RANGELANDS
NRM CLUSTER

CLIMATE CHANGE IN AUSTRALIA

IMPACTS & ADAPTATION INFORMATION
FOR AUSTRALIA'S NRM REGIONS

IT'S HOT AND GETTING HOTTER:

AUSTRALIAN RANGELANDS AND CLIMATE CHANGE – REPORTS OF THE RANGELANDS CLUSTER PROJECT

Citation

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Executive summary

In 2012, the Australian Government established the regional Natural Resource Management Planning for Climate Change Fund, with the aim of improving the capacity of regional natural resource management (NRM) organisations to plan for climate change. The fund included regional-level planning support (Stream 1) as well as a series of research projects (Stream 2) to provide regional-level climate change information and projections. Stream 2 has been delivered via the National Projections Project and eight regional cluster projects (shown on the map below). The Rangelands Cluster is the largest of the clusters and includes seven NRM regions across five jurisdictions.

The Rangelands Cluster Project was a collaboration between the Rangelands NRM Alliance, CSIRO, University of Canberra and Ninti One. The Rangelands NRM Alliance represents seven NRM regions: Rangelands WA, Territory NRM, Alinytjara Wilurara NRM (SA), SA Arid Lands NRM, Desert Channels Qld, South West NRM (Qld) and Western Local Lands Services.

To agree on priorities for information to support NRM planning across the rangelands, a range of consultation and engagement methods were used, including face-to-face meetings, workshops, surveys and establishment of a reference group and scientific advisory panel. Through these processes, a series of priorities were identified. Relevant information was gathered, collated and interpreted to produce a report on each topic.

All the reports have also been compiled and form chapters in this document. The key points from each report are included in this Executive Summary. The URLs for the full reports are included under each section.

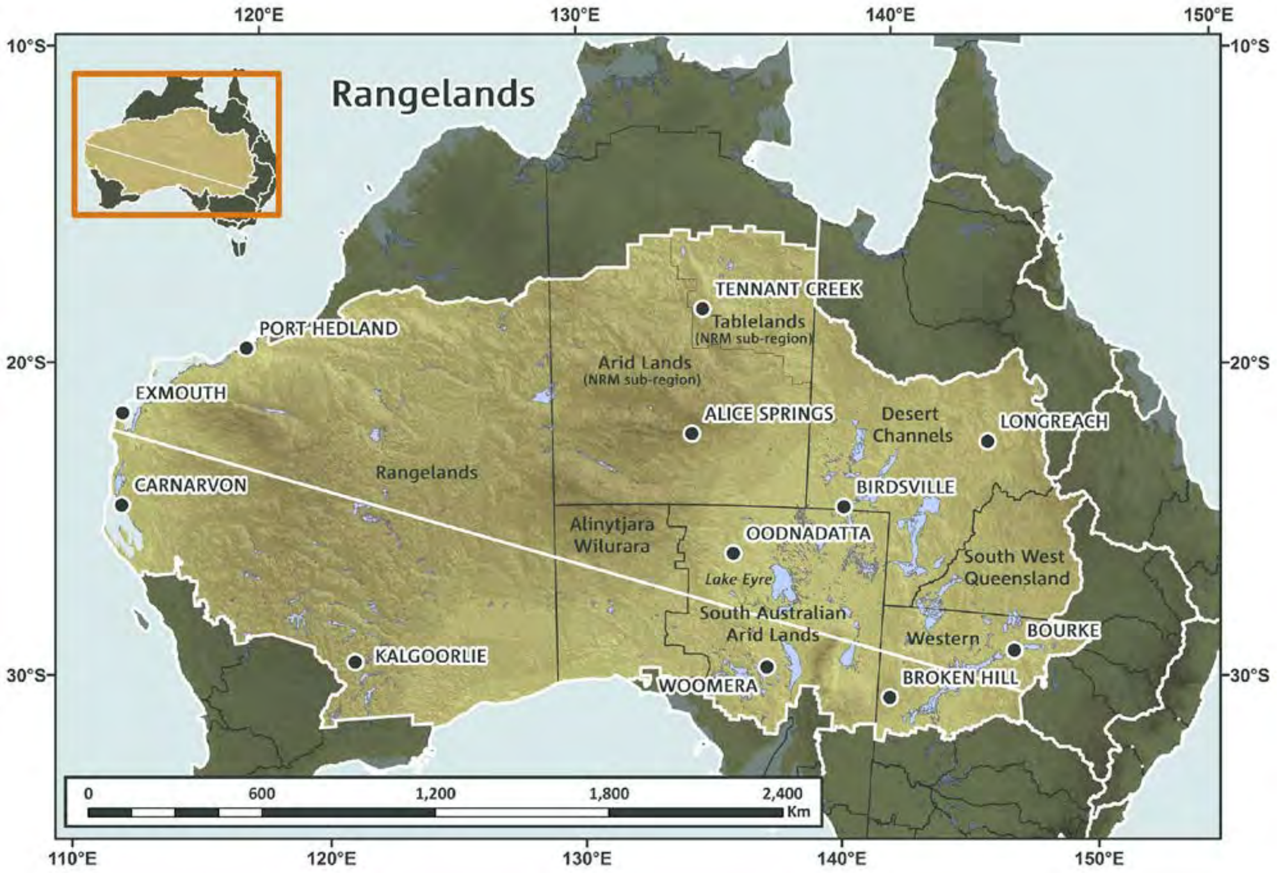
Map showing the eight regional clusters

Climate projections – Rangelands

The projections for the rangelands in the report are based on the outputs of a set of 40 global climate models (GCMs) developed by Australian and international scientists. Climate models are based on established laws of physics and are rigorously tested for their ability to reproduce past climate. These projections draw on the full breadth of available data and peer-reviewed literature to provide a robust assessment of the potential future climate.

Rainfall systems in the cluster vary from seasonally reliable monsoonal influences in the far north through to very low and variable rainfall patterns in much of the centre and south. Given this, the Rangelands Cluster was divided into Rangelands North and Rangelands South subclusters for the projections work, as shown by the white line bisecting the Rangelands Cluster on the map below.

The table below is a summary of the predicted changes in a range of climate variables within the Rangelands Cluster region by 2090.



Map showing the Rangelands Cluster north–south division

CLIMATE VARIABLE	PROJECTED CHANGE	CONFIDENCE
Temperature	Increase in all seasons	Very high
Extreme temperatures	Increase in hot days and warm spells Decrease in frosts	Very high High
Rainfall variability	Remain high	High
Extreme rainfall events	Increase in intensity	High
Winter and spring rainfall	A decrease in the south likely	High
Summer and autumn rainfall	Trend is unclear	
Drought	Increase over the course of the century	Medium
Potential evapotranspiration	Increase in all seasons	High
Mean sea level	Continue to rise	Very high
Height of extreme sea-level events	Increase	Very high

Website

http://www.climatechangeinaustralia.gov.au/en/regional-climate-change-explorer/super-clusters/?current=RA

Rainfall variability and pasture growth

From a biological perspective, sequences of rainfall can be treated as events, defined here as one or more closely spaced rainfalls that are large enough to produce a significant vegetation response.

For this analysis, >25 mm of rain over consecutive wet days is considered the minimum requirement for pasture growth to occur across much of the Rangelands Cluster region, and a >50 mm event over the same period should provide ideal growing conditions – particularly where grazed land is maintained in good condition. There are exceptions, of course, to this general guide. Smaller events (e.g. as low as 10 mm) may be effective in cooler weather and for specific locations and vegetation types (e.g. new leaf growth in chenopod shrublands on the Nullarbor Plain). At the other end of the scale, degraded rangeland may respond minimally to >50 mm events.

The frequency of probable past pasture growth events based on daily rainfall gives some indication of what lies ahead for the Rangelands Cluster region under the climate change projection of continuing high natural variability in rainfall.

Findings

- The last 60 years of rainfall data show that periods of rainfall suitable for marginal to ideal growing conditions were infrequent throughout much of the Rangelands Cluster region. The median return period (in days) between >25 mm and >50 mm events lengthens for locations with lower and more variable annual rainfall – that is, to the south (Port Augusta, Cook, Kalgoorlie) and towards the more arid interior (Coober Pedy, Marree, Birdsville, Oodnadatta).
- The median return period for >50 mm events is close to one year for the more arid parts of the cluster region.
- Given the highly episodic nature of rainfall across inland Australia, no trends in return period for specific rainfall amounts were detected.

- As part of this work, a template spreadsheet for users to calculate their own return-period statistics for any rainfall amount and location where historic daily rainfall data are available was developed. This tool summarises periods of continuous daily rainfall; it cannot calculate rainfall intensity. The URL is http://www.nintione.com.au/resource/AustralianRangelandsAndClimateChange_RainfallVariabilityPastureGrowth_RainfallTemplate.xlsx.
- The reported probabilities are unlikely to improve under forecast continuing rainfall variability. Projected temperature increases will increase soil moisture losses through greater evaporation and evapotranspiration. This will mean that smaller continuous daily rainfalls (>10 and >25 mm events) will be less effective for pasture growth, particularly during hotter weather. At such times, even >50 mm events that are well separated in time may become marginal for effective growth.

Suggested adaptation responses

- A continuing cautious approach to stocking levels should be taken, as well as strict control of total grazing pressure and increased drought preparedness.

Full report

http://www.nintione.com.au/resource/AustralianRangelandsAndClimateChange_RainfallVariabilityAndPastureGrowth.pdf

Meteorological drought

Drought is a complex phenomenon with mixed environmental, social and economic implications.

This report includes the recent history (since 1950) of meteorological drought, which is characterised by severe rainfall deficiency over periods of 12 months or more. Spatially interpolated rainfall data since 1950 were examined to determine the timing and severity of rainfall deficits as an indicator of meteorological drought.

Findings

- For most regions, the longest and most severe rainfall deficit occurred in the late 1950s, extending to the mid-1960s. Other periods of general rainfall deficiency occurred in the early 1980s and the mid-2000s. Deficits also occurred in the 1950s, early 1970s and parts of the 1990s for some regions.
- This analysis of rainfall deficiency for the recent past should provide a guide to the probable severity of future meteorological droughts under continuing, and perhaps enhanced, rainfall variability. Drought will continue to be a recurrent feature in the Rangelands Cluster region.

Suggested adaptation responses

- The key adaptation response for the pastoral industry is simply to be prepared: utilise reliable climate forecasting services and implement drought management strategies promptly as key dates or trigger points for decision-making are reached.

Full report

http://www.nintione.com.au/resource/AustralianRangelandsAndClimateChange_MeteorologicalDrought.pdf

Heatwaves

Heatwaves are continuous periods beyond a week when the threshold temperature (either 36° or 40°C) was exceeded.

Findings

- Recent decadal patterns in the number of summer days exceeding a threshold daily maximum temperature and the number and length of heatwaves were observed. Temperature data were sourced from the Bureau of Meteorology for 16 towns in (or on the edge of) the Rangelands Cluster.
- Most towns in the region have had more hot days and heatwaves, and longer heatwaves, in the recent past, particularly during the first decade of this century. This pattern is consistent with projected hotter temperatures as part of climate change. More recent contributing factors also included low humidity, cloudless days and increased reflected and transmitted heat from areas with low ground cover associated with protracted and widespread drought conditions during much of the 2000s.
- The trend in heatwave conditions appears to be moderated for northern urban centres (Longreach, Mount Isa and Tennant Creek; not so for Newman). Here, the summer monsoon probably has a moderating effect on extreme maximum daily temperatures (i.e. periods of cloud cover, higher humidity, variable rainfall and increased ground cover).
- It is hot and getting hotter – the regional projections report advises that the Rangelands Cluster region has warmed at a rate of 0.05–0.15°C per decade since 1911.

Suggested adaptation responses

- The recent experience of many rangelands communities in coping with increasing summer temperatures provides some foundation for adjusting to what is projected to come. This acknowledged, there will still be a considerable requirement for further adjustment and adaptation for humans, stock and wildlife. Vulnerability frameworks may assist communities in this process.

Full report

http://www.nintione.com.au/resource/AustralianRangelandsAndClimateChange_Heatwaves.pdf

Remotely sensed ground cover

Targets specifying the maintenance of minimum levels of ground cover are a common feature of regional NRM plans. Setting realistic targets for broadly different land types within each region is a challenge. Targets should be set and reviewed with climate variability, and change, in mind.

National remote sensing capability now means that fractional cover derived from 500 m MODIS imagery, extending back to late 2000, is available. The bare soil component of fractional cover can potentially assist in setting, monitoring and reviewing regional cover targets. Knowing how amounts of bare soil have varied under recent climate variability, fire regime and grazing management provide some basis for specifying appropriate targets for broadly different land types under continuing rainfall variability and possible long-term change.

Findings

- Fractional cover images for mid-March and mid-September 2001–2013 were analysed to determine how the percentage area of bioregions within NRM regions varied for different threshold levels of bare soil. Threshold values of bare soil within 25 ha MODIS pixels were ≥0.7, ≥0.6, ≥0.5, ≥0.4 and ≥0.3. The mid-March date represents likely maximal yearly bare soil in the southern part of the Rangelands Cluster, and the mid-September date is its equivalent in the central and northern parts of the cluster.
- Using the former NSW Western CMA as an example, the analysis suggests that threshold levels of allowable bare soil should vary with land type (e.g.

bioregion). A blanket target for an entire NRM region is not appropriate, particularly where mean annual rainfall, soil and vegetation type vary spatially within the region. Maximum allowable levels of bare soil should be lower in areas receiving higher or more reliable rainfall and where more perennial vegetation should be present. Conversely, more bare soil is permitted in arid parts of the Rangelands Cluster and where predominantly annual vegetation naturally occurs.

- Maximum threshold levels of bare soil have been nominated for major bioregions within all NRM regions of the Rangelands Cluster.

Suggested adaptation responses

- Reviewing ground cover targets periodically, as they may need to be adjusted under continuing climate variability and projected change.
- Strategies such as patch burning to reduce extensive wildfire, improved grazing land management and control of feral herbivores should increase vegetation cover in most years.

Full report

http://www.nintione.com.au/resource/AustralianRangelandsAndClimateChange_RemotelySensedGroundCover.pdf

Fire

Fire is extensive and common in northern Australia, particularly the tropical savanna. In the Rangelands Cluster region, extensive wildfire is more common in the spinifex-dominant deserts and following two or more years of above-average rainfall.

Findings

- Analysis of the recent fire record available from satellite-based fire-scar mapping can provide useful context for predicting what may occur under climate change. Data supplied to the Australian Collaborative Rangelands Information System (ACRIS) by WA Landgate is used to describe the 2011 and 2012 fire regime (extent and frequency) for bioregions within Rangelands Cluster NRM regions.
- It is anticipated that fire regimes in the Rangelands Cluster region will be modified by climate change in three main ways:
  - Although annual rainfall will continue to be highly variable, a greater summer component may increase grass biomass and thereby fire risk, particularly following extended wetter periods.
  - Warmer temperatures will extend the meteorological fire season and greatly increase fire danger following successive wetter years. Within the fire season, increased periods of very high temperature and low humidity will increase periods of potential very high fire danger. This may translate to widespread intense wildfire where fuel loads are sufficient, ignition occurs and there is limited capacity to implement prior strategic controlled burning and other fuel-reduction practices to reduce this risk.
  - The predicted continued spread and thickening of buffel grass will exacerbate this risk.
- Buffel grass can greatly change the fire regime at local scale: it increases fuel loads, responds readily to fire disturbance and has the capacity to make local environments in which it thrives much more fire-prone.

Suggested adaptation responses

- The key adaptation response for fire in the rangelands is to use all available climate information to plan and manage to reduce the risk of wildfire.

Full report

http://www.nintione.com.au/resource/AustralianRangelandsAndClimateChange_Fire.pdf

Cenchrus ciliaris (buffel grass)

Buffel grass (*Cenchrus ciliaris*) is one of the most widespread exotic grasses in Australia. It is native to tropical Africa and Asia and has been planted widely in central, tropical and subtropical Australia as a pasture species. It has also naturalised throughout this range, invading areas reserved for nature conservation. This contentious species presents special challenges for determining the adaptation response to climate change, because it is both a threat and a beneficial species.

Findings

- Buffel grass has been shown to acclimate to higher temperatures and to maintain competitiveness and response to fire under increased CO_2, conditions expected under climate change.
- Distribution modelling and plant physiological studies indicate that the area where buffel grass is currently present will remain suitable under future climates, thus maintaining or increasing (due to loss of other palatable grasses) its importance for agriculture.
- Modelling the distribution of buffel grass indicates a southward spread in Australia by 2070. This represents a particular threat to the high value nature conservation areas such as the Great Western Woodlands, the Alinytjara Wilurara Natural Resources Management Region and the Great Victoria Desert bioregion.
- There is a risk that many plant species will not survive in a future climate that is hotter and drier. If buffel grass proves to have greater resilience than other plant species, then it might form the basis for a novel ecosystem. Research is needed into ways that buffel grass can be managed to maximise its value to other components of the ecosystem.
- Research is also needed into the genetic diversity in buffel grass with a view to identifying genotypes that are invasive and/or suitable for pasture improvement under climate change.

Suggested adaptation responses

- Containment strategies for buffel grass are required for high value environmental assets, given that eradication will be impossible without considerable resources. Likewise, control is likely to be very difficult, if not impossible, in areas where the plant is already widespread. This makes containment the best strategy for new infestations, given that reinvasion is highly likely.

Full report

http://www.nintione.com.au/resource/AustralianRangelandsAndClimateChange_CenchrusCiliarisBuffelGrass.pdf

Dust

The level of dust in the air is related to ground cover and provides an indicator of wind erosion rate, although the amount of dust observed is influenced by several factors (e.g. actual weather conditions, soil type, vegetation type and amount of ground cover).

Visibility as affected by atmospheric dust can indicate wind erosion rate, although actual weather conditions, soil type, vegetation type and amount of ground cover are also important.

Findings

- There have been some dramatic year-to-year changes in dust activity in the recent past, particularly between 2009 (when there was substantial dust in the atmosphere) and 2010 (minimal atmospheric dust). These changes were mainly associated with rainfall, that is, improved seasonal quality in 2010.
- In the recent past (1992–2010) within the Rangelands Cluster region, most dust appeared to emanate from within the more arid parts of the Lake Eyre Basin (particularly the Simpson–Strzelecki Dunefields and Channel Country bioregions) extending west into central Australia (the MacDonnell Ranges), north into the Mitchell Grass Downs and Mount Isa Inlier bioregions, east and south-east into the Mulga Lands and Riverina and

south into the Gawler bioregion (SA Arid Lands). The WA Rangelands were less active as a dust source.

- Griffith University uses a Dust Storm Index (DSI) to report wind erosion activity across Australia. The index is based on historic visibility data recorded by Bureau of Meteorology observers. DSI maps indicate the likely sources of dust and their levels over time.
- It is probable that the domains and magnitudes of recent dust activity in drought periods will recur with continuing climate variability, particularly rainfall. Increased frequency and intensity of heatwaves and lower humidity may also contribute to increased dust.

Suggested adaptation responses

- Atmospheric dust provides a local- to regional-scale indicator of the effectiveness of grazing management in pastoral country and the recent fire regime in spinifex deserts. Land managers should endeavour to maintain critical levels of ground cover so as to minimise soil and nutrient loss via dust resulting from wind erosion in dry times.

Full report

http://www.nintione.com.au/resource/AustralianRangelandsAndClimateChange_Dust.pdf

Aquatic refugia

Refugia are defined as habitats that biota retreat to, persist in and potentially expand from under changing environmental conditions. Different types of refugia are important for different species over differing spatial and temporal scales. Two major types of refugial habitats are recognised: evolutionary refugia and ecological refuges.

