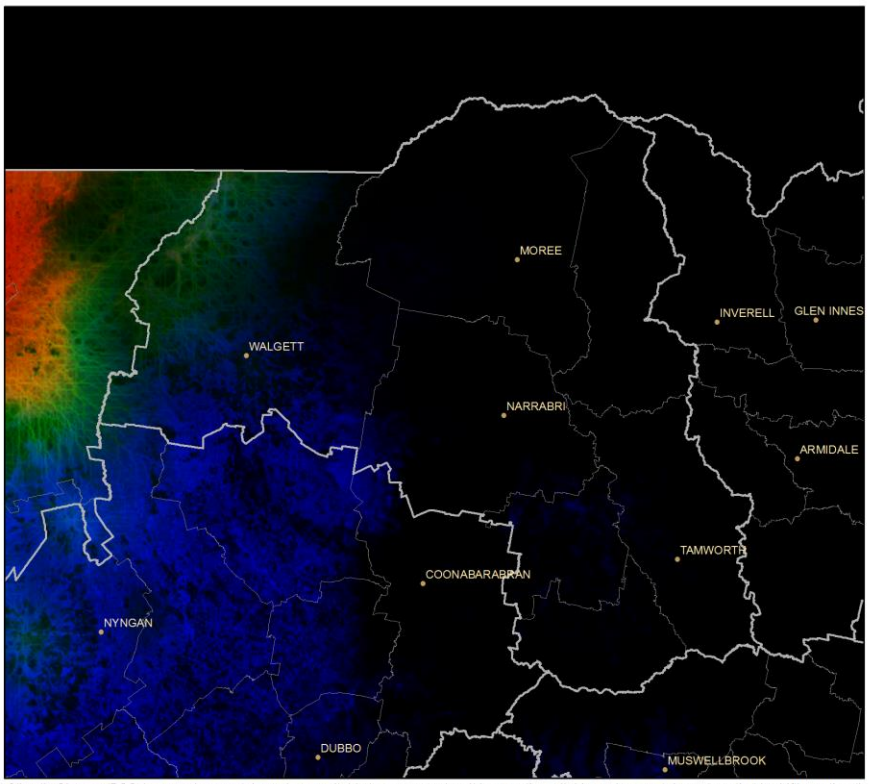

Bio-Climatic Class 37 Distribution Shift

Example output from 3CMP analysis showing predicted distribution shift for one BCC from 1990 to 2050.

The pyramid legend indicates the range of combinations within the combined 1990-2050 envelopes.

Red indicates occupancy in 1990;

Blue indicates occupancy in 2050;

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Other colours indicate combinations eg:

Pink (red + blue), occupied 1990 and 2050;

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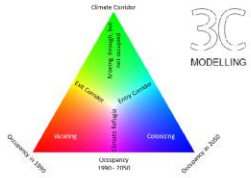