Findings

- Evolutionary refugia are defined as those waterbodies that contain short-range endemics (species that occur only within a very small area) or vicariant relicts (species with ancestral characteristics that have become geographically isolated over time). Although these species often have very small geographical ranges, their populations are relatively stable and high levels of genetic diversity are present. All aquatic evolutionary refugia in the NRM Rangelands Cluster regions are groundwater-dependent ecosystems. Evolutionary refugia are most likely to persist into the future and should be accorded the highest priority in NRM adaptation planning.
- Ecological refugia are defined according to the water requirements of the species they protect. Obligate aquatic organisms (fishes and some aquatic invertebrates that can only disperse via water) need perennial (permanent) aquatic habitats, or closely located near-perennial habitats, to ensure persistence. In contrast, important ecological refugia for waterbirds are the large temporary or ephemeral freshwater lakes and salt lakes that hold water after infrequent but large episodic rainfall events. The conservation significance of ecological refugia, and the priority assigned to their conservation, depends on the level of knowledge available for the species they support.
- The indirect effects of climate change, particularly an increase in human demands for water (for direct consumption and production of food, fibre and energy), are likely to have greater impacts than direct climatic effects. Excessive groundwater drawdown will destroy spring-based evolutionary refugia, and the construction of surface water impoundments will destroy the aquatic connectivity essential for the persistence of riverine waterholes as ecological refugia. The existing adverse impacts of livestock, feral herbivores, invasive fishes, exotic plants, recreation and tourism must also be managed.
- Tools for NRM adaptation planning provided in this report include a list of priority aquatic refugia (sites likely to act as future refugia) and a decision support tree. The latter will aid the identification of major types of waterbodies and the refugia they provide, vulnerability assessments and development of management responses to address direct and indirect climate impacts and other stressors. A site register of important rangelands aquatic refugia is

provided at http://www.nintione.com.au/resource/AustralianRangelandsAndClimateChange_AquaticRefugia_RegisterAquaticRefugia.zip. This is regarded as a living register that should be updated as more information becomes available.

Suggested adaptation responses

- The NRM Rangelands Cluster region is highly water-limited, and all water (surface and groundwater) in the region is environmentally, culturally and economically important. Given that water scarcity is likely to continue under all climate change scenarios, the identification, management and restoration of aquatic refugia is a critical adaptation strategy for rangelands ecosystems and the biota they support.

Full report

http://www.nintione.com.au/resource/AustralianRangelandsAndClimateChange_AquaticRefugia.pdf

Native species

Australia supports a unique and globally significant diversity of plants and animals. An important component of this diversity occurs within the Rangelands Cluster region.

Findings

- Macro-ecological modelling indicates that the impacts of climate change will vary across biological groups and, for a number of these groups, will be greater in some regions of the Rangelands Cluster.
- The three groups that will be most impacted by climate change are plants, snails and reptiles; impacts on mammals will be moderate, whereas impacts on birds and frogs will be low.
- Future climate refugia are modelled to occur in the MacDonnell and Central Ranges (NT Arid Lands subregion, WA Rangelands and Alinytjara Wilurara regions), the Channel Country (Desert Channels and SA Arid Lands regions), Mount Isa Inlier (Desert Channels region), the Gibson Desert, the Pilbara (both WA Rangelands), the Nullarbor (WA Rangelands and Alinytjara Wilurara regions) and parts of inland Queensland and NSW (Western Local Land Services and South West Queensland regions).

Suggested adaptation responses

- Adaption options require careful assessment of the relevant species, but may take the form of one of the following management options: in-situ management, facilitate responses of wild populations, ex-situ management, and monitoring and research to improve understanding and predict what may happen.

Full report

http://www.nintione.com.au/resource/AustralianRangelandsAndClimateChange_NativeSpecies.pdf

Invasive animals

The invasive animals having the most impact and considered the greatest management concern in the Australia rangelands include large herbivores, mammalian carnivores and the cane toad.

The ten species of significant vertebrate pest in the Rangelands Cluster region are considered in this report: feral goat, one-humped camel, feral horse/brumby, feral donkey, feral pig, red fox, feral domestic cat, dingo, European rabbit and cane toad.

Findings

- Predicted changes in abundance and distribution with climate change indicate a decrease in the abundance and/or distribution of five species within the region (cat, goat, pig, rabbit and cane toad), with a further three species predicted to have stable abundance and distribution (camel, horse and donkey).
- Only two species, red fox and dingo, may show increased abundance and/or distribution in response to climate change.

Suggested adaptation responses

- Management recommendations in response to climate change are essentially to do more of the same. That is, to continue actively managing the species and their impacts.

Full report

http://www.nintione.com.au/resource/AustralianRangelandsAndClimateChange_InvasiveAnimals.pdf

Guidance to support adaptation

Rangelands have distinct ecologies and social systems, such that conventional approaches to climate adaptation may not always work in these remote areas.

Findings

- Rangelands researchers have developed a unique framework tailored to remote areas.
- The approach brings together two different sides to adaptation, vulnerability reduction and enhancing resilience in a single coordinated framework. Rangelands populations tend to think long term – and this is exactly the approach put forward in the remote area framework – using some types of management strategies to 'buy time' while other types of strategies are coming into effect.
- This framework is illustrated with case studies drawing on past research, including research about human responses to heatwaves, to show how different strategies for reducing vulnerability and building resilience can be combined over time (Maru et al. 2014). The framework is also considered in relation to buffel grass management.
- The approach balances resilience and vulnerability reduction and draws on the existing capacity of rangelands residents.

Full report

http://www.nintione.com.au/resource/AustralianRangelandsAndClimateChange_GuidanceToSupportAdaptation.pdf

Pastoral production and adaptation

Grazing of livestock is the most extensive land use in the Rangelands Cluster region. Projected changes in climate will impact the future ways in which pastoralism occurs and adaptations will be required, both at enterprise scale and regionally.

Findings

- A linked vulnerability and resilience framework was used to illustrate how the range of available pastoral adaptations might best be implemented across the different NRM regions in the Rangelands Cluster.
- Among the climate change projections, hotter maximum temperatures and associated heatwaves, continuing highly variable rainfall and the probable occurrence of both more frequent drought and intense rainfall are considered the most adverse factors affecting future pastoralism.
- Good practical examples and appropriate technical advice are available to guide required short- to medium-timeframe adaptation responses to continuing rainfall variability and recurrent drought (e.g. out to about 2030). Longer term adaptation may require a fundamentally more conservative approach to stocking rates, adjusting stocking rates as local pasture productivity changes and increasing the robustness of pastures by encouraging regeneration of palatable perennial forage (where possible). Repairing formerly productive, but now degraded, country may also have increased prominence as maximising rain use efficiency becomes more important through increased evaporation and reduced soil water availability.
- Hotter maximum temperatures and increased frequency and duration of heatwaves will place

greater emphasis on human safety and wellbeing and animal welfare (particularly when stock is being handled). Both aspects may need to be more formally recognised and planned as part of routine station management.

- Longer periods of hotter weather will also require increased robustness in stock water supply. There will be a reduced safety margin around existing supplies as livestock consume more water in such periods. Repairs following failure will become more time critical, and human occupational health and safety will also be paramount when attempting repairs to failed water infrastructure during heatwaves.
- Increased rainfall intensity has the potential to damage station infrastructure and increase erosion. The latter can be partly mitigated by maintaining minimum critical levels of ground cover on the most vulnerable soil types. Reducing the actual and financial risk of infrastructure damage may require its relocation to less vulnerable areas, a degree of over-engineering (by present-day standards) and increased use of insurance.
- Higher temperatures negatively affect pasture growth by reducing the efficiency with which plants use water, but this will be partly offset by the beneficial effects of rising atmospheric CO_2 on pasture. Tropical and subtropical grasses with the C_4 photosynthetic pathway are likely to expand ranges southward at the expense of existing C_3 grasses. The digestibility and nutritive value of pastures are likely to decline from the combined effects of rising temperatures, increasing CO_2 and increases in C_4 grasses, so overall animal production may decrease. This can be alleviated for cattle by introducing/increasing *Bos indicus* genetics and increased use of nutritional supplements. C_4 grasses are more flammable, and more extensive and frequent fires that burn hotter may result.

Suggested adaptation responses

- It is anticipated that both gradual and transformational adaptation responses are required to suitably respond to likely climate change impacts on pastoral land.
- Appropriate transformational change will probably require a fundamental shift in the current thinking (paradigm) about how rangelands are managed towards a more conservative risk-based approach to the use of natural resources. This will be a gradual process that requires facilitation, structural change and perhaps supporting legislation to achieve the best long-term outcomes for the pastoral industry and the natural resources on which grazing is based.
- It is unlikely that current best-management practices will remain so under projected climate change.

Full report

http://www.nintione.com.au/resource/AustralianRangelandsAndClimateChange_PastoralProduction.pdf

Adaptation User Guide – incorporating climate information into NRM planning

- Through the Rangelands Cluster Project, a considerable amount of rangelands specific climate information has been developed and made available to support NRM planning for climate change. One of the challenges is how to incorporate that information in planning and planning processes.
- It is recognised that for planning for climate change adaptation, we need relevant information, climate projections, potential adaptations and a process for incorporating information into planning, including identifying priority actions.
- A simple framework (shown below) has been developed to assist regional NRM organisations to work through the available information and the climate projections, identify likely impacts/risks and then identify priority actions.

- The framework is part of a simple process for use at NRM Board, NRM organisation/staff or community level to incorporate project information, and other information that may be accessible, into regional NRM planning process by supporting the development of priority actions.
- Users take information relevant to their region about the projected/likely climate impacts (as developed under the Rangelands Cluster Project) and populate the table with respect to each of the specific issues. This process helps identify priority actions for each issue.

To enable people planning for NRM in the rangelands to easily access relevant and current climate information, these reports have been collated into one document. Further information, including that prepared for other parts of Australia and tools to help communicate and understand climate change, is available at www.climatechangeinaustralia.gov.au.

Framework

Projected/likely climate impacts	Rainfall and pasture growth	Meteorological Drought	Heatwaves	Ground cover	Fire	Buffel grass	Dust	Aquatic refugia	Native species	Invasive animals	Pastoral production
Increased temperatures											
Increased extreme temperatures											
Increased rainfall variability											
Decreased winter rainfall											
Increased evapotranspiration											
Priority ACTIONS											

1. Introduction

In 2012, the Australian Government prepared the Clean Energy Future Plan. Out of this plan came the Regional Natural Resource Management Planning for Climate Change Fund, which provided $43.9 million over four financial years to improve regional planning for climate change and help guide the location of carbon and biodiversity activities. The aim of the fund was to improve the capacity of regional natural resource management (NRM) organisations to plan for climate change.

There were two streams of funding:

- Stream 1 ($28.9 million) – funding directly to regional NRM organisations to revise existing regional NRM plans to help identify where in the landscape adaptation and mitigation activities should be undertaken
- Stream 2 ($15 million) – funding to produce regional-level climate change information (National Projections Project) and provide guidance on the integration of that information into regional NRM and land use planning (Impacts and Adaptation Project: eight regional cluster projects and a national project).

1.1 The Rangelands Cluster

The Australian Rangelands cover over 80% of the continent and can be split into the monsoonal north and the arid and semi-arid south. The arid and semi-arid areas make up the Rangelands Cluster. The Natural Resource Management regions (with area shown in brackets) included in the cluster are (Figure 1.1):

- The former Western Catchment Management Authority (CMA) in New South Wales (251,125 km^2). This region has now expanded to the Western Local Land Service, but most reporting is confined to the Western CMA
- South West NRM in Queensland (187,138 km^2)
- Desert Channels Queensland (510,267 km^2)
- South Australian Arid Lands NRM region (521,782 km^2)
- The Alinytjara Wilurara NRM region in South Australia (283,050 km^2)
- The Arid Lands and Tablelands subregions of Territory NRM (657,870 km^2 and 205,461 km^2 respectively)

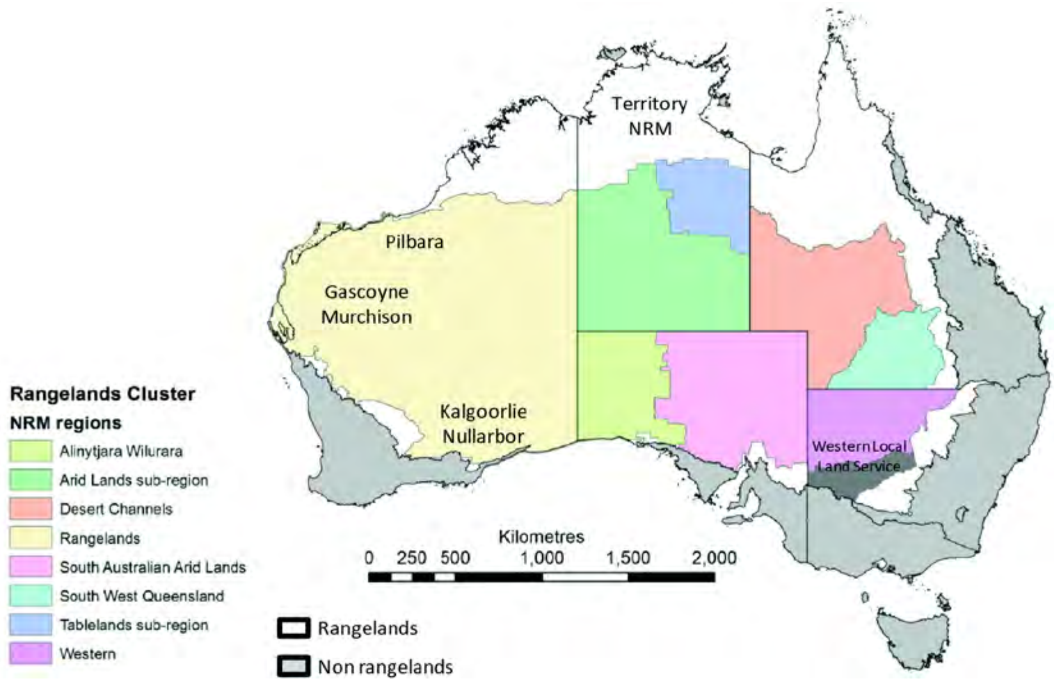


Figure 1.1 Rangelands Cluster NRM regions

- The arid and semi-arid parts of Rangelands WA (1,903,063 km^2). In the chapters of this report, this very large region is variously subdivided into the Pilbara, Gascoyne-Murchison and Kalgoorlie-Nullarbor subregions.

The Rangelands Cluster Project was aimed at facilitating climate change science into NRM planning across some of the driest and hottest country on earth. The current climate system is complex and impacted by components as varied as the Southern Ocean, El Niño/La Niña and the Indian Ocean dipole. This complex system is expressed in the most highly variable climate across Australia.

Planning for climate change adaptation in the rangelands encompasses many unique challenges including:

- small (and declining) populations
- poor institutional and governance capacity, struggling to implement delivery models based on closer settled coastal communities
- limited investment in and access to rangelands-specific information and expertise
- low socio-economic status communities
- large distances
- different seasonal 'cycles' from temperate Australia (i.e. not four seasons)
- production systems that mostly rely on managing naturally occurring systems for production outcomes.

Residents who live in the rangelands and work with current pastoral systems and practices feel capable in dealing with existing climate variability, but it is unclear whether this will be possible in the future. Adding the likely rise in temperatures and uncertainty regarding rainfall means that these already vulnerable communities will face even greater challenges. To help them plan for these, NRM groups within the rangelands are looking for information, relevant tools and guidance, as well as flexibility in 'the system' to enable better planning for adaptation.

The project was a collaboration between the Rangelands NRM Alliance (representing the NRM groups), CSIRO, University of Canberra and Ninti One. Ninti One had the role of knowledge broker, facilitating the connection between the scientists and the NRM groups.

The project has assisted rangeland NRM groups to include planning for climate change impacts into their normal NRM planning processes to ensure:

- informed decisions and strategic investments
- long-term sustainability of rangeland communities and industries.

1.2 Approach to determining priorities for climate change information for NRM planning

As partners, three organisations (CSIRO, University of Canberra and Ninti One) developed the project application for funding with advice from the Rangelands NRM Alliance, identifying Ninti One in the role of project manager. The application recognised the sparse information available to help understand and plan for climate change and adaptation in the rangelands.

The objectives of the project were to:

- work with regional NRM organisations to identify information needs and plan responses to climate change that deliver optimum NRM and adaptation outcomes
- provide highest quality climate change adaptation information that acknowledges the unique characteristics of the rangelands and can be easily integrated with existing information used by NRM planners
- build the capacity of both NRM planners and climate change researchers and create multidisciplinary networks to deliver adaptive responses in the future.

The Rangelands Cluster Project included researchers with specialised knowledge in rangelands systems and information, biodiversity and aquatic ecosystems, as these were areas known to be of interest and importance to NRM planners and where some work had already been undertaken. (Part of the project brief was that no new research was to be undertaken due to the limited resources available; the project was to be an analysis of existing data and information.)

To determine priorities for research within the Rangelands Cluster Project, various methods of consultation and engagement were used, including cluster-wide workshops with both NRM groups and researchers, face-to-face meetings in regions, teleconferences, surveys and emails as well as the establishment of a reference group and a scientific advisory panel to support and advise the project.

Through these processes, over a course of several months, agreement was reached about what the information priorities were to support NRM planning for climate change that were also achievable within the time and resourcing available.

The table below shows the agreed list of priorities and the corresponding reports (chapters in this document) produced to provide the information.

Researchers undertook collation of data and information on each of these and prepared reports that form the content of this document. The chapters were prepared as individual reports and are available separately as well (see links at end of each section in the Executive summary).

Concurrently, the National Projections Project team developed projections at a cluster level. The result of that work is included here at Chapter 2.

Collectively, these reports provide information and guidance for NRM regional planning, especially for climate change adaptation.

Reference

Scott JK, Murphy H, Kriticos DJ, Webber BL, Ota N and Loechel B (2014) *Weeds and Climate Change: supporting weed management adaptation*. CSIRO, Australia.

Table 1.1 Agreed priorities and their reports

AGREED INFORMATION PRIORITY	RESULTING REPORT/INFORMATION
Regionally specific climate change data	Rangelands Cluster Climate Projections (Ch 2) Rainfall variability and pasture growth (Ch 3) Heatwaves (Ch 5)
Drought	Meteorological drought (Ch 4) Remotely sensed ground cover (Ch 6) Dust (Ch 9)
Fire and fire risk	Rangeland fire (Ch 7)
Weeds	*Cenchrus ciliaris* (buffel grass) (Ch 8) Other significant rangelands weeds have been included in the national project*
Aquatic ecosystems adaptation framework	Aquatic refugia (Ch 10)
Native species	Native species (Ch 11)
Invasive animals	Invasive animals (Ch 12)
Guidance to support climate change adaptation	Guidance to support climate change adaptation (Ch 13)
Pastoral production	Pastoral production and adaptation (Ch 14)
Synthesis	Executive summary Adaptation User Guide (Ch 15)

* Scott et al. (2014)

Climate change in the Rangelands

Ian Watterson

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2. Climate change in the rangelands

Key messages for the Rangelands

Average temperatures will continue to increase in all seasons.

More hot days and warm spells, and fewer frosts.

Changes to summer rainfall are possible but unclear. Less winter rainfall is projected in the south.

Increased intensity of extreme daily rainfall events.

Mean sea level will continue to rise. Height of extreme sea-level events will also increase.

On annual and decadal basis, natural variability in the climate system can act to either mask or enhance any long-term human induced trend, particularly in the next 20 years and for rainfall.

2.1 Introduction

The international scientific community accepts that increases in greenhouse gases due to human activities have been the dominant cause of observed warming since the mid-20th century. Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system.

Australia's changing climate represents a significant challenge to individuals, communities, governments, businesses and the environment. Australia has already experienced increases in average temperatures over the past 60 years, with more frequent hot weather, fewer cold days, shifting rainfall patterns, and rising sea levels.

To assist the planning and management of Natural Resource Management (NRM) regions, CSIRO and the Australian Bureau of Meteorology have prepared climate change projections for eight regions of Australia, termed NRM clusters.

The Rangelands Cluster (Figure 2.1) comprises NRM regions in four States and the Northern Territory. This vast region contains many varied landscapes, including the Flinders Ranges, the ranges of the Pilbara and 'The Centre'; hence much of the iconic 'Outback'. Many Indigenous Australians live in this region. Cattle and sheep grazing are important agricultural activities.

Rainfall systems vary from seasonally reliable monsoonal influences in the far north through to very low and variable rainfall patterns in much of the centre and south. Given this, the Rangelands Cluster has been divided into Rangelands North and Rangelands South sub-clusters.

2.2 Climate change projections

Projections for the Rangelands are based on the outputs of a set of 40 global climate models (GCMs) developed by Australian and international scientists. Climate models are based on established laws of

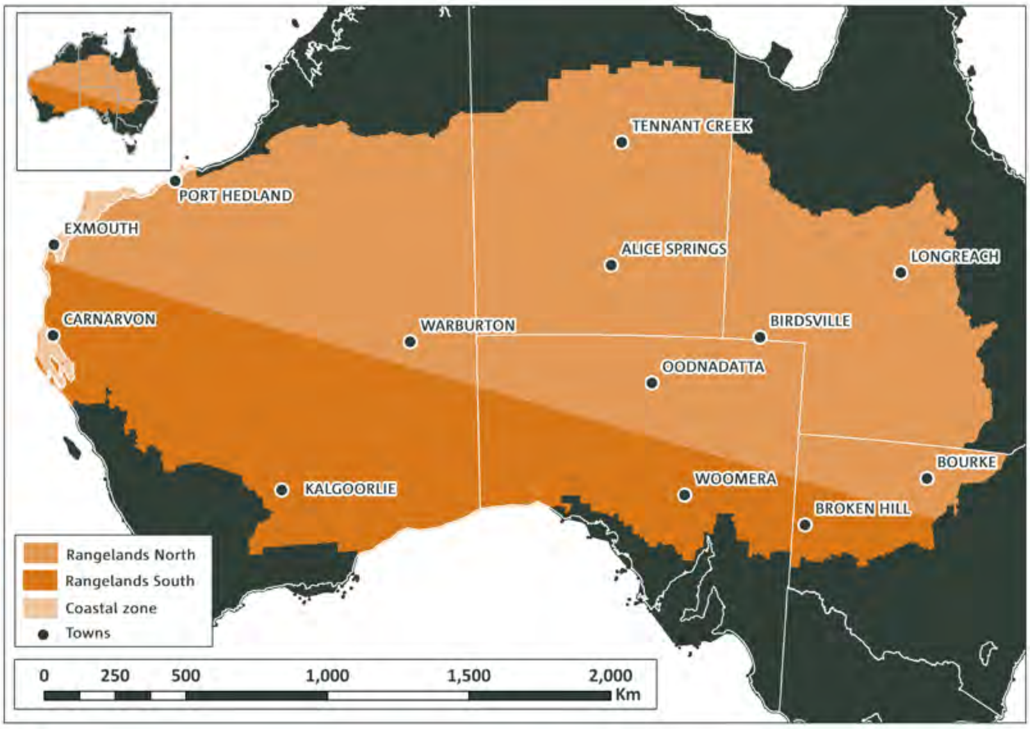

Figure 2.1 Map of the Rangelands Cluster

physics and are rigorously tested for their ability to reproduce past climate. These projections draw on the full breadth of available data and peer-reviewed literature to provide a robust assessment of the potential future climate.

Projections for the Rangelands are based on four Representative Concentration Pathways (RCPs) underpinned by emission scenarios. More information on climate models and RCPs can be found here.

◗ **FOR MORE COMPREHENSIVE INFORMATION ABOUT THE RANGELANDS, READ THE CLUSTER REPORT AVAILABLE ON THE CLIMATE CHANGE IN AUSTRALIA WEBSITE:**
www.climatechangeinaustralia.gov.au

2.3 Past temperature trends

Temperatures have increased over the past century, with the rate of warming higher since 1960. Mean temperature increased between 1910 and 2013 by around 0.9 °C in the north and 1.0 °C in the south.

2.4 Temperature projections

Average temperatures will continue to increase in all seasons (*very high confidence*).

There is *very high confidence* in continued substantial increases in projected mean, maximum and minimum temperatures in line with our understanding of the effect of further increases in greenhouse gas concentrations.

For the near future (2030), the annually averaged warming across all emission scenarios is projected to be around 0.6 to 1.4 °C above the climate of 1986–2005. By late in the century (2090), for a high emission scenario (RCP8.5) the projected range of warming is 2.9 to 5.3 °C (Table 2.1 and Figure 2.2). Under an intermediate scenario (RCP4.5) the projected warming is 1.5 to 2.9 °C.

Table 2.1 Projected temperature change (°C), compared to 1986–2005, for 20-year periods (centred on 2030 and 2090) and three RCPs. The median projection across the models is shown, with the 10th to 90th percentile range of model results in brackets.

	RCP2.6 LOW EMISSIONS	RCP4.5 INTERMEDIATE EMISSIONS	RCP8.5 HIGH EMISSIONS
2030	0.9 (0.6 to 1.3)	1.0 (0.6 to 1.4)	1.0 (0.8 to 1.4)
2090	1.1 (0.6 to 1.8)	2.1 (1.5 to 2.9)	4.3 (2.9 to 5.3)

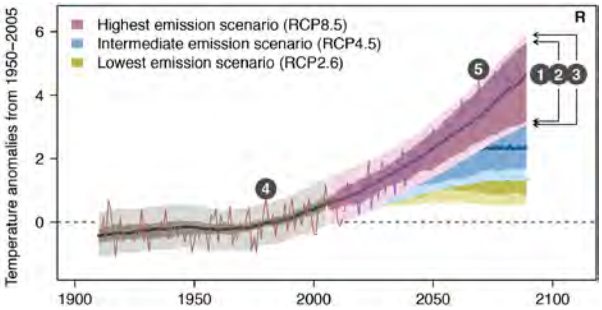

Figure 2.2 Simulated historical and projected temperature (°C) time-series for the Rangelands Cluster, shown as differences from the 1950–2005 average (see explanation below).

2.4.1 Explanation of the temperature time-series

1. The projected multi-model median temperature. Half the models have projections above, and half below, this line.
2. 10th to 90th percentile of projected 20-year average climate. 80 per cent of model results lie in this range.
3. 10th to 90th percentile of individual years (taking into account year to year variability). 80 per cent of years lie in this range.
4. The observed time-series for 1910–2013 is overlaid on the simulated climate for the corresponding period (grey line and shading as per 1–3).
5. One climate model is shown to illustrate how the warming future may unfold. Note that models simulate realistic variability in annual temperature.

2.5 Past rainfall trends

Observations show an increasing trend in summer rainfall over the north-west of the Rangelands, although with intermittent periods of wetter and drier conditions throughout the 20th century. The recent wet year, 2011, was the highest on record to the south. Year to year variability is strongly influenced by the El Niño Southern Oscillation.

2.6 Rainfall projections

In the near future (2030) natural variability is projected to predominate over trends due to greenhouse gas emissions. Winter rainfall in the south is projected to decline over the century under both intermediate (RCP4.5) and high (RCP8.5) emission scenarios (high confidence). There is a good understanding of the physical mechanisms driving this change (southward shift of winter storm systems together with rising mean pressure over the region).

Changes to annual and summer rainfall for late in the century are possible, but the direction of change cannot be confidently projected given the spread of model results. Impact assessment in this region should consider the risk of both a drier and wetter climate.

Changes to summer rainfall are possible but unclear. Winter rainfall is projected to decrease in the south with *high confidence*. For the near future the natural variability in the climate system will mask any projected trends due to human influence.

CONSULT THE RANGELANDS CLUSTER REPORT FOR MORE DETAILED DESCRIPTIONS OF THE RESULTS USING DIFFERENT MODELLING METHODS (E.G. DOWNSCALING).

Table 2.2 Projected rainfall differences (per cent), compared to 1986–2005, for 20-year periods (centred on 2030 and 2090) and three RCPS. The 10th to 90th percentile range of model results is shown. For 2030, results for all RCPS are similar so only RCP4.5 values are shown.

	RCP4.5 2030	RCP2.6 2090	RCP4.5 2090	RCP8.5 2090
ANNUAL	-11 to +6	-21 to +3	-15 to +7	-32 to +18
SUMMER	-16 to +7	-22 to +8	-16 to +10	-22 to +25
AUTUMN	-23 to +20	-26 to +18	-23 to +27	-42 to +32
WINTER	-20 to +14	-31 to +12	-34 to +7	-50 to +18
SPRING	-21 to +19	-32 to +15	-26 to +11	-50 to +23

Median results are not shown here because models do not always agree on the direction of change.

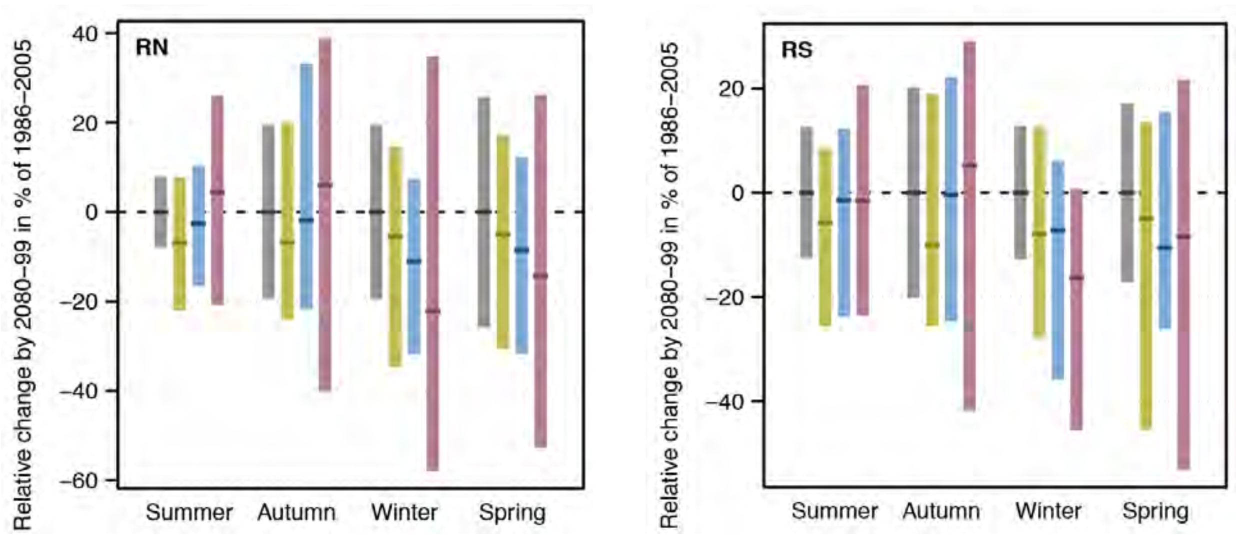

Figure 2.3 Projected rainfall differences (per cent) for three RCPs for the Rangelands sub-clusters for 20 years centred on 2090 compared to 1986–2005. Bars indicate the 10th to 90th percentile range of model results. The horizontal line indicates the median.

2.7 Representative concentration pathways

- Future changes in greenhouse gases, aerosols (suspended particles in the atmosphere) and land use depend on human behaviour.
- The scientific community defined a set of four scenarios, called Representative Concentration Pathways (RCPs) for the *Fifth Assessment Report* of the Intergovernmental Panel on Climate Change.
- The RCPs reflect plausible trajectories of future greenhouse gas and aerosol concentrations to the year 2100 and represent a range of economic, technological, demographic, policy, and institutional futures.
- Climate projections are available from model simulations using four RCPs: RCP8.5 (high emissions), RCP6.0 and RCP4.5 (intermediate scenarios resulting from moderate emissions reduction, with differing timing of peak emissions) and RCP2.6 (low emissions; ambitious and sustained global emissions reduction). RCPs are named in accordance with the level of influence these gases have on the Earth's energy balance.
- Not every combination of RCP and climate variable is available for all GCMs in the projections presented here.
- Projections for RCP6.0 are not presented here, but are available on the website.

2.8 Extreme temperature

Extreme temperatures are projected to increase at a similar rate to mean temperature, with a substantial increase in the temperature reached on hot days, the frequency of hot days, and the duration of warm spells (*very high confidence*).

For Alice Springs, for example, days with temperatures over 35 °C could occur for more than a third of the year under an intermediate emission scenario (RCP4.5) by late in the century (Table 2.3).

Where frosts (minimum temperatures under 2 °C) occur in the cluster, these are projected to decrease.

More hot days and warm spells are projected with *very high confidence*. Fewer frosts are projected with *high confidence*.

CALCULATE THE FREQUENCY OF DAYS EXCEEDING SELECTED TEMPERATURE THRESHOLDS ON THE WEBSITE THRESHOLD CALCULATOR.

Table 2.3 Average annual number of days above 35 and 40 °C for Alice Springs for the 30-year period centred on 1995 (1981–2010) and for future 30-year periods (centred on 2030 and 2090).

THRESHOLD	ALICE SPRINGS (RANGELANDS NORTH)			
	1995	2030 RCP4.5	2090 RCP4.5	2090 RCP8.5
OVER 35 °C	94	113 (104 to 122)	133 (115 to 152)	168 (145 to 193)
OVER 40 °C	17	31 (24 to 40)	49 (33 to 70)	83 (58 to 114)
BELOW 2 °C	33	24 (28 to 19)	13 (20 to 8.4)	2.1 (6.0 to 0.8)

2.9 Extreme rainfall & drought

Understanding of the physical processes that cause extreme rainfall, coupled with modelled projections (Figure 2.4), indicate with *high confidence* a future increase in the intensity of extreme rainfall events, although the magnitude of the increases cannot be confidently projected.

Time spent in drought is projected, with *medium confidence*, to increase over the course of the century.

Increased intensity of extreme rainfall events is projected, with *high confidence*.

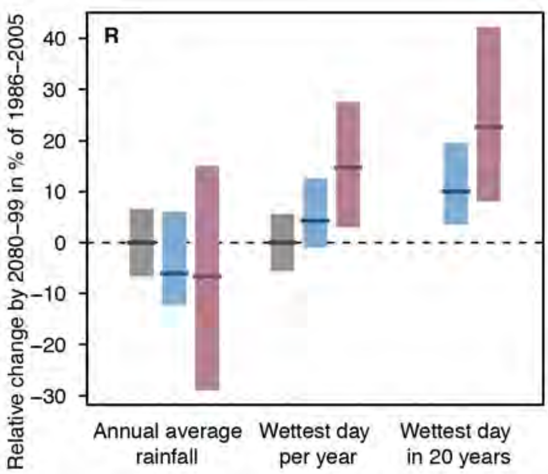

Figure 2.4 Modelled differences (per cent) in annual average rainfall, rainfall on the wettest day per year, and rainfall on the wettest day in 20 years for 2080–2099 compared to 1986-2005. (Bars as per Figure 2.3)

2.10 Marine and coastal projections

For 1966 to 2009, the average rate of relative sea-level rise for Australia, from observations along the coast, was 1.4 mm/year.

There is *very high confidence* in future sea-level rise. By 2030 the projected range of sea-level rise at Port Hedland is 0.07 to 0.17 m above the 1986–2005 level, with only minor differences between emission scenarios. As the century progresses projections are sensitive to concentration pathways. By 2090, the intermediate emissions case (RCP4.5) is associated with a rise of 0.28 to 0.65 m and the high case (RCP8.5) a rise of 0.40 to 0.85 m. Under certain circumstances, sea-level rises higher than these may occur (see Table 2.4 caption).

Table 2.4 Projected sea-level change (metres) for two Rangelands sites, compared to 1986–2005, for 20-year periods (centred on 2030 and 2090) and three RCPs. The median projection across the models is shown, with the range of model results in brackets. These ranges of sea-level rise are considered 'likely'. However, if a collapse in the marine based sectors of the Antarctic ice sheet were initiated, these projections could be several tenths of a metre higher by late in the century.

SEA-LEVEL CHANGE	PORT HEDLAND (RANGELANDS NORTH)		CARNARVON (RANGELANDS SOUTH)	
	2030	2090	2030	2090
RCP2.6	0.11 (0.07–0.16)	0.38 (0.22–0.55)	0.12 (0.07–0.16)	0.39 (0.22–0.57)
RCP4.5	0.12 (0.07–0.16)	0.46 (0.28–0.64)	0.12 (0.07–0.16)	0.46 (0.28–0.65)
RCP8.5	0.12 (0.08–0.17)	0.61 (0.40–0.84)	0.13 (0.08–0.18)	0.62 (0.40–0.85)

Late in the century warming of the Rangelands coastal waters poses a significant threat to the marine environment through biological changes in marine species, including local abundance, community structure, and enhanced coral bleaching risk. Sea surface temperature is projected to increase in the range of 2.4 to 3.7 °C by 2090 under high emissions. The sea will also become more acidic, with acidification proportional to emissions growth.

Mean sea levels will continue to rise and height of extreme sea-level events will also increase (*very high confidence*).

2.11 Fire weather

Bushfire in the Rangelands depends highly on fuel availability, which mainly depends on rainfall. A tendency toward increased fire weather risk is expected in future, due to higher temperature and lower rainfall, but there is *low confidence* in the magnitude of fire weather projections.

2.12 Other variables

HUMIDITY: Little change in relative humidity is projected for the near future (2030) while later in the century a decrease is projected in winter and spring (*high confidence*) and in summer and autumn (*medium confidence*).

SOLAR RADIATION: There is little change projected for solar radiation in the near future (2030), and for later in the century, increased radiation is projected in the south in winter (*medium confidence*).

EVAPORATION: Potential evapotranspiration is projected to increase in all seasons as warming progresses (*high confidence*).

WWW.CLIMATECHANGEINAUSTRALIA.GOV.AU

This website provides comprehensive information about the future climate and its impacts, and how communities, in particular the NRM sector, can adapt to these projected changes.

A number of interactive tools allow exploration of a range of climate variables up to late in the 21st century.

A full report for the cluster can be found on the site, as well as specific impacts and adaptation information.

Australian rangelands and climate change – rainfall variability and pasture growth

Gary Bastin

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3. Australian rangelands and climate change – rainfall variability and pasture growth

Key points

- The frequency of probable past pasture growth events based on daily rainfall gives some indication of what lies ahead for the Rangelands Cluster region under the climate change projection of continuing high natural variability in rainfall.
- For this analysis, >25 mm of rain over consecutive wet days is considered the minimum requirement for pasture growth to occur across much of the Rangelands Cluster region, and a >50 mm event over the same period should provide ideal growing conditions – particularly where grazed land is maintained in good condition. There are exceptions, of course, to this general guide. Smaller events (e.g. as low as 10 mm) may be effective in cooler weather and for specific locations / vegetation types (e.g. new leaf growth in chenopod shrublands on the Nullarbor Plain). At the other end of the scale, degraded rangeland may respond minimally to >50 mm events.
- The last 60 years of rainfall data show that periods of rainfall suitable for marginal to ideal growing conditions were infrequent throughout much of the Rangelands Cluster region. The median return period (in days) between >25 mm and >50 mm events lengthens for locations with lower and more variable annual rainfall – that is, to the south (Port Augusta, Cook, Kalgoorlie) and towards the more arid interior (Coober Pedy, Marree, Birdsville, Oodnadatta).
- The median return period for >50 mm events is close to one year for the more arid parts of the cluster region.
- Given the highly episodic nature of rainfall across inland Australia, no trends in return period for specific rainfall amounts were detected.
- The reported probabilities are unlikely to improve under forecast continuing rainfall variability. Projected temperature increases will increase soil moisture losses through greater evaporation and evapotranspiration. This will mean that smaller continuous daily rainfalls (>10 and >25 mm events) will be less effective for pasture growth, particularly during hotter weather. At such times, even >50 mm events that are well separated in time may become marginal for effective growth. In short, a continuing cautious approach to stocking levels, strict control of total grazing pressure and drought preparedness are required into the future.
- We provide a template spreadsheet for users to calculate their own return-period statistics for any rainfall amount and location where historic daily rainfall data are available. This tool summarises periods of continuous daily rainfall; it cannot calculate rainfall intensity. The URL is http://www.nintione.com.au/resource/AustralianRangelandsAndClimateChange_RainfallVariabilityPastureGrowth_RainfallTemplate.xlsx.

3.1 Introduction

Native pastures support pastoral production throughout much of the Rangelands Cluster region. Appropriate stocking rates that ensure safe levels of pasture utilisation and maximise the opportunity of forage species to respond to episodic rainfall when received underpin the continued sustainable use of the rangelands for livestock production. What does the future hold in terms of projected climate change?

Winter rainfall is expected to decline in the southern part of the Rangelands Cluster region, and spring rainfall may also decrease (Watterson et al. 2015). Changes to rainfall in other seasons, and annually, are possible but the direction of change is uncertain. There is high confidence, however, that past high natural variability in rainfall will continue, and this may mask any trend in average rainfall for some decades to come, particularly in the summer season.

We cannot be certain as to what these projections mean in terms of future pasture growth and the forage base for livestock. However, we do know that both variability and uncertainty will continue to prevail. Analysis and interpretation of past rainfall records may provide useful context for better understanding the future.

In this section, we examine the frequency with which past probable growth events occurred using the daily rainfall data for selected rainfall recording stations throughout the Rangelands Cluster. Pasture growth models (e.g. GRASP at paddock scale and AussieGRASS[1] at landscape scale) estimate forage availability on a monthly to annual basis and provide a much more sophisticated interpretation of historic rainfall. However, these modelling approaches were not available to this project and we simply use various amounts of continuous daily rainfall to indicate likely growth events. This approach, via a spreadsheet template, could easily be expanded and adopted for continuing use by NRM planners within their regions.