Local Land Service Regions

Local Government Areas

Major Towns

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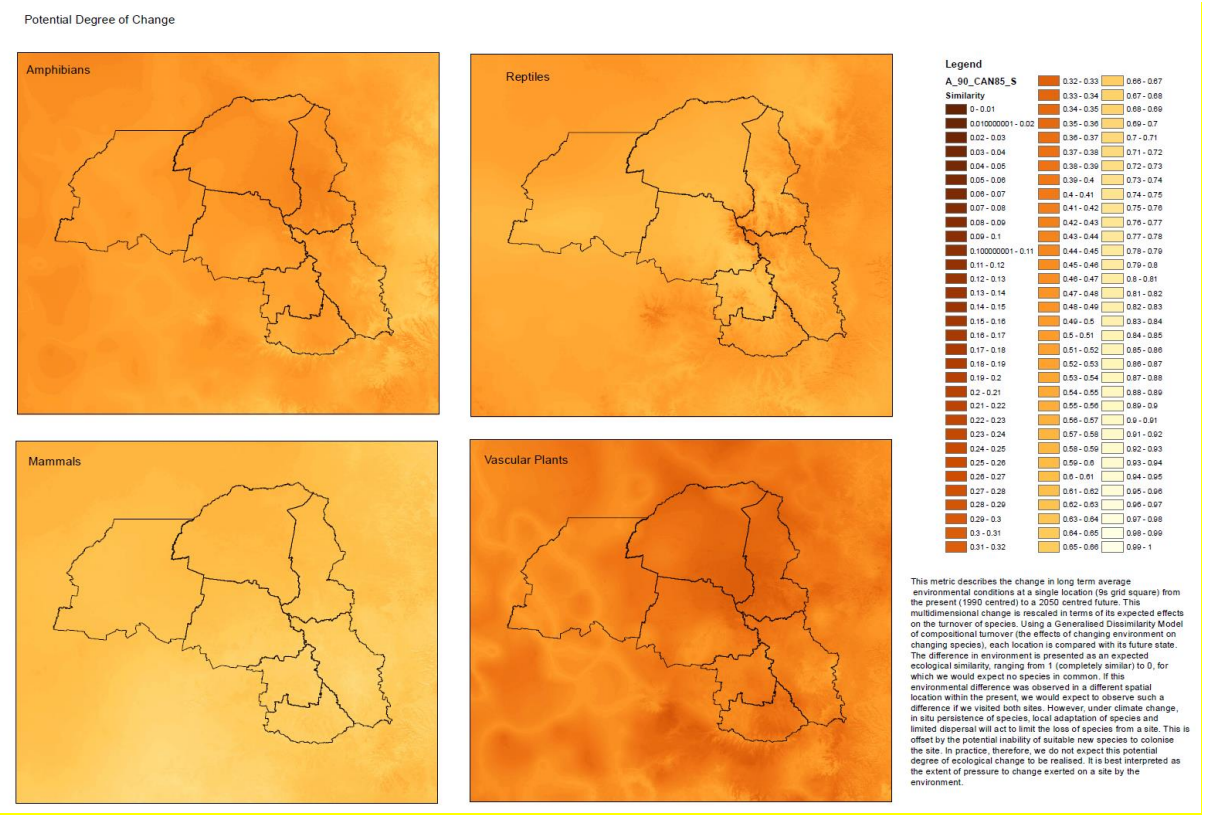
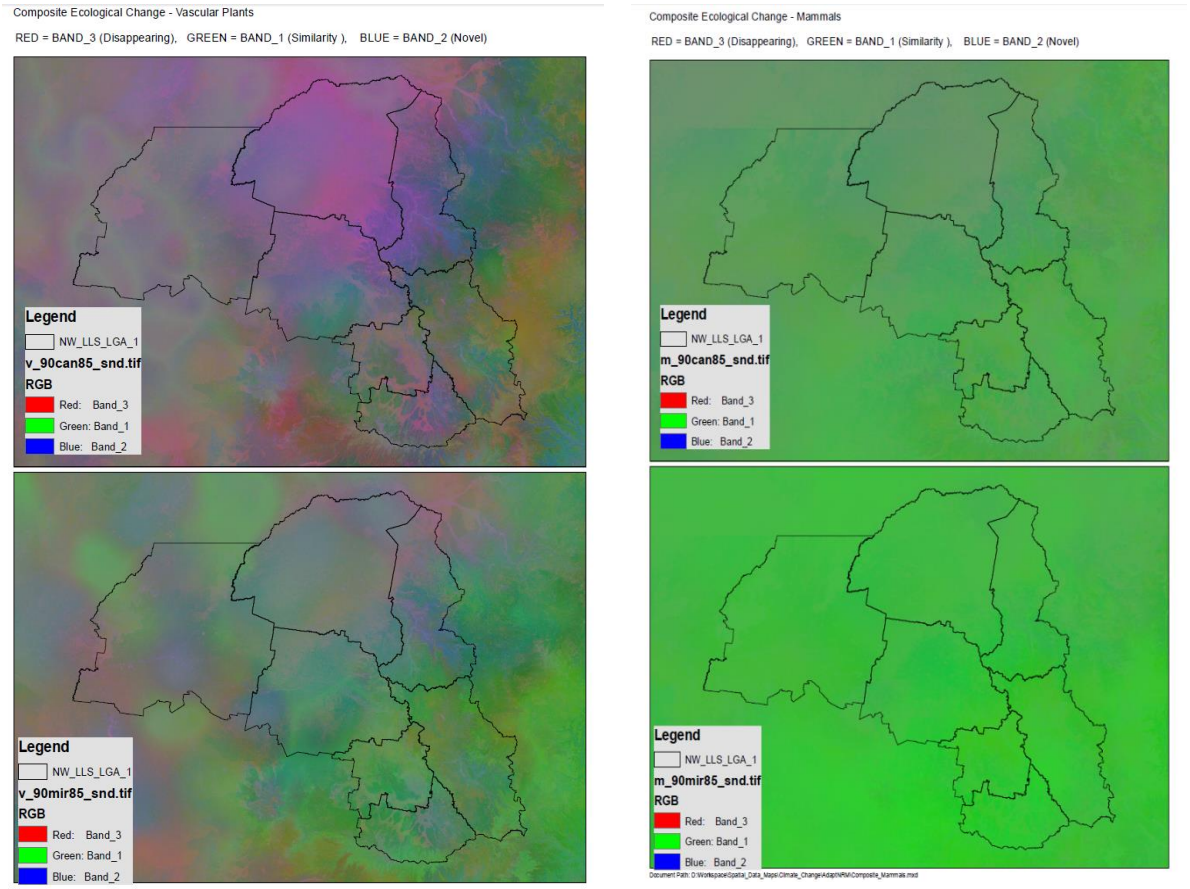
Data credit: Drielsma et al. 2014.