3.1.1 Rainfall as a proxy for growth events

From a biological perspective, sequences of daily rainfall can be treated as events, defined here as one or more closely spaced rainfalls which are large enough to produce a significant vegetation response – i.e. a substantial pulse of plant growth which produces forage for livestock (Noy-Meir 1973; Stafford Smith and Morton 1990; Ludwig et al. 1997; Stafford Smith and McAllister 2008). This translates, for example, into events of about 50 mm in a week in the Alice Springs region. Based on an event size of 50 mm or more, several events may occur within one year, but it is also possible for several years to pass without a larger event (Pickup and Stafford Smith 1993).

There are no definitive or established rules for estimating pasture growth from rainfall alone although, as described above, sophisticated pasture growth models such as GRASP can predict biomass production following variable amounts of rainfall at paddock scale for specified soil types. As a far simpler approach, the following analyses use threshold amounts of cumulative rainfall over successive days as a qualitative indicator of probable pasture growth. Timing of rainfall (i.e. seasonality), rainfall intensity, soil and vegetation type, soil moisture availability and land condition (particularly the amount of palatable perennial grasses) will all affect actual pasture response to rainfall. Thus the interpretations drawn from analysis of rainfall event-size should be used cautiously as part of NRM planning.

For this analysis, >10 mm, >25 mm and >50 mm of rain over consecutive days are treated as events of varying effectiveness. In central Australia, an event of 25 mm or more is probably marginal for effective growth, particularly in summer when evapotranspiration is high. For the same location, a >50 mm event should equate with ideal growing conditions, particularly where land is in good condition and perennial pasture plants can

[1] The Australian Grassland and Rangeland Assessment by Spatial Simulation (AussieGRASS) is a tool developed to monitor, at regional scale, key biophysical processes associated with pasture degradation and recovery. It also provides early warning of when and where regional livestock numbers may be out of balance with likely forage supply. Further information available at www.longpaddock.qld.gov.au/about/researchprojects/aussiegrass/index.html (accessed 23/4/2014).

readily respond to such rainfall. Contrasting with this, an event as small as 10 mm during the cooler winter months in the southern Rangelands (e.g. the Nullarbor), may allow for an effective vegetation response.

Yearly rainfall in the northern part of the Rangelands Cluster is concentrated in the summer months with the wet season arbitrarily defined as extending from mid October to mid April. Elsewhere, rainfall is generally aseasonal with pasture growth occurring throughout the year if/when sufficient rainfall is received (and presuming that frosts do not limit winter herbage growth).

3.2 Method

Daily rainfall data were accessed through SILO[2] for 36 recording stations throughout or close to the boundary of the cluster region (Figure 3.1). Data between 1950 and 2013 were imported to spreadsheets, and:

- the occurrence of continuous daily rainfalls exceeding 10 mm, 25 mm and 50 mm were identified (for northern stations, summer rainfall only and for mid-latitude stations, rainfall analysis included the continuous and wet-season records)
- for each rainfall threshold, the event date (last day of continuous rainfall), event size (mm rainfall) and number of wet days were summarised

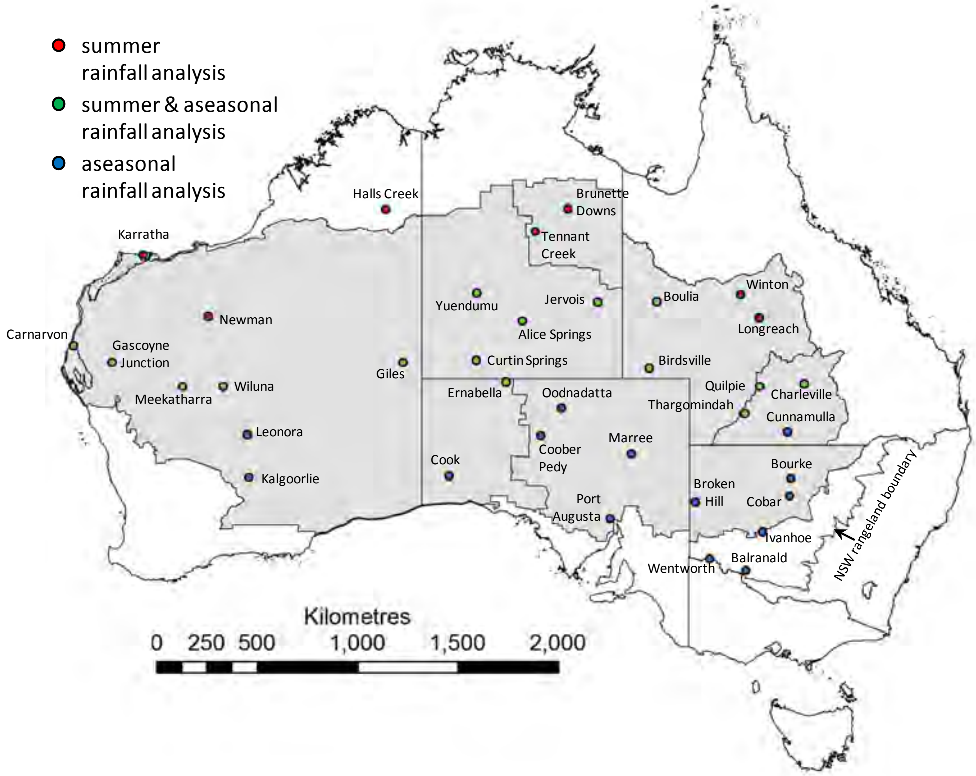


Figure 3.1 Recording stations in the Rangelands Cluster region used to analyse the return period of different-sized rainfall events

[2] http://www.longpaddock.qld.gov.au/silo/ppd/index.php, accessed 8 November 2013

- the return period, defined as the number of days from the end of one rainfall event to the start of the next, was also calculated and summarised (as the median number of days between events for each location and the frequency of events on a monthly basis).

Rainfall analysis for mid-latitude stations (green dots) used both wet-season (summer) rainfall and the continuous record.

3.3 Data source

SILO patched-point daily rainfall data are readily available for many locations in the Rangelands Cluster. Data files can be downloaded from the Longpaddock URL provided above in footnote 2 or from the Bureau of Meteorology (BoM) web site (www.bom.gov.au). Long-term (pre-1950) recording stations are generally more numerous in the pastorally occupied parts of the cluster region than in the deserts.

An Excel spreadsheet template[3] accompanying this report provides for ready analysis of daily rainfall according to the specified event thresholds. A brief explanation is provided in the 'read me' worksheet of the template. For daily rainfall delivered using the 'rainfall' format through the Longpaddock URL in footnote 2, simply copy and paste rainfall values to the 'rf (mm)' column of the 'ex SILO' worksheet (date range 1/1/1889 to 7/11/2013). Summary statistics are automatically updated in the following event-threshold worksheets ('10 mm', '25 mm' and '50 mm').

3 http://www.nintione.com.au/resource/AustralianRangelandsAndClimateChange_RainfallVariabilityPastureGrowth_RainfallTemplate.xlsx.

3.4 Caveats

Caveats and limitations associated with this analysis include:

1. The assumption that the specified rainfall threshold does actually indicate the described growth event for the location being considered. For example, 25 mm is a marginal growth event and 50 mm an ideal event for Alice Springs. Countering this limitation, many event sizes have exceeded the specified threshold (see following Figure 3.2 example for Alice Springs), thereby increasing the probability of the indicated effectiveness of the event.
2. Effective pasture growth is primarily interpreted with regard to the pastoral industry (i.e. probable forage availability for grazing). Analysis of historic rainfall for desert locations is included to increase geographic spread throughout the Rangelands Cluster. The value of threshold event sizes for promoting growth in spinifex communities and other desert vegetation is uncertain.
3. Land (or rangeland) condition is an important factor in how well vegetation responds to rainfall, particularly when events are small and well separated in time. For example, events of 50 mm or more in central Australia will promote a much larger growth of forage where perennial grasses are present than where grass and herbage species have to germinate and grow from a bare-ground situation.
4. Season and associated temperature effects are ignored in this analysis. Growth response may be limited by cooler winter temperatures in the southern and central parts of the cluster region, but evapotranspiration will also be lower providing a longer period of soil moisture availability. Temperature is not a major limitation for plant growth in the warmer months and evapotranspiration is increased. C_3 plants grow more rapidly in the cool months at the start of the growing season, while growth of C_4 plants (such as tropical grasses) peaks later in the warmer parts of the season.

5. Each event is defined by continuous daily rainfall. This means that one or more dry days in an otherwise wet period ends the initial event and may lead to a subsequent event close in time. This may overstate the number (and frequency) of events, reduce the event size and shorten the return period between events compared with a more flexible approach to defining events (e.g. allowing one or more dry days during an extended wet period). This bias is likely to be more common in wetter years and is not considered a major limitation to interpreting the following results.
6. Rainfall analysis is based on the period 1/1/1950 to 30/04/2013. More recent rainfall analysis requires that formulas in the template spreadsheet are varied accordingly. This requires copying column formulas down for additional rows (in each event-size worksheet) and extending the relevant array sizes for summary statistics (again, each event-size worksheet).

3.5 Findings

3.5.1 Analysis of Alice Springs rainfall

We use the Alice Springs rainfall record to illustrate comprehensive summary statistics for various-sized rainfall events. A subset of these statistics is summarised for all locations within the Rangelands Cluster in the following section with further summary data tabulated in Appendix A, Tables A1 and A2.

Event size and duration

The duration of rainfall events increased as event size increased (Table 3.1). The 10th and 90th percentiles of each parameter were correspondingly related.

There were 443 separate events for the 10 mm threshold, 182 events for the 25 mm threshold and 69 events greater than 50 mm during the 63-year period.

Approximately 70% of events exceeded 60 mm (and extended over three of more days) for the 50 mm event-threshold (Figure 3.2).

There was no consistent decadal pattern in the number of 25 mm or 50 mm events (Figure 3.3); basically, the 1970s was a wetter period, and the 1950s, 1960s and 1990s had a reduced number of 50 mm events.

Table 3.1 Summary statistics for event size (mm rainfall) and length (days) for various thresholds of continuous daily Alice Springs rainfall, 1950–2012

PARAMETER	EVENT SIZE (THRESHOLD)								
	10 mm			25 mm			50 mm		
	10%	median	90%	10%	median	90%	10%	median	90%
Rainfall (mm)	11.4	21.4	63.4	27.0	42.8	113.6	53.4	81.6	200.5
Rain days	1	3	5	2	3	6	2	4	7

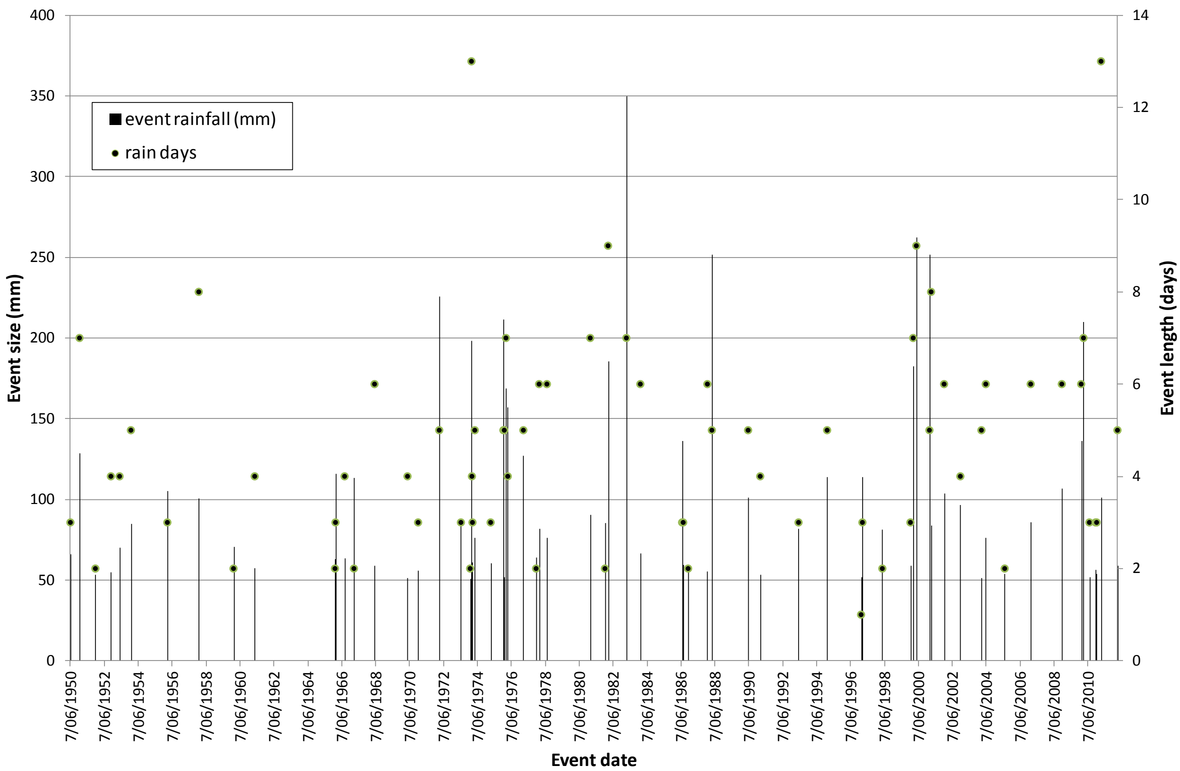


Figure 3.2 Timing, size and length of Alice Springs rainfall events between 1950 and 2012 that comprised more than 50 mm of continuous daily rainfall

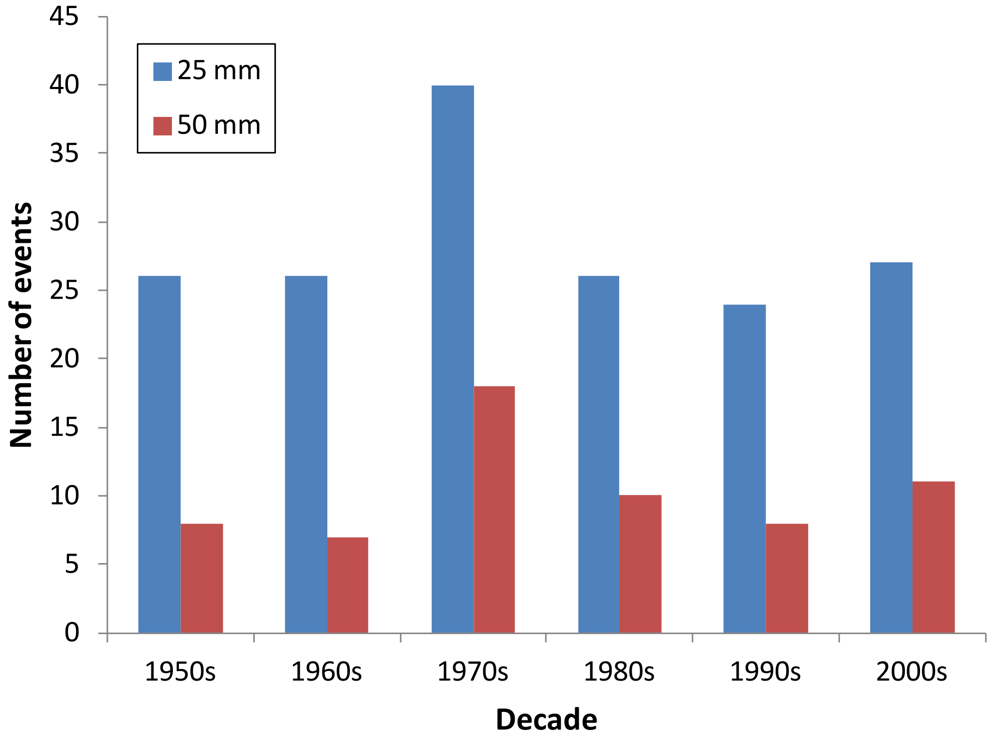


Figure 3.3 Decadal occurrence of >25 mm and >50 mm rainfall events for Alice Springs

3.5.2 Return period of events

Based on the requirement for continuous daily rainfall, 25 mm rainfall events were separated by a median return period of 82 days (Table 3.2). This increased to 272 days for 50 mm events. Significantly, 33 of the 63 calendar years between 1950 and 2012 did not have a 50 mm event.

Table 3.2 Median return period (days) for continuous daily rainfall events of varying size at Alice Springs

PARAMETER	MEDIAN RETURN PERIOD (DAYS) FOR EVENT SIZE OF:		
	10 mm	25 mm	50 mm
Continuous rainfall record 1950 to 2012	28	82	272
Wet season rainfall 1950–51 to 2012–13	25	40	60
Number of calendar years without an event	2	11	24
Number of wet seasons without an event	1	10	25

Return periods are based on the continuous rainfall record and summer (wet season) rainfall. The number of calendar years and wet seasons missing an event between 1950–51 and 2012–13 is also listed.

The return period for 25 mm and 50 mm events shortens to 40 and 60 days respectively for summer rainfall (mid-October to mid-April). Of the 63 wet seasons between 1950–51 and 2012–13, 10 failed to have a 25 mm event and 25 missed a 50 mm event.

As described above, there were 182 events of 25 mm (or more) rainfall over continuously wet days between 1950 and 2012. Fifty-eight of these events were separated by less than a month (Figure 3.4, left-hand graph) with these more frequent occurrences associated with sequences of wetter years. The frequency of >25 mm events progressively decreased as the separation between events increased, with 11 events being separated by more than a year. This progressive separation of marginal growth events was associated with individual dry years and runs of drier years (i.e. drought).

Corresponding frequencies for a 50 mm (or more) event were lower (Figure 3.4, right-hand graph). There were 69 events for the 63-year record; 17 of these were separated by one to two months (most commonly in 1974 and 2010, particularly wet years) and 24 by more than one year.

Truncating the rainfall record to wet-season rainfall generated 179 events of >25 mm rainfall (96 events of >50 mm). Most of the smaller events were separated by less than a month within each wet season, with ~85% of

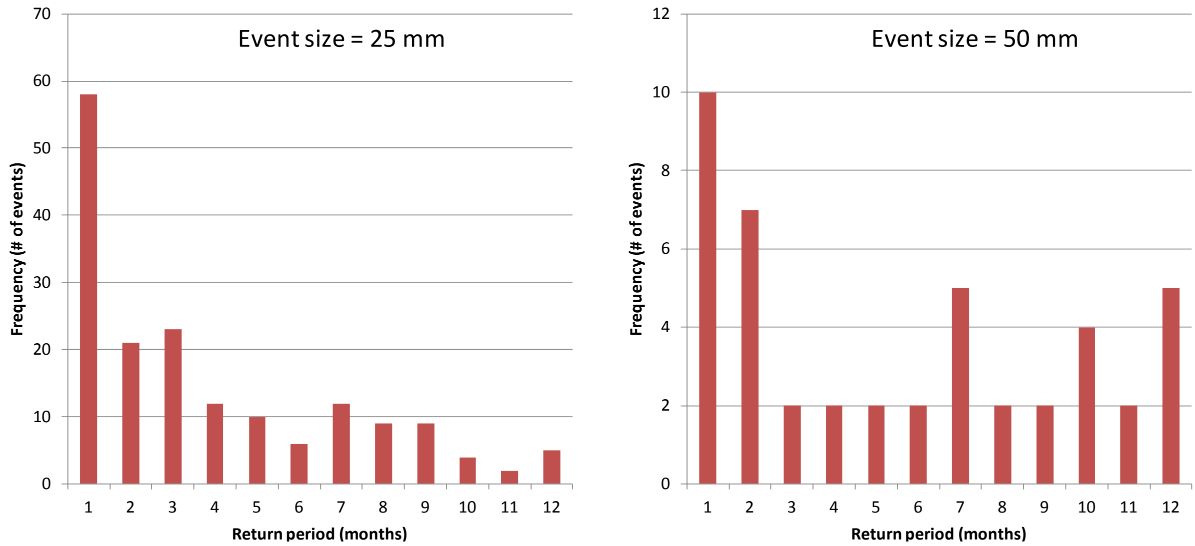


Figure 3.4 Frequency of return periods (months) for 25 and 50 mm rainfall events based on Alice Springs rainfall

events being separated by three or less months. Most of the >50 mm events were separated by two months within each wet season, and 70% of all events within each wet season occurred within three months of each other.

These results illustrate that probable marginal and ideal growing conditions (based on receiving either >25 mm or >50 mm rainfall over consecutive rainy days) are infrequent and widely separated in time for Alice Springs. This simple analysis is embedded within cycles of wetter and drier sequences that are separated by ten or more years (Figure 3.5).

Since 1950, the median return period for marginal and ideal growth events (i.e. >25 mm and >50 mm respectively) was shorter during the summer months but was still of the order of 1.5 to 2 months. Significantly also, ten years (16% of occurrences) did not experience even a marginal growth event over this period.

The take-home message is that, for Alice Springs, rainfall events sufficient for marginal and better pasture growth is infrequent and generally widely separated in time. This situation is unlikely to change under climate change predictions of continued high natural variability.

The frequency and median return periods of probable marginal and ideal growth events are embedded within considerable year-to-year rainfall variability.

3.5.3 Regional analysis of rainfall

The median return period of >25 and >50 mm events plus the number of calendar years (or wet seasons) without either event are mapped in Figure 3.6 and Figure 3.7, and summarised in Tables 5.3–5.10 (arranged by location within NRM region). Wet-season data are presented for those stations having distinct dominance of summer rainfall (red dots in Figure 3.1). Data for all other stations are based on the continuous rainfall record.

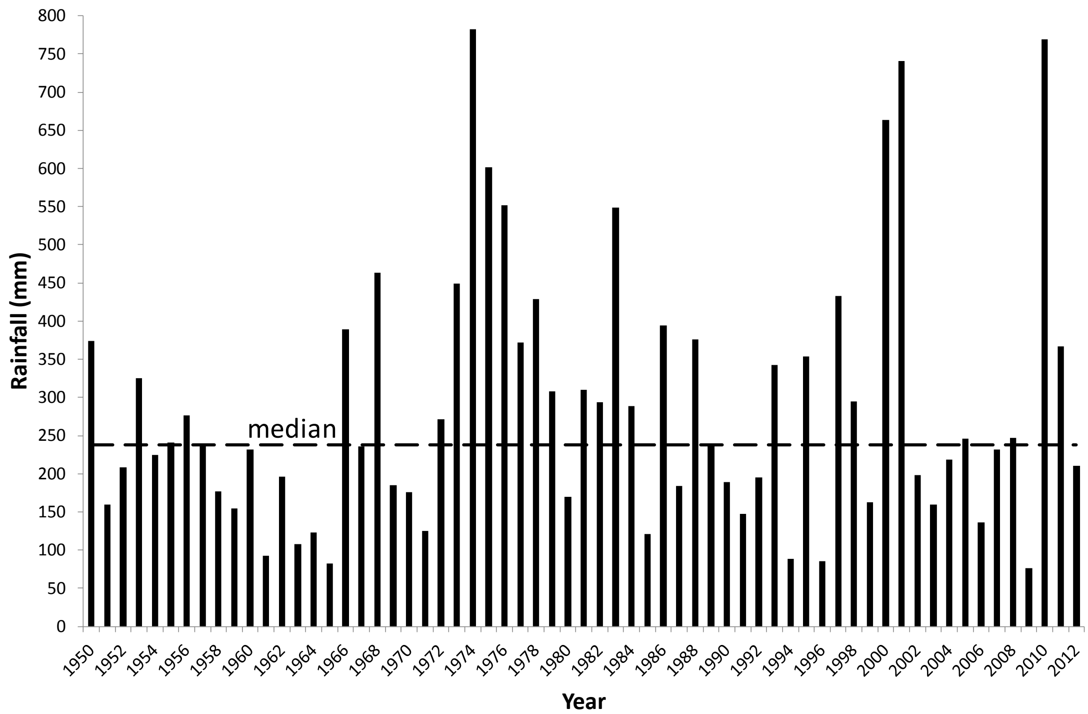
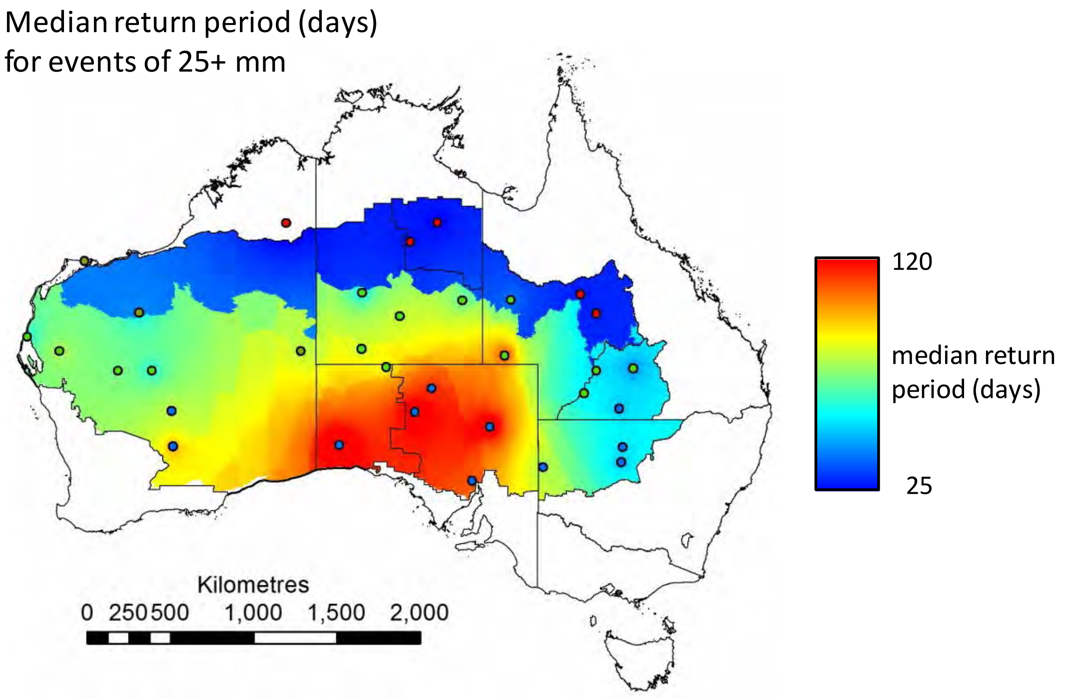


Figure 3.5 Yearly and median rainfall for Alice Springs between 1950 and 2012



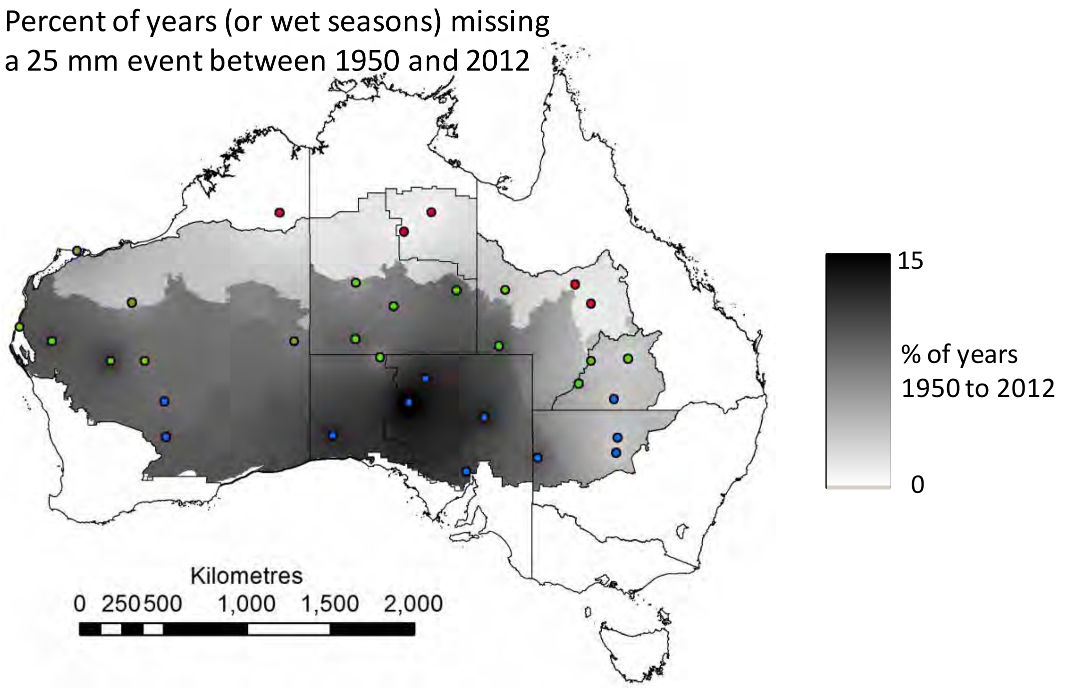
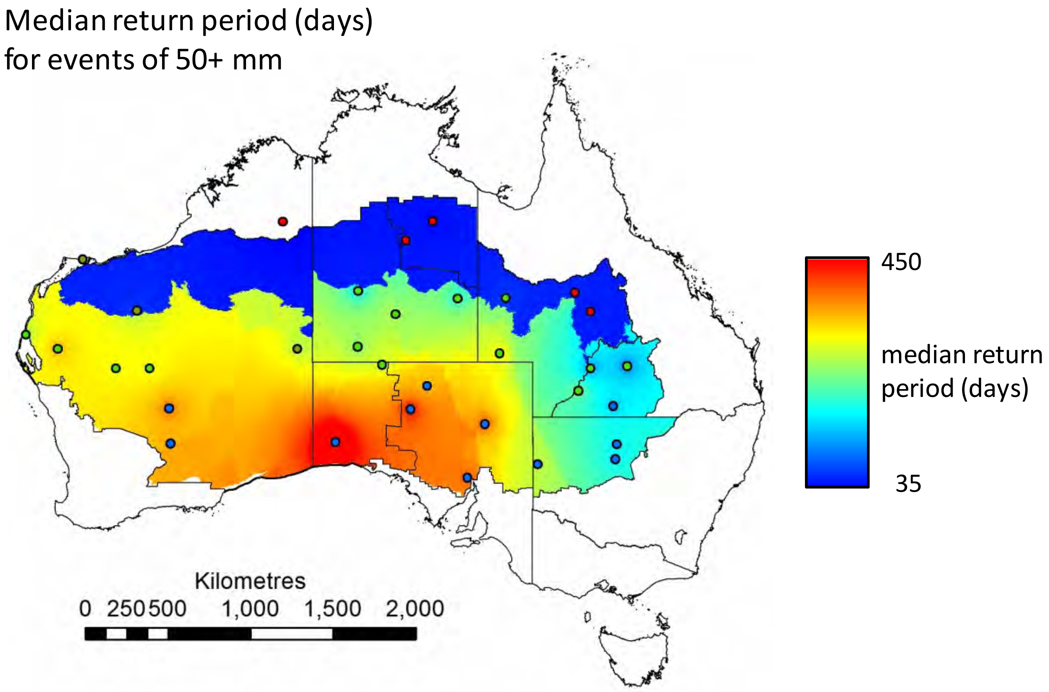


Figure 3.6 Top: interpolated median return period of >25 mm rainfall events over continuously wet days based on the continuous rainfall record 1950–2012 or summer (wet season) rainfall for the northern part of the Rangelands Cluster; Bottom: percentage of years 1950–2012 not having a >25 mm event in the calendar year (or summer wet season for the northern part of the Rangelands Cluster region)



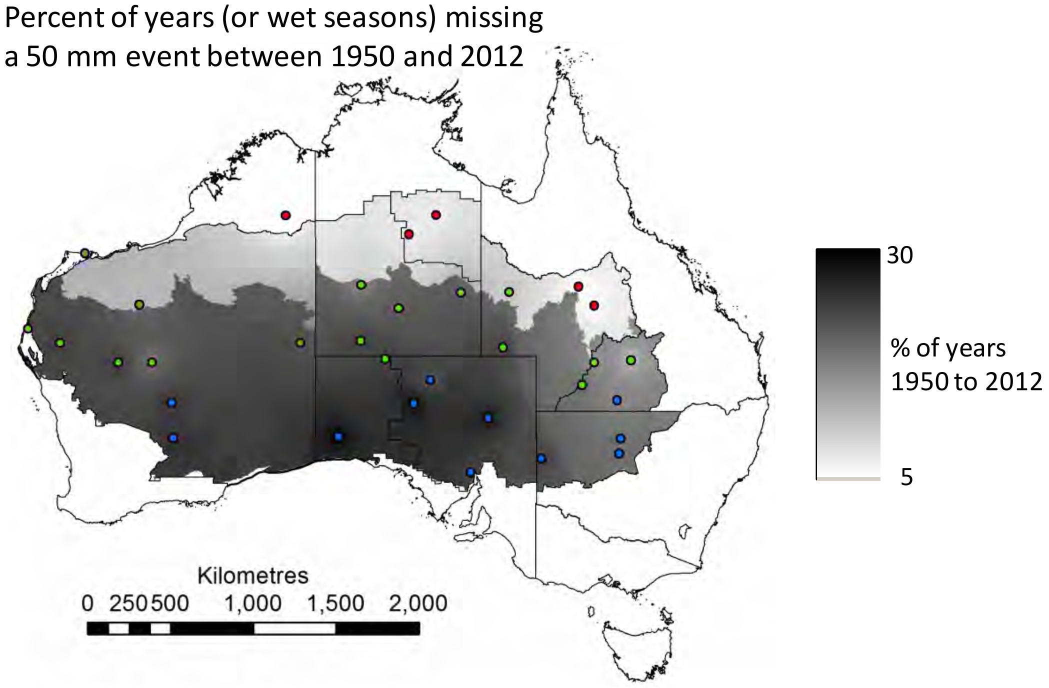


Figure 3.7 Top: interpolated median return period of >50 mm rainfall events over continuously wet days based on the continuous rainfall record 1950–2012 or summer (wet season) rainfall for the northern part of the Rangelands Cluster; Bottom: percentage of years 1950–2012 not having a >50 mm event in the calendar year (or summer wet season for the northern part of the Rangelands Cluster region)

The maps were produced using linear distance-weighted interpolations of the values for locations listed in Tables 5.3–5.10. These maps are intended as a pictorial guide only; that is, interpolated values indicate possible (not actual) values between stations. Interpolated values should be used cautiously for downscaling to parts of NRM regions.

The maps and following tables show that:

- The median return period lengthens for locations with lower and more variable annual rainfall, that is, to the south (Port Augusta, Cook, Kalgoorlie) and towards the more arid interior (Coober Pedy, Marree, Birdsville, Oodnadatta).
- The median return period for >50 mm events in parts of the arid zone is extreme: ~1 year or more for Cook, Coober Pedy, Marree, Oodnadatta, Port Augusta, Leonora, Gascoyne Junction and Kalgoorlie, and >200 days for 13 other locations, including Alice Springs. Some of these recording stations are outside the pastoral zone and thus of reduced value for indicating the frequency of probable pasture growth events.
- Lower evapotranspiration in southern Australia may mean that continuous daily rainfalls of >25 mm produce more forage than in northern and central Australia. This is particularly the case on the Nullarbor where cool rainy periods occur in winter, and here cumulative wet periods of >10 mm may promote pasture growth.
- Generally, however, the last 60+ years of rainfall data show that periods of rainfall suitable for marginal to ideal pasture growth conditions are infrequent throughout much of the Rangelands Cluster region.

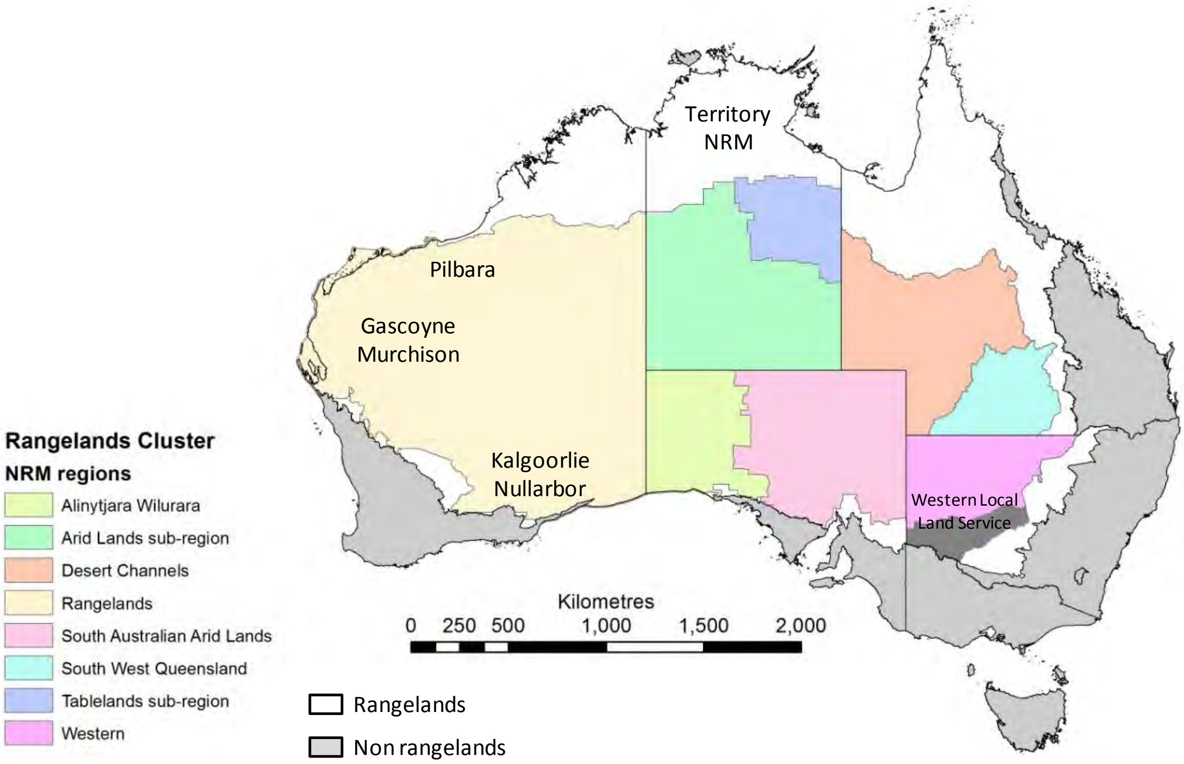


Figure 3.8 NRM regions in the Rangelands Cluster

Also shown is the Rangelands boundary as defined by the Australian Collaborative Rangelands Information System, the current Western Local Land Service in NSW and the extent of Territory NRM in the NT.

- These probabilities are unlikely to improve under forecast continuing rainfall variability. A continuing cautious approach to stocking levels, strict control of total grazing pressure and drought preparedness are required into the future.

The frequency of monthly return periods for recording stations and type of analysis is summarised in Appendix A. These data are similar to those described for Alice Springs in Figure 3.4 and essentially indicate the likely frequency of marginal and ideal growing conditions throughout the year (or summer wet season for northern locations).

As for Alice Springs, both >25 and >50 mm events were more common in wetter years for most recording stations (i.e. higher frequencies for the one- and two-month separations).

NSW: Western Local Land Service region (includes former Western CMA)

Analysis of the continuous rainfall record, 1950–2012, is shown in Table 3.3 (see Figure 3.8 above for the location of NRM regions).

Comments:

- Bourke rainfall is indicative of the Mulga Lands bioregion where a >50 mm event is probably required to initiate worthwhile pasture growth, although >25 mm events in the cooler winter months should promote useful herbage growth.
- The Cobar rainfall is relevant to the Cobar Peneplain where, due to invasive native scrub and general land degradation, >50 mm of rainfall is probably required to promote useful pasture growth, with 25 mm or more being valuable in the cooler months.
- Broken Hill rainfall is representative of the Broken Hill Complex bioregion, where a >25 mm event should encourage new leaf growth on chenopod shrubs, and >50 mm provides an ideal pasture growth event.
- The Ivanhoe, Balranald and Wentworth rainfall figures provide a regional spread through the Murray–Darling Depression bioregion (mixed woodlands, mallee and chenopod shrublands) where >25 mm of rain should promote pasture growth on sandy soils and freshen chenopods. Larger rainfall events (i.e. >50 mm) are ideal for worthwhile pasture growth. In winter, smaller falls (10 mm or more) should also encourage pasture growth.
- The Balranald rainfall is also representative of the western Riverina where >25 mm is useful, and lesser amounts in winter (10 mm or more) may result in a limited response by perennial chenopods and other herbage species.

Table 3.3 Median event size (mm), return period (days) between continuous daily rainfall events exceeding 10, 25 or 50 mm and number of years without an event during the 1950–2012 period for locations in the NSW Western Local Land Service region.

LOCATION	EVENT SIZE THRESHOLD (MM)			RETURN PERIOD (DAYS)			NO. YEARS WITHOUT EVENT		
	10 mm	25 mm	50 mm	10 mm	25 mm	50 mm	10 mm	25 mm	50 mm
Balranald	19.0	36.6	68.2	18	54	296	0	4	42
Bourke	22.1	38.8	72.1	20	50	171	0	4	31
Broken Hill	19.6	37.7	66.8	29	74	287	0	18	40
Cobar	21.6	38.5	66.7	18	44	166	0	3	31
Ivanhoe	19.0	36.9	67.1	21	61	282	0	8	43
Wentworth	18.0	35.2	64.8	26	104	379	0	15	46

Queensland: South West NRM

Analysis of the continuous rainfall record, 1950–2012, for four locations is presented in Table 3.4.