Figure 11. Potential degree of change – vascular plants, amphibians, reptiles and mammals (CANESM2) for North West LLS region



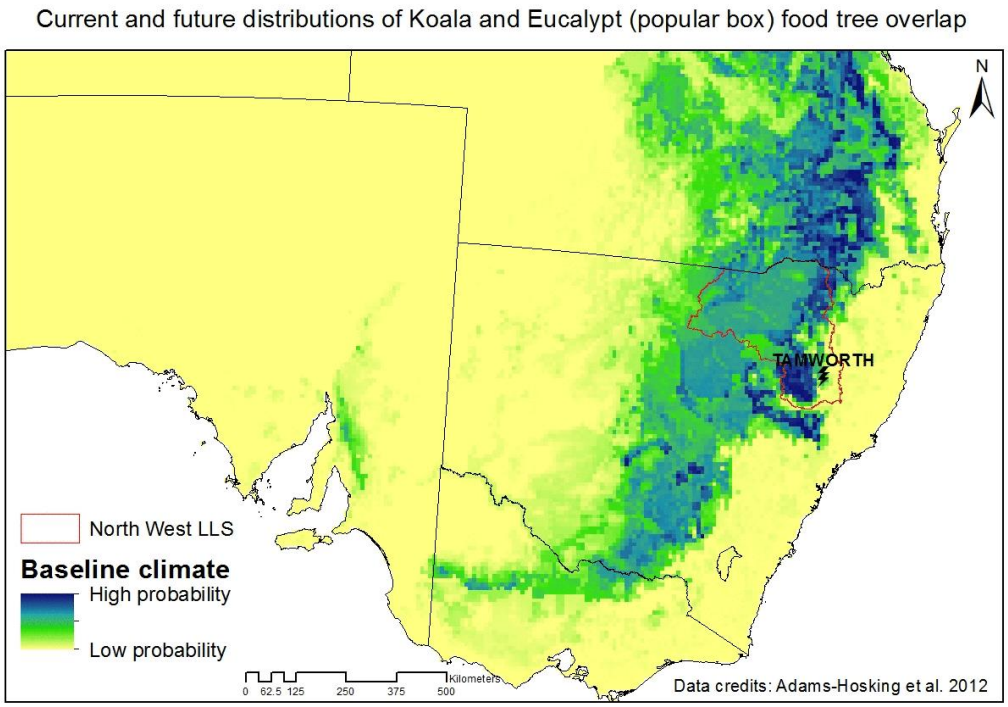
Source: Williams et al. 2014 and Prober et al. 2015.