Comments:

- The Mulga Lands is the most extensive bioregion in this NRM region, and Charleville, Cunnamulla and Quilpie provide a good geographic spread of rainfall stations through this broad land type. Woody density has thickened across much of the bioregion, and a long history of heavy grazing by livestock, kangaroos and goats has also degraded pastures. Rainfall events of >50 mm are probably required to promote effective pasture growth, although >25 mm in the cooler months should also produce a growth response.

Thargomindah is near the boundary of the Mulga Lands and Channel Country (and also close to the neighbouring Desert Channels NRM region). Rainfall events of 50 mm or more are probably required to produce good pasture growth, and >25 mm events will provide a lesser response.

Queensland: Desert Channels

Analysis of the continuous rainfall record, 1950–2012, and summer period (1950–51 to 2012–13) for Longreach and Winton is shown in Table 3.5.

Comments:

- Boulia, Longreach and Winton provide a geographic spread of rainfall pattern through the Mitchell Grass Downs bioregion. Restricting rainfall analysis to the summer months (wet season) shortens the return interval on >25 and >50 mm events. The high evapotranspiration rates associated with this grassland region mean that >50 mm events are required to initiate significant pasture growth. Smaller events of 25 mm or more will then prolong the growing season and may promote a limited herbage response in the cooler months (normally, the dry season).
- Birdsville, at the western edge of the Channel Country and close to the Simpson Desert, is a truly arid location with almost a year (median interval) separating significant pasture growth events (i.e. >50 mm) and 62% of the years between 1950 and 2012 not experiencing one of these larger rainfall events. Substantial herbage growth does of course result from widespread flooding following good rains in the catchment of the desert channels. Smaller rainfall events (>25 mm) will promote forage growth on sandy country and in the gilgais and watercourses of the stony Channel Country as a result of run-on from adjacent slightly higher areas.

Table 3.4 Median event size (mm), return period (days) between continuous daily rainfall events exceeding 10, 25 or 50 mm and number of years without an event during the 1950–2012 period for locations in the South West NRM region.

LOCATION	EVENT SIZE THRESHOLD (MM)			RETURN PERIOD (DAYS)			NO. YEARS WITHOUT EVENT		
	10 mm	25 mm	50 mm	10 mm	25 mm	50 mm	10 mm	25 mm	50 mm
Cunnamulla	23.5	40.1	76.8	20	45	128	0	3	24
Charleville	24.1	44.0	68.4	15	35	73	0	2	13
Quilpie	22.8	43.3	70.4	22	47	70	0	3	24
Thargomindah	22.6	39.1	75.4	26	54	275	0	9	33

South Australia: Arid Lands

Analysis of the continuous rainfall record, 1950–2012, is listed in Table 3.6.

Comments:

- Coober Pedy, Marree and Oodnadatta are located in the extensive Stony Plains bioregion, with the Simpson and Strzelecki Deserts situated to the east and north of the Stony Plains. Medium-sized rainfall events (>25 mm) should promote a reasonable pasture response in both broad land types with growth in the Stony Plains resulting from run-on to gilgais, drainage lines and watercourses. The larger events (>50 mm) will enhance this response, but Table 3.6 demonstrates that these good rainfalls are rare in this arid part of Australia.
- Port Augusta is at the edge of the Gawler bioregion and adjacent to the Flinders Ranges, and summary statistics from analysis of its rainfall may have some indicator value for both pastoral regions. For land in good condition, >25 mm events should generate worthwhile pasture growth, with >10 mm events being of some value on sandy country and in the cooler winter months. Larger (>50 mm) events are rare and provide a bonus for forage growth when received.

Table 3.5 Median event size (mm), return period (days) between continuous daily rainfall events exceeding 10, 25 or 50 mm and number of years without an event during the 1950–2012 period for locations in the Desert Channels NRM region.

LOCATION	EVENT SIZE THRESHOLD (MM)			RETURN PERIOD (DAYS)			NO. YEARS WITHOUT EVENT		
	10 mm	25 mm	50 mm	10 mm	25 mm	50 mm	10 mm	25 mm	50 mm
Birdsville	21.9	40.5	68.5	46	123	331	3	18	39
Boulia	23.3	43.0	74.1	27	63	281	0	9	31
Longreach	25.6	44.5	77.9	18	36	70	0	2	12
Winton	24.4	49.8	82.3	17	32	87	1	6	14

Based on analysis of wet-season rainfall (i.e. mid-October to mid-April)

LOCATION	MEDIAN RETURN PERIOD FOR EVENT SIZE		NO. YEARS WITHOUT EVENT	
	25 mm	50 mm	25 mm	50 mm
Longreach	29	53	1	7
Winton	27	56	2	6

Table 3.6 Median event size (mm), return period (days) between continuous daily rainfall events exceeding 10, 25 or 50 mm and number of years without an event during the 1950–2012 period for locations in the SA Arid Lands NRM region.

LOCATION	EVENT SIZE THRESHOLD (MM)			RETURN PERIOD (DAYS)			NO. YEARS WITHOUT EVENT		
	10 mm	25 mm	50 mm	10 mm	25 mm	50 mm	10 mm	25 mm	50 mm
Coober Pedy	17.1	36.7	72.6	44	152	499	6	33	50
Marree	18.8	37.3	70.9	45	158	443	9	24	49
Oodnadatta	20.5	38.4	69.3	46	119	344	1	23	31
Port Augusta	17.3	35.3	59.0	31	113	422	0	19	36

South Australia: Alinytjara Wilurara

Analysis of the continuous rainfall record, 1950–2012, is presented in Table 3.7.

Comments:

- The Ernabella rainfall summary has some indicator value for likely forage availability and security for small-scale cattle enterprises on Aboriginal country in the far north of the region. Where land can be maintained in good condition, >25 mm events should produce a limited growth response and >50 mm events an ideal response. However, these larger events are infrequent, and 60% of years since 1950 (to 2012) failed to receive such rainfall.
- Cook, on the Transcontinental Railway, is in the Nullarbor region where large rainfall events are very rare (median return period of almost two years for >50 mm events and 80% of recent years not experiencing such an event). The vegetation has obviously adapted to persist under such low rainfall, and cool moist days in winter (e.g. >10 mm of rainfall) can apparently produce useful new leaf growth on chenopod shrubs. Medium-sized events (>25 mm) will likely produce a herbage response by annual species, particularly in the cooler months.

Northern Territory: Arid Lands sub-region

Analysis of the continuous rainfall record, 1950–2012, is listed in Table 3.8.

Comments:

- Alice Springs, Yuendumu and Jervois rainfall summaries have some indicator value for the Burt Plain pastoral bioregion (although Jervois is actually in the far western part of the Channel Country bioregion). Alice Springs is also relevant to the MacDonnell Ranges and northern Finke bioregions. Where pastoral land is in good condition, 25 mm events constitute a marginal growth event, and >50 mm should provide for ideal growing conditions. Water redistribution (i.e. run-on to lower slopes and watercourses) is particularly important for promoting growth beyond actual rainfall received. The smaller events (~25 mm) will encourage greater herbage and grass response on sandy soils and in the cooler months.
- Similar comments apply to the Curtin Springs rainfall history (western part of the Finke bioregion), but the medium-sized events (i.e. 25 mm) may promote greater pasture growth because there is an increased probability of receiving such rainfall in the cooler months of the year when evaporation is reduced.

Table 3.7 Median event size (mm), return period (days) between continuous daily rainfall events exceeding 10, 25 or 50 mm and number of years without an event during the 1950–2012 period for locations in the Alinytjara Wilurara NRM region.

LOCATION	EVENT SIZE THRESHOLD (MM)			RETURN PERIOD (DAYS)			NO. YEARS WITHOUT EVENT		
	10 mm	25 mm	50 mm	10 mm	25 mm	50 mm	10 mm	25 mm	50 mm
Cook	17.3	35.2	65.6	40	155	711	1	22	50
Ernabella	21.6	38.1	75.9	25	80	278	0	8	38

Table 3.8 Median event size (mm), return period (days) between continuous daily rainfall events exceeding 10, 25 or 50 mm and number of years without an event during the 1950–2012 period for locations in the NT Arid Lands NRM sub-region.

LOCATION	EVENT SIZE THRESHOLD (MM)			RETURN PERIOD (DAYS)			NO. YEARS WITHOUT EVENT		
	10 mm	25 mm	50 mm	10 mm	25 mm	50 mm	10 mm	25 mm	50 mm
Alice Springs	21.4	42.8	81.6	28	82	272	2	11	33
Curtin Springs	21.0	40.2	75.3	29	77	222	0	16	39
Jervois	23.1	43.0	80.7	30	62	160	2	17	33
Yuendumu	22.8	44.9	83.1	20	43	130	0	6	21

Northern Territory: Tablelands sub-region

Analysis of both annual rainfall (1950–2012) and wet-season rainfall (1950–51 to 2012–13) is shown in Table 3.9.

Comments:

- Brunette Downs rainfall data are relevant to the extensive Mitchell Grass Downs on the Barkly Tableland, where >50 mm rainfall events are probably required to initiate substantial pasture growth in the wet season, and follow-up medium-sized events (~25 mm) extend the growing season.
- Tennant Creek rainfall data apply to the less pastorally productive Davenport Murchison Ranges bioregion where, again, >50 mm events are required for worthwhile pasture growth but >25 mm events may have some value with moisture redistribution (runoff and run-on) associated with the greater relief of the more useful grazing country in this bioregion.

For both locations, excluding the cooler (normally dry season) months from analysis shortens the median return period for larger events and reduces the number of years (wet seasons) failing to record such an event.

Western Australia: Rangelands

Analysis of the continuous rainfall record, 1950–2012, for all locations and wet-season rainfall (1950–51 to 2012–13) for northern recording stations is listed in Table 3.10.

Comments:

- The Leonora, Meekatharra and Wiluna rainfall data apply to the Murchison bioregion, an extensive area of mainly low mulga woodlands. It is likely that rainfall events of 25 mm or more should initiate some pasture response where grazing land is in satisfactory condition, particularly in the cooler months when evaporation is reduced. Larger (>50 mm) events will be more beneficial but, as for most of the arid rangelands, these larger rainfall pulses are infrequent with a median return period greater than nine months and almost two-thirds of years between 1950 and 2012 missing such an event.
- Kalgoorlie is on the boundary between the Murchison and Coolgardie bioregions, the latter comprising perennial chenopods where palatable species provide an important forage source for sheep (less so for cattle). Again, >25 mm rainfall events should be valuable where land is in better condition, with this value enhanced by a greater probability of rainfall occurring in the cooler months. Extending into the Nullarbor bioregion to the east, lesser rains (even 10 mm or more over several days during winter) have increasing value for forage growth (see comments above with regard to rainfall statistics for Cook in the Alinytjara Wilurara region).

Table 3.9 Median event size (mm), return period (days) between continuous daily rainfall events exceeding 10, 25 or 50 mm and number of years without an event during the 1950–2012 period for locations in the NT Tablelands NRM sub-region.

LOCATION	EVENT SIZE THRESHOLD (MM)			RETURN PERIOD (DAYS)			NO. YEARS WITHOUT EVENT		
	10 mm	25 mm	50 mm	10 mm	25 mm	50 mm	10 mm	25 mm	50 mm
Brunette Downs	28.2	51.9	76.2	13	20	38	0	2	12
Tennant Creek	25.6	48.5	92.3	15	25	64	0	1	20

Based on analysis of wet-season rainfall (i.e. mid-October to mid-April)

LOCATION	MEDIAN RETURN PERIOD FOR EVENT SIZE		NO. YEARS WITHOUT EVENT	
	25 mm	50 mm	25 mm	50 mm
Brunette Downs	23	36	0	9
Tennant Creek	27	47	0	9

- The Carnarvon and Gascoyne Junction rainfall summaries are relevant to the Carnarvon bioregion, another pastoral region of mainly acacia or chenopod shrublands. Similar comments describing the Murchison bioregion apply: >25 mm rainfall events are useful, particularly as significant rainfall is received in the cooler months, and larger events approaching 50 mm are particularly beneficial. Again, however, larger amounts of extended rainfall are rare in this region (median return period approaching one year).
- It is probable that relatively large (>50 mm) rainfall events are required to initiate significant pasture growth in the Pilbara (Newman and Karratha rainfall records) with smaller events (>25 mm) extending the growing season if received within sufficient time to maintain adequate soil moisture for plant growth. The topography of the region has a mediating effect on rainfall received through localised redistribution (i.e. runoff and run-on). Rainfall effectiveness is also limited by generally high evapotranspiration rates, although its effect on resultant pasture growth is countered by the C_4 photosynthetic pathway of much of the herbage layer.

Table 3.10 Median event size (mm), return period (days) between continuous daily rainfall events exceeding 10, 25 or 50 mm and number of years without an event during the 1950–2012 period for locations in the southern WA Rangelands NRM sub-region.

LOCATION	EVENT SIZE THRESHOLD (MM)			RETURN PERIOD (DAYS)			NO. YEARS WITHOUT EVENT		
	10 mm	25 mm	50 mm	10 mm	25 mm	50 mm	10 mm	25 mm	50 mm
Carnarvon	22.4	41.6	71.2	23	56	255	1	17	37
Gascoyne Junction	19.8	38.8	68.2	26	82	364	1	18	39
Giles	20.9	41.8	76.8	26	77	266	1	11	35
Halls Creek	26.6	45.6	87.1	8	14	38	0	0	9
Kalgoorlie	19.0	36.4	63.5	31	104	366	0	16	42
Karratha	28.1	53.0	86.0	22	49	117	3	8	21
Leonora	20.0	37.3	64.6	31	82	410	0	13	41
Meekatharra	20.0	45.0	68.6	29	72	305	0	22	40
Newman	22.2	44.2	75.9	21	50	246	0	6	28

Based on analysis of wet-season rainfall (i.e. mid-October to mid-April)

LOCATION	MEDIAN RETURN PERIOD FOR EVENT SIZE		NO. YEARS WITHOUT EVENT	
	25 mm	50 mm	25 mm	50 mm
Halls Creek	19	31	0	5
Karratha	42	54	11	21
Newman	43	63	5	19

3.6 Key adaptation strategies

Comments relevant to the pastoral industry

- Manage for a dry year – stock conservatively and control total grazing pressure.
- Maintain good levels of ground cover for prevailing seasonal conditions – this slows runoff and aids infiltration when rains come.
- Projected hotter temperatures will increase evapotranspiration and decrease rainfall effectiveness, particularly during hot spells. At such times, even 50 mm events that are well separated in time may become marginal for effective growth. This emphasises the importance of maximising rain use efficiency (following dot point).
- Maintain (or encourage regeneration) of palatable perennial forage species on productive land types – perennials respond more rapidly to infrequent/episodic rainfall.

Appendix A Frequency of rainfall-return period and total number of rainfall events

The following tables summarise the frequency of monthly return periods by event size for recording stations. The total number of events of each magnitude between 1950 and 2012 is tallied in the final column. These data indicate the likely frequency of >25 mm and >50 mm growing events throughout the year. For most stations, higher frequencies for shorter return periods (1–2 months) were associated with particularly wet years. Conversely, longer separation periods occurred in drier years (or continuous dry years).

A1. Yearly rainfall: >25 mm

RECORDING STATION	RETURN PERIOD (MONTHS)												NO OF EVENTS
	1	2	3	4	5	6	7	8	9	10	11	12	
NSW: Western CMA													
Balranald	75	38	15	14	17	8	10	11	8	6	4	6	216
Bourke	93	55	36	23	14	12	8	5	6	4	5	2	267
Broken Hill	41	31	21	15	6	6	12	2	5	2	5	0	164
Cobar	124	67	40	33	14	12	9	3	5	2	1	2	315
Ivanhoe	75	33	29	18	13	7	10	8	7	4	4	3	218
Wentworth	37	24	12	6	17	8	13	4	8	4	3	2	152
Queensland: South West NRM													
Charleville	173	91	36	26	15	9	15	3	3	1	2	2	378
Cunnamulla	127	62	33	30	17	8	10	3	3	3	5	3	307
Quilpie	104	60	31	17	12	6	15	9	7	4	3	3	274
Thargomindah	77	40	27	21	10	9	8	8	6	5	5	1	225
Queensland: Desert Channels													
Birdsville	25	14	11	12	8	5	10	5	3	3	8	5	126

RECORDING STATION	RETURN PERIOD (MONTHS)												NO OF EVENTS
	1	2	3	4	5	6	7	8	9	10	11	12	
Boulia	62	31	16	13	9	9	5	8	5	5	9	6	187
Longreach	153	68	33	17	10	9	12	9	6	4	6	0	329
Winton	141	48	18	14	8	8	10	15	6	7	2	2	285
South Australia: Arid Lands													
Coober Pedy	15	10	5	7	4	4	3	4	1	3	3	1	84
Marree	16	6	12	8	6	7	3	3	4	5	3	4	98
Oodnadatta	15	18	11	12	8	8	1	4	0	5	8	6	108
Port Augusta	20	23	14	13	6	8	11	5	2	5	2	4	131
South Australia: Alinytjara Wilurara													
Cook	15	14	11	5	6	10	3	5	4	7	5	1	104
Ernabella	53	23	18	17	10	8	11	6	12	6	5	2	179
Northern Territory: Arid Lands sub-region													
Alice Springs	58	21	23	12	10	6	12	9	9	4	2	5	182
Curtin Springs	46	28	12	10	7	8	7	9	7	6	5	3	161
Jervois	60	28	20	12	8	4	12	7	5	5	1	3	180
Yuendumu	90	49	23	8	8	8	10	5	14	6	3	6	236
Northern Territory: Tablelands sub-region													
Brunette Downs	175	45	18	3	3	5	2	13	9	14	9	6	304
Tennant Creek	144	37	18	12	5	5	5	12	13	9	10	4	275
Western Australia: Rangelands													
Carnarvon	67	16	13	10	8	2	8	9	8	7	1	3	165
Gascoyne Junction	43	21	9	9	4	2	6	4	8	6	5	6	140
Giles	53	29	15	10	12	9	8	10	4	11	3	3	178
Halls Creek	262	35	18	7	5	8	6	12	13	10	7	3	386

RECORDING STATION	RETURN PERIOD (MONTHS)												NO OF EVENTS
	1	2	3	4	5	6	7	8	9	10	11	12	
Kalgoorlie	29	31	10	12	11	15	6	7	5	6	4	2	151
Karratha	78	37	14	8	7	6	11	5	9	1	7	10	201
Leonora	42	26	16	18	6	5	14	8	8	2	4	3	163
Meekatharra	44	21	11	16	6	4	5	5	7	2	3	1	143
Newman	80	31	16	9	8	8	7	6	10	8	8	8	204
Wiluna	69	34	15	12	6	6	11	9	3	8	6	3	193

A2. Yearly rainfall: >50 mm

RECORDING STATION	RETURN PERIOD (MONTHS)												NO OF EVENTS
	1	2	3	4	5	6	7	8	9	10	11	12	
NSW: Western CMA													
Balranald	6	8	2	1	1	0	0	1	1	4	2	1	45
Bourke	19	5	12	3	2	3	2	3	3	4	7	2	87
Broken Hill	12	3	5	2	1	0	0	0	2	0	3	3	49
Cobar	23	12	2	3	3	3	4	5	0	5	3	1	88
Ivanhoe	4	8	4	2	3	0	1	0	3	2	0	3	51
Wentworth	6	3	0	0	4	1	1	0	2	1	0	0	39
Queensland: South West NRM													
Charleville	44	27	12	5	3	3	11	4	6	8	7	9	151
Cunnamulla	27	7	6	7	5	4	4	2	3	3	10	5	101
Quilpie	39	15	5	3	1	1	1	3	5	5	8	6	110
Thargomindah	14	5	4	3	0	2	3	2	2	7	3	5	70
Queensland: Desert Channels													
Birdsville	7	2	3	0	1	3	3	1	1	2	2	3	48
Boulia	17	6	1	2	2	1	4	3	2	3	4	9	77
Longreach	45	21	14	5	0	3	2	7	14	5	12	7	146
Winton	44	20	9	8	5	4	3	7	2	5	11	12	142
South Australia: Arid Lands													
Coober Pedy	1	0	1	2	0	0	0	2	0	0	0	2	24
Marree	6	1	2	1	0	0	0	0	0	0	3	1	25
Oodnadatta	3	2	2	3	1	1	0	2	1	1	1	5	37

RECORDING STATION	RETURN PERIOD (MONTHS)												NO OF EVENTS
	1	2	3	4	5	6	7	8	9	10	11	12	
Port Augusta	1	0	1	1	0	0	0	0	2	0	0	3	21
South Australia: Alinytjara Wilurara													
Cook	2	2	0	0	1	3	0	0	1	0	1	0	22
Ernabella	9	3	4	3	0	5	0	0	3	3	2	6	54
Northern Territory: Arid Lands sub-region													
Alice Springs	10	7	2	2	2	2	5	2	2	4	2	5	69
Curtin Springs	6	9	4	5	3	1	0	2	1	5	2	1	56
Jervois	17	11	7	0	2	2	4	2	3	2	1	5	76
Yuendumu	22	16	7	5	4	0	5	5	8	6	3	8	104
Northern Territory: Tablelands sub-region													
Brunette Downs	75	20	5	3	2	3	0	5	9	10	8	10	161
Tennant Creek	49	14	9	1	1	1	3	4	6	9	7	8	128
Western Australia: Rangelands													
Carnarvon	9	6	2	0	5	1	0	5	3	5	2	0	59
Gascoyne Junction	5	2	1	1	2	0	2	4	2	3	0	1	46
Giles	8	12	3	1	2	2	1	2	2	4	4	2	65
Halls Creek	78	19	9	6	2	4	0	4	7	14	14	8	172
Kalgoorlie	4	0	2	2	1	2	3	1	1	2	1	3	44
Karratha	28	11	9	6	3	1	1	4	7	5	6	5	105
Leonora	6	1	3	2	0	2	0	2	0	1	0	4	44
Meekatharra	15	3	1	3	0	0	0	4	2	0	4	1	57
Newman	13	10	2	3	2	3	4	1	6	4	4	9	82
Wiluna	7	7	1	2	2	0	1	3	2	2	4	2	57

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Australian rangelands and climate change – meteorological drought

Gary Bastin

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4. Australian rangelands and climate change – meteorological drought

Key points

- Drought is a complex phenomenon with mixed environmental, social and economic implications. Here, we report on the recent history (since 1950) of meteorological drought, which is characterised by severe rainfall deficiency over periods of 12 months or more.
- Spatially interpolated rainfall data since 1950 were examined to determine the timing and severity of rainfall deficits as an indicator of meteorological drought.
- For most regions, the longest and most severe rainfall deficit occurred in the late 1950s extending to the mid-1960s. Other periods of general rainfall deficiency occurred in the early 1980s and the mid-2000s. Deficits also occurred in the 1950s, early 1970s and parts of the 1990s for some regions.
- This analysis of rainfall deficiency for the recent past should provide a guide to the probable severity of future meteorological droughts under continuing, and perhaps enhanced, rainfall variability. Drought will continue to be a recurrent feature in the Rangelands Cluster region, so a key adaptation response for the pastoral industry is simply to be prepared: utilise reliable climate forecasting services and implement drought management strategies promptly as key dates or trigger points for decision making are reached.

4.1 Introduction

Drought is a complex environmental, economic and social phenomenon. Part of this complexity results from its differential impact across sections of society, including the agricultural sector and the community. From an environmental perspective alone, drought can be considered in terms of:

- Meteorological conditions: combinations of rainfall deficit and evapotranspiration that collectively determine meteorological drought.
- Hydrological drought: soil water deficits and reduced runoff that greatly reduces water availability at different scales, particularly for towns and cities when dams are low.
- Agricultural drought: reduced pasture and/or crop growth resulting from extended low rainfall and depleted soil water availability.

For this component, we confine our discussion to meteorological drought. There are two indices used in the United States (and elsewhere) to characterise the severity of meteorological drought, but neither appear to have currency in Australia (i.e. they are not listed on the Bureau of Meteorology web site, www.bom.gov.au). This may be due to the highly variable nature of rainfall across much of Australia and particularly in the Rangelands Cluster region.

These indices are:

1. The Palmer Drought Index (also known as the Palmer Drought Severity Index), which provides a measurement of dryness based on recent precipitation and temperature (detailed information in Palmer 1965). The index is based on water balance, including supply (precipitation), demand (evapotranspiration) and loss (runoff). Its application requires that many parameter values be set and index values appear difficult to calculate (although a FORTRAN program is available). Its suitability to the Australian rangelands is not known.
2. The Standardised Precipitation Index is a probability index that considers only precipitation. The index is endorsed by the World Meteorological Organization.

Further information on both indices is available on the web (NOAA 2013).

The Bureau of Meteorology (BoM) reports on drought in terms of rainfall deficiency, both its duration and regional extent (BoM 2014). This BoM approach is used here with regional historical rainfall data.

4.2 Method

Analysis and reporting of historic rainfall data is confined to the main areas of pastoral estate in each NRM region of the Rangelands Cluster (Figure 4.1).

Gridded monthly rainfall data for Australia since 1890 had been compiled within the Australian Collaborative Rangelands Information System (ACRIS) (ACRIS n.d.) and are used as a convenient (i.e. readily accessible) dataset for this analysis. Pixel size is 0.05° (~5 km by ~5 km), with the rainfall amounts for individual grid cells interpolated from long-term recording stations. Grid-cell data are used here to allow spatial averaging of rainfall for pastoral districts within NRM regions (or part regions, Figure 4.1). This provides a more reliable estimate of district-wide rainfall anomaly, as an indicator of meteorological drought, than the point-based analysis of rainfall in Bastin (2014).

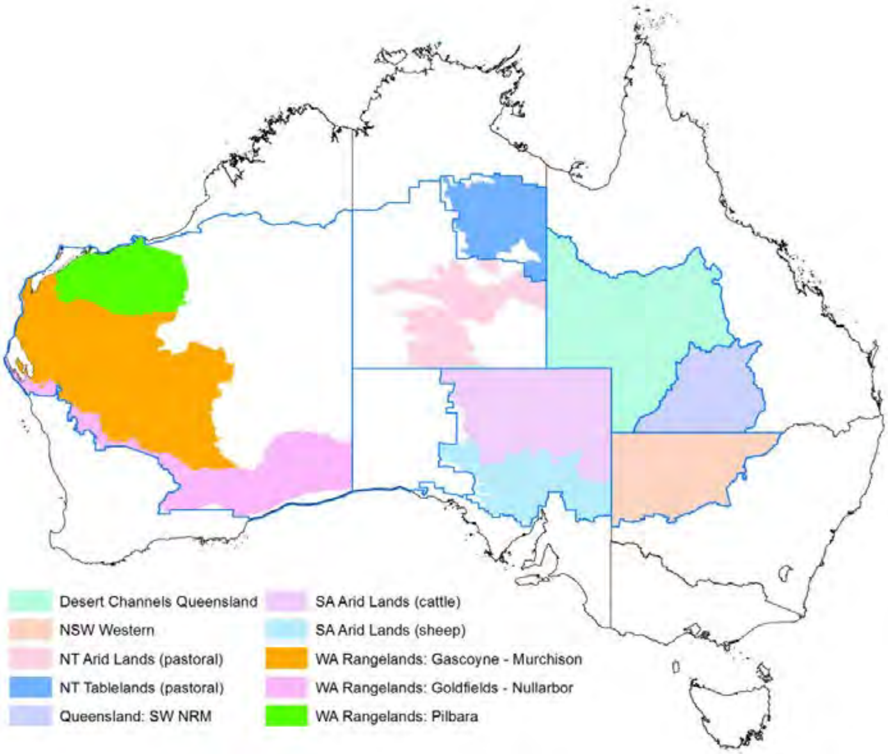

Figure 4.1 Pastoral areas within NRM regions of the Rangelands Cluster used for reporting recent periods of meteorological drought.

Blue lines show NRM regions / sub-regions.

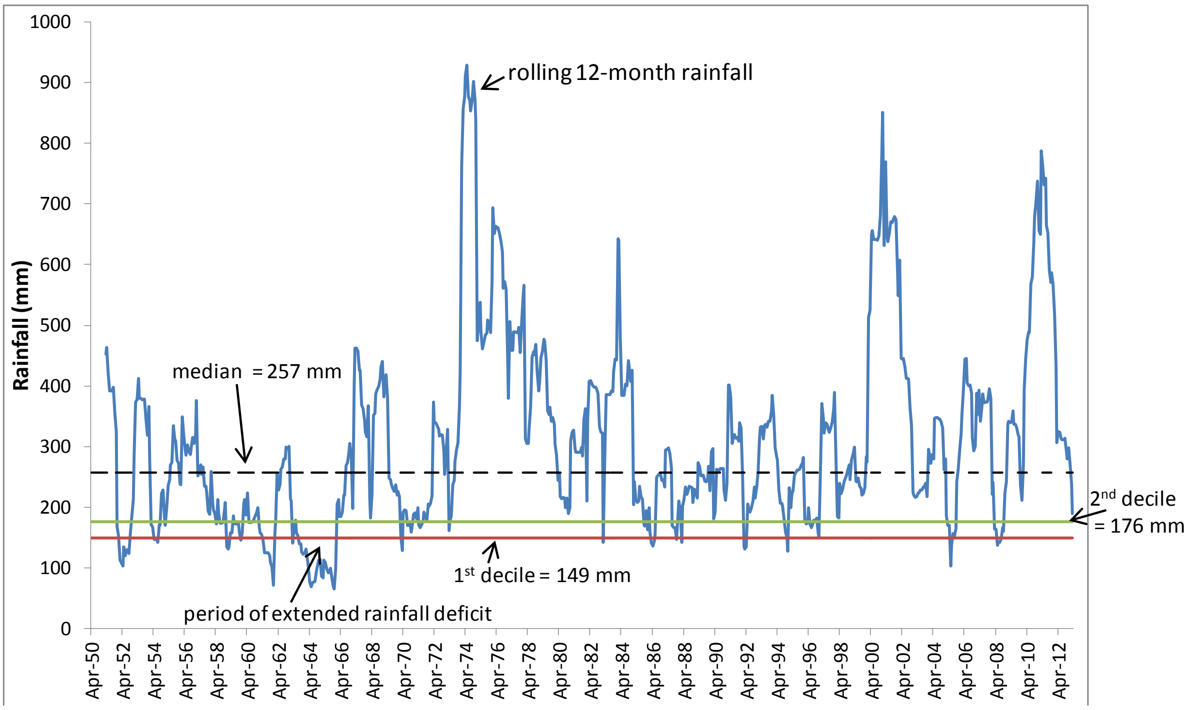

Figure 4.2 Spatially averaged monthly rainfall for the pastoral region of the NT Arid Lands sub-region accumulated on a rolling 12-month basis since April 1950. Horizontal lines show the first, second and fifth deciles for the same region based on April–March rainfall between 1890–91 and 2012–13.

The data were processed in the following way:

1. Spatially interpolated rainfall data were summed for each April–March rainfall year.[4]
2. Yearly rainfall data (1890–91 to 2012–13) were spatially averaged for each pastoral NRM region (Figure 4.1) and rainfall amounts corresponding with the first, second and fifth deciles determined. The fifth decile is the median.
3. Monthly rainfall data between April 1950 and March 2013 (63 years, 756 months) were similarly spatially averaged for each pastoral NRM region.
4. The monthly spatial averages were summed (in Excel) on a rolling 12-month basis (i.e. April 1950 to March 1951, May 1950 to April 1951, … , April 2012 to March 2013) and the accumulated amounts compared with the first and second deciles and the median (Figure 4.2). Periods with accumulated 12-month rainfall below the first or second deciles were likely associated with considerable moisture deficit and could usefully indicate meteorological drought.
5. Periods longer than one year with cumulative monthly rainfall less than the first decile were determined (Table 4.1). These indicate the most severe (meteorological) drought conditions since 1950 and give some guide to the future under predicted enhanced rainfall variability.

4.3 Data source

For these analyses we used an ACRIS dataset which stores interpolated monthly rainfall data for Australia since 1890. The historic period used in these analyses was April 1950 to March 2013 (as per point 1 above, ACRIS uses an April–March rainfall year to avoid splitting northern monsoonal rainfall across calendar years). Recent monthly rainfall grids are available at BoM (n.d.).

4.4 Caveats

Caveats and limitations associated with this analysis include:

1. Deciles of rainfall anomaly provide a statistical indication of probable past meteorological drought. They cannot indicate actual drought conditions in terms of duration and severity, nor levels of hardship for those affected at the time.
2. Rainfall data are interpolated from sparse recording stations for much of the Rangelands Cluster region and can only approximate the actual amount received at specific locations. Additionally, rainfall data were averaged across quite large NRM regions and this conceals often quite large variation in rainfall received. Both factors mean that actual monthly rainfall anomaly for some locations may have varied from that calculated.

4.5 Findings

4.5.1 Regional drought

Rolling 12-monthly rainfall and likely past periods of moderate to severe meteorological drought are shown for other pastoral NRM regions in Figures 4.3–4.11 (see Figure 4.1 for locations). The longest dry periods are summarised in Table 4.1.

[4] ACRIS uses an April–March rainfall year to avoid splitting northern monsoonal rainfall across calendar years.

Table 4.1 Some characteristics of regional meteorological drought since 1950

PASTORAL NRM REGIONS	FIRST DECILE (MM)	SECOND DECILE (MM)	LONGEST DRY PERIOD BASED ON DECILE 1 RAINFALL	COMMENTS
NSW: Western CMA	145	177	16 months ending April 1966	Several very dry periods with the most negative rainfall anomalies occurring in December 1957, September 1965, January 1973, November 1982 and March 2003.
Queensland: South West NRM	232	273	16 months ending June 2003	12-month rainfall less than the first decile extending either side of January 1952, July 1958, November 1965, May 1980, January 1983, September 1985 and March 2003.
Queensland: Desert Channels	187	229	18 months ending November 1969	Several 12-month periods with less than decile 1 rainfall: January 1952, October 1965, January 1967, July 1969, February 1983, December 2002.
SA Arid Lands: south of the Dog Fence (mainly sheep)	93	102	18 months ending September 1983	Many 12-month periods with < decile 1 rainfall. More significant events included October 1957, August 1961, July 1964, October 1970, January 1973, October 1977, February 1983 and October 2002.
SA Arid Lands: north of the Dog Fence (i.e. cattle)	69	79	18 months ending July 1965	Several periods of accumulated rainfall below the first decile, most notably in the 1960s. Other periods include November 1970, January 1973, February 1983, July 1985, December 1994, May 2005, December 2006 and May 2008.
NT Arid Lands (pastoral area)	149	176	22 months ending November 1965	Severe rainfall deficiency in the first half of the 1960s. Other occasions include March 1952 and May 2005.
NT Tablelands sub-region (pastoral area)	339	390	22 months ending December 1952; part of this period includes the preceding ‘winter’ months which are normally dry	Several periods with < decile 1 rainfall, most notably the 1952 period in the previous column. Other periods include March 1958, December 1961 and the early 1990s (1990 and 1992).
WA Rangelands: Goldfields – Nullarbor pastoral area	116	142	17 months ending April 1977	Longer periods of severe rainfall deficiency (i.e. 12-month totals < decile 1) in the early 1970s and 1976–77. Other dry periods included January 1953, December 1957 and late 1961. The rainfall data (Figure 4.9) suggest that rainfall is increasing (despite considerable year-to-year variability) and recent dry years have been above decile 1 rainfall.
WA Rangelands: Gascoyne – Murchison	127	157	20 months ending November 1977	An extended very dry period in 1977 with other very dry periods in March 1970 and April 1991. As for the Goldfields – Nullarbor region, the data suggest that yearly rainfall is increasing (although still highly variable, Figure 4.10).
WA Rangelands: Pilbara pastoral area	165	203	18 months ending December 1972, although this includes the preceding normally dry winter months	Very dry periods in March 1953, July 1959, April 1970, late 1972, January 1991 and May 2005.

NSW: Western CMA

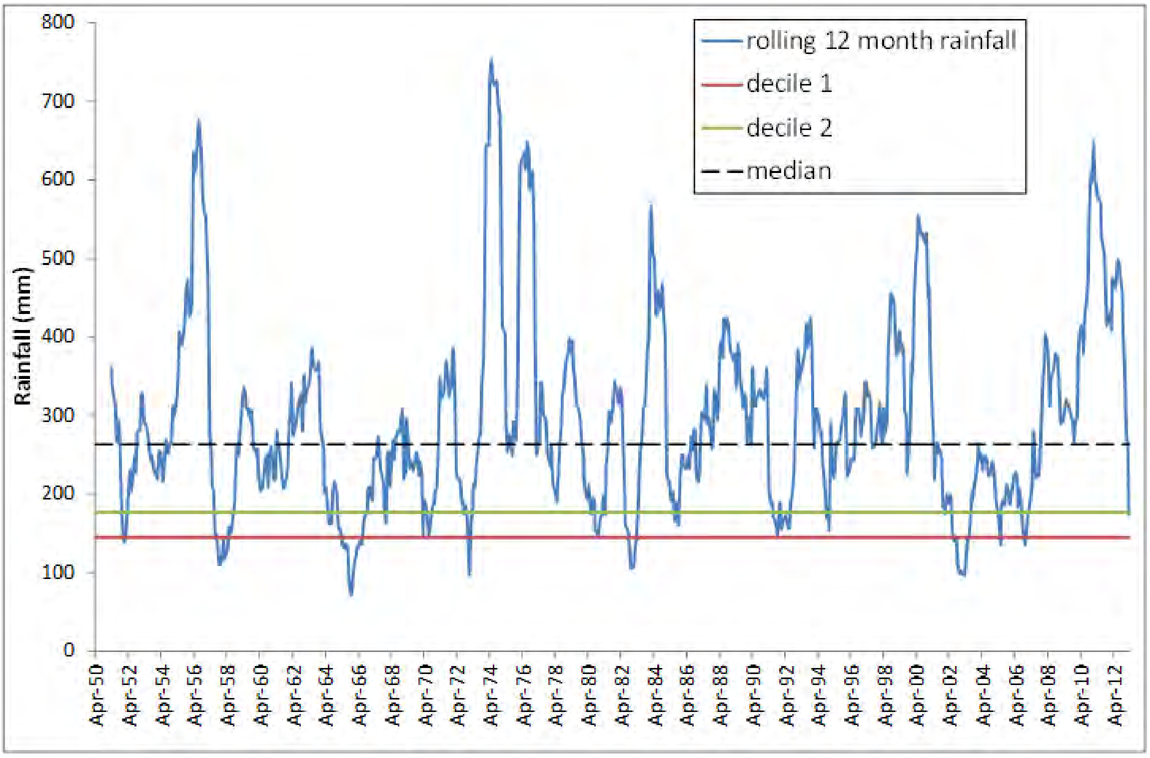

Figure 4.3 Spatially averaged monthly rainfall for the NSW Western CMA region accumulated on a rolling 12-month basis since April 1950. Horizontal lines show the first, second and fifth deciles for the same region based on April–March rainfall between 1890–91 and 2012–13.

Queensland: South West NRM

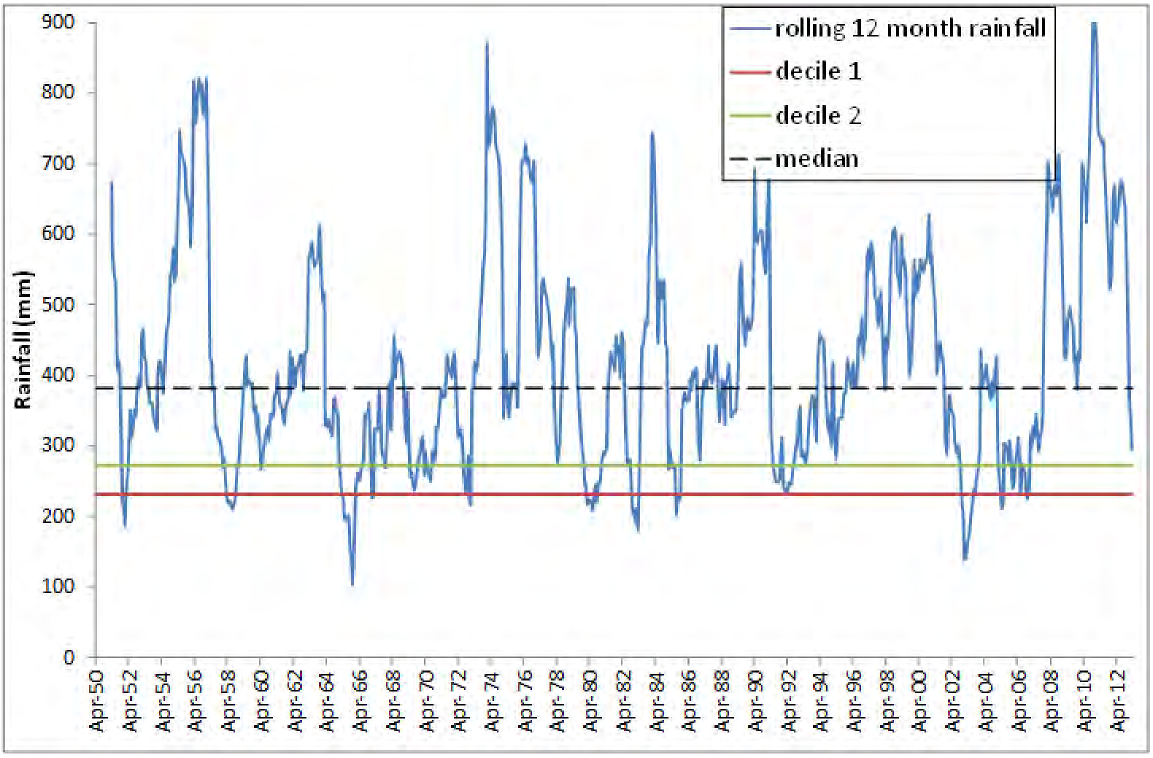

Figure 4.4 Spatially averaged monthly rainfall for the Queensland South West NRM region accumulated on a rolling 12-month basis since April 1950. Horizontal lines show the first, second and fifth deciles for the same region based on April–March rainfall between 1890–91 and 2012–13.