Figure 12. Composite ecological change for vascular plants and mammals for MIROC5 and CANESM2 climate scenarios for North West LLS region



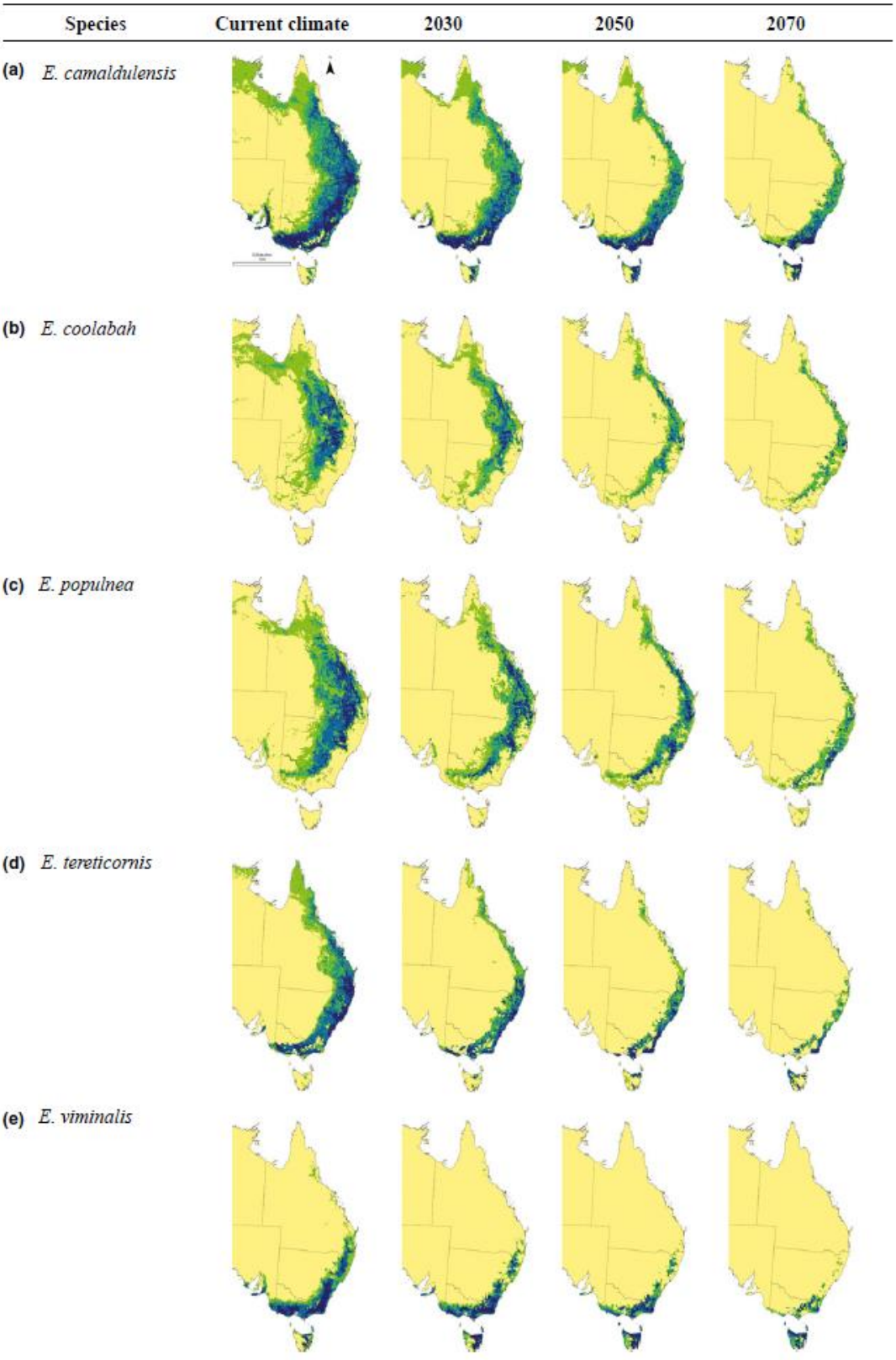
Source: Williams et al. 2014 and Prober et al. 2015.

Figure 13. Current and future distributions of koala and eucalypt (poplar box) food tree overlap



Data credit: Adams-Hosking et al. 2012.

Figure 14. Koala distribution and five koala fodder tree distribution under climate change scenarios



Adapted from Adams-Hosking et al. 2012.

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