Queensland: Desert Channels

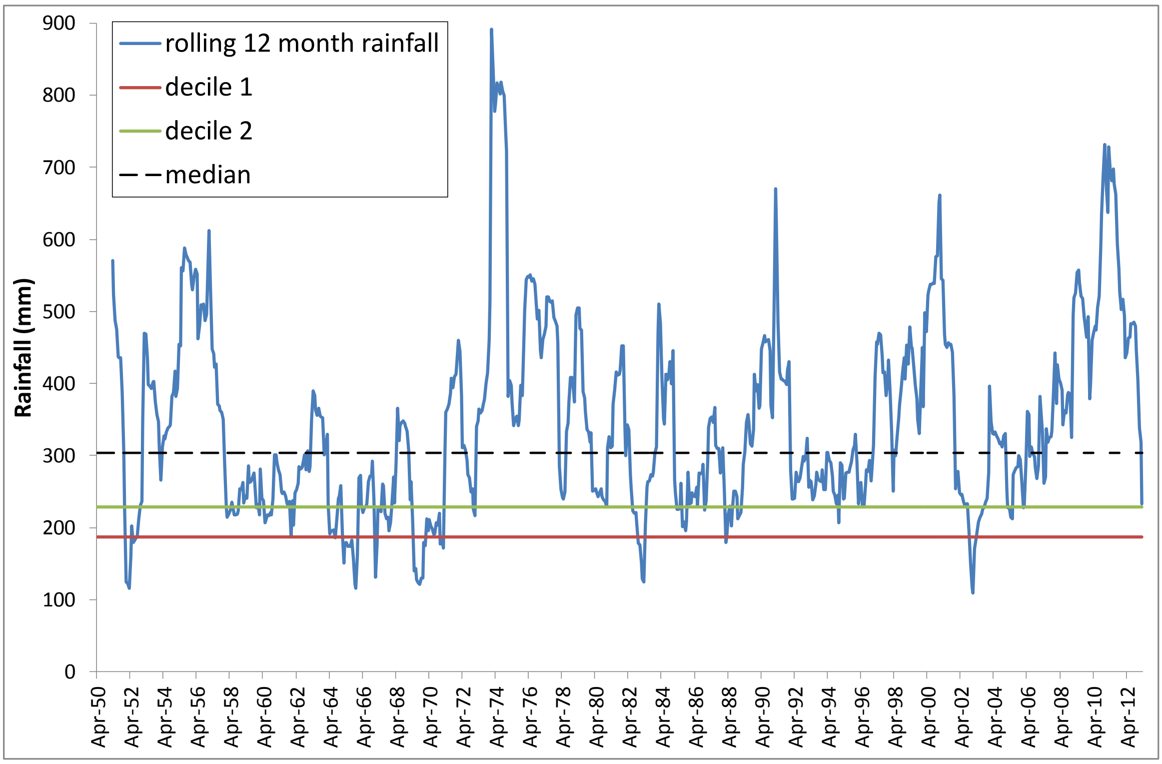

Figure 4.5 Spatially averaged monthly rainfall for the Queensland Desert Channels region accumulated on a rolling 12-month basis since April 1950. Horizontal lines show the first, second and fifth deciles for the same region based on April–March rainfall between 1890–91 and 2012–13.

South Australian Arid Lands southern sheep zone

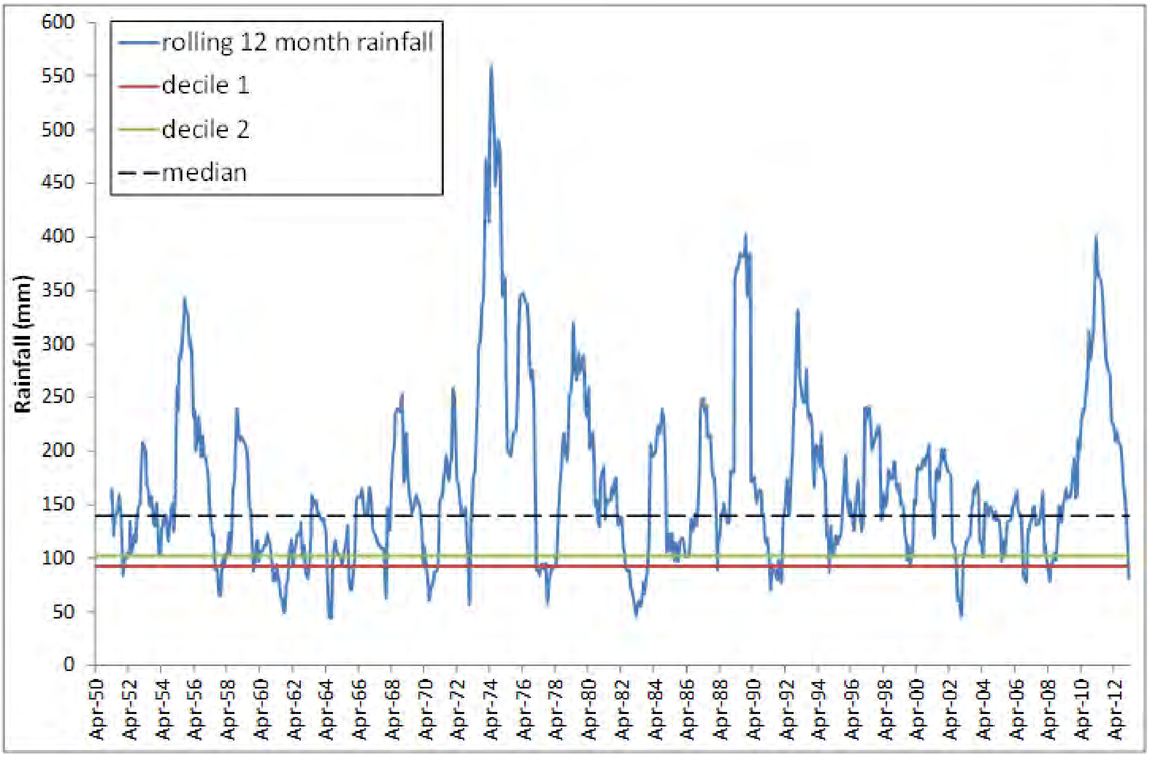

Figure 4.6 Spatially averaged monthly rainfall for the SA Arid Lands southern sheep region accumulated on a rolling 12-month basis since April 1950. Horizontal lines show the first, second and fifth deciles for the same region based on April–March rainfall between 1890–91 and 2012–13.

South Australian Arid Lands northern cattle zone

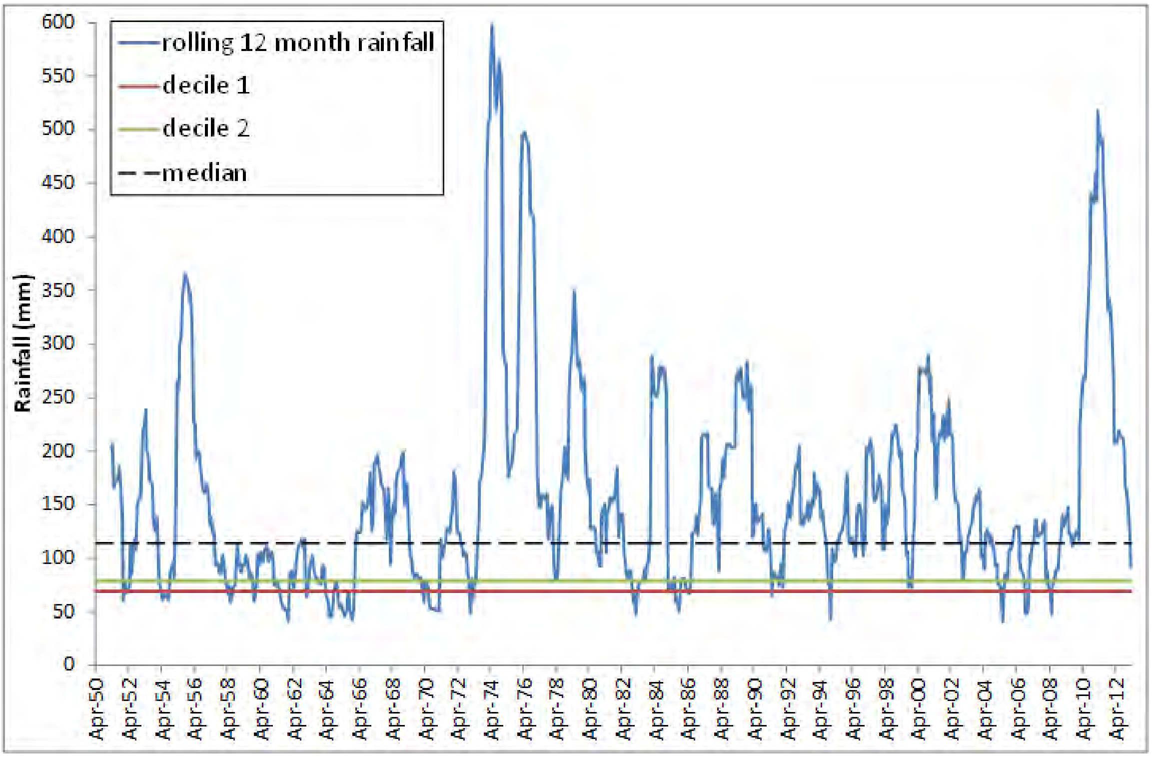

Figure 4.7 Spatially averaged monthly rainfall for the SA Arid Lands northern cattle region accumulated on a rolling 12-month basis since April 1950. Horizontal lines show the first, second and fifth deciles for the same region based on April–March rainfall between 1890–91 and 2012–13.

NT Tablelands sub-region (pastoral area)

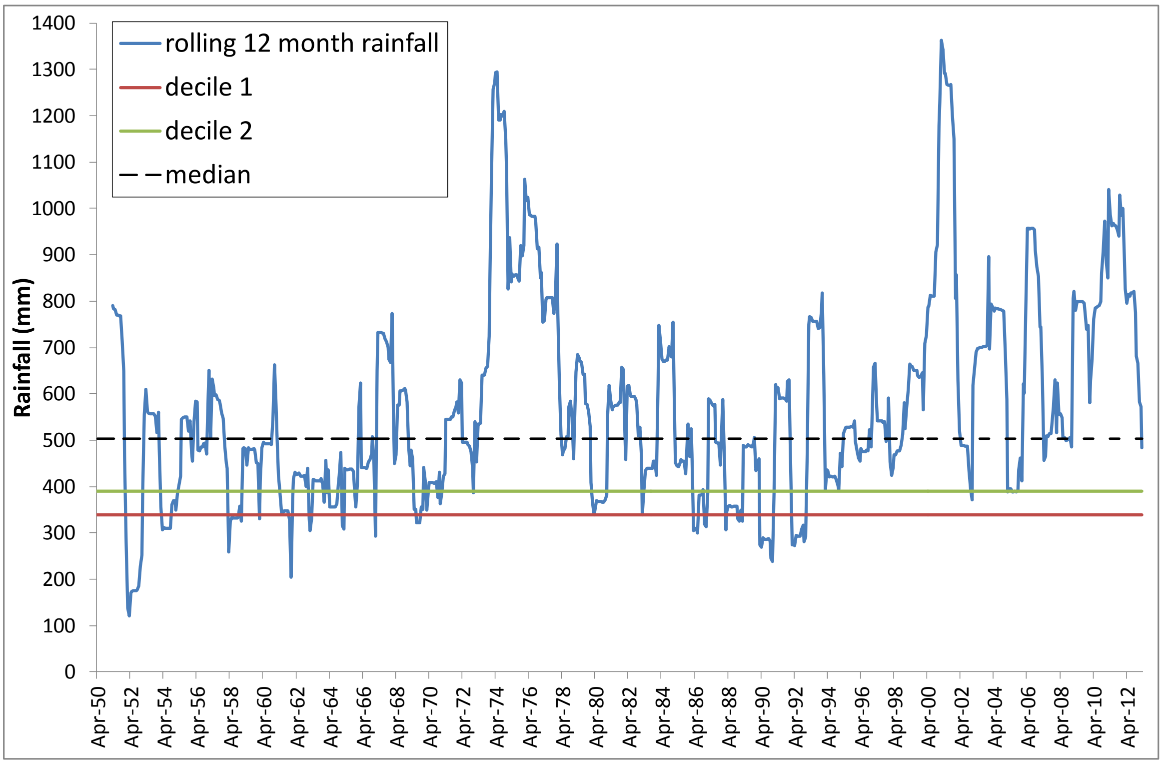

***Figure 4.8** Spatially averaged monthly rainfall for the pastoral region of the NT Tablelands sub-region accumulated on a rolling 12-month basis since April 1950. Horizontal lines show the first, second and fifth deciles for the same region based on April–March rainfall between 1890–91 and 2012–13.*

WA Rangelands: Goldfields – Nullarbor pastoral area

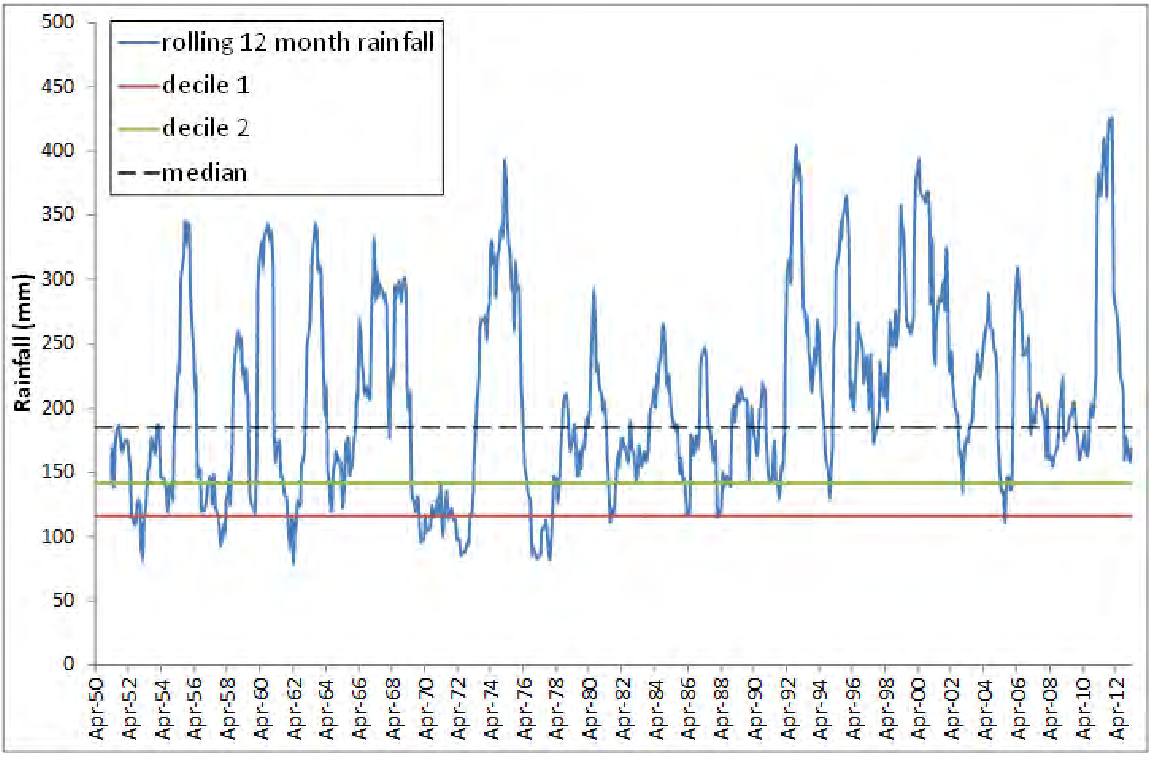

Figure 4.9 Spatially averaged monthly rainfall for the Goldfields – Nullarbor pastoral region of the WA Rangelands accumulated on a rolling 12-month basis since April 1950. Horizontal lines show the first, second and fifth deciles for the same region based on April–March rainfall between 1890–91 and 2012–13.

WA Rangelands: Gascoyne – Murchison pastoral area

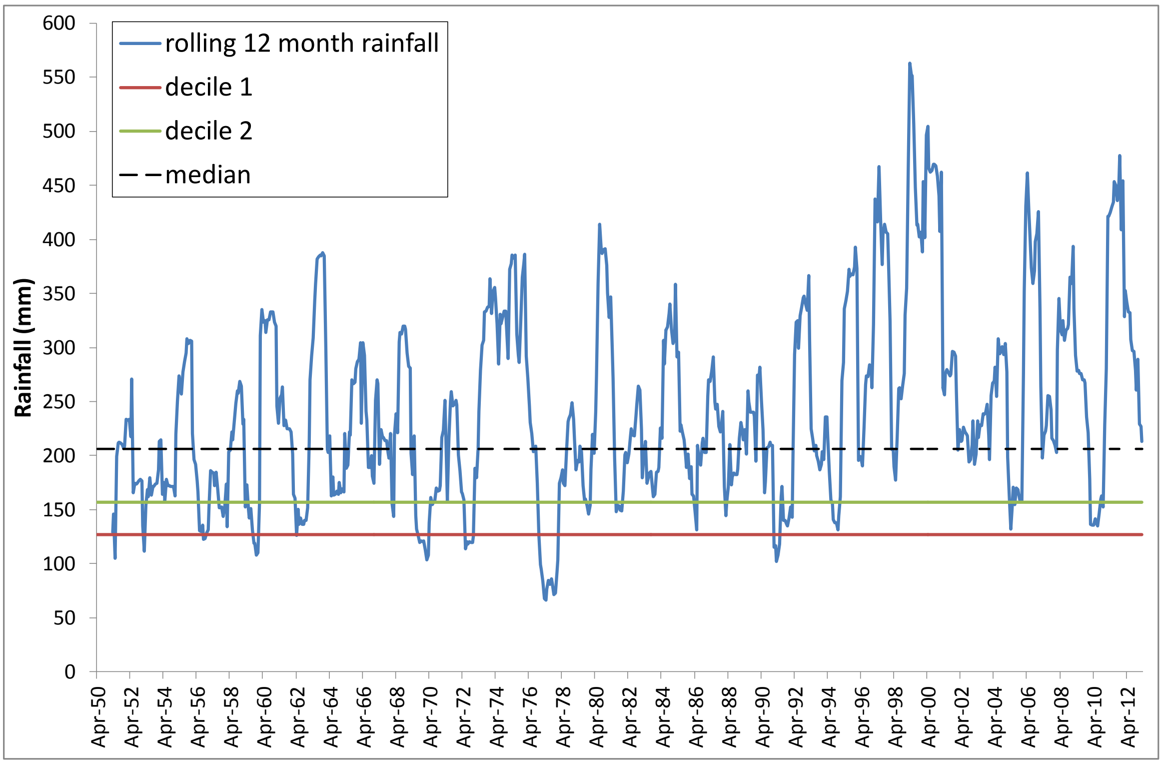

Figure 4.10 Spatially averaged monthly rainfall for the Gascoyne – Murchison pastoral region of the WA Rangelands accumulated on a rolling 12-month basis since April 1950. Horizontal lines show the first, second and fifth deciles for the same region based on April–March rainfall between 1890–91 and 2012–13.

WA Rangelands: Pilbara pastoral area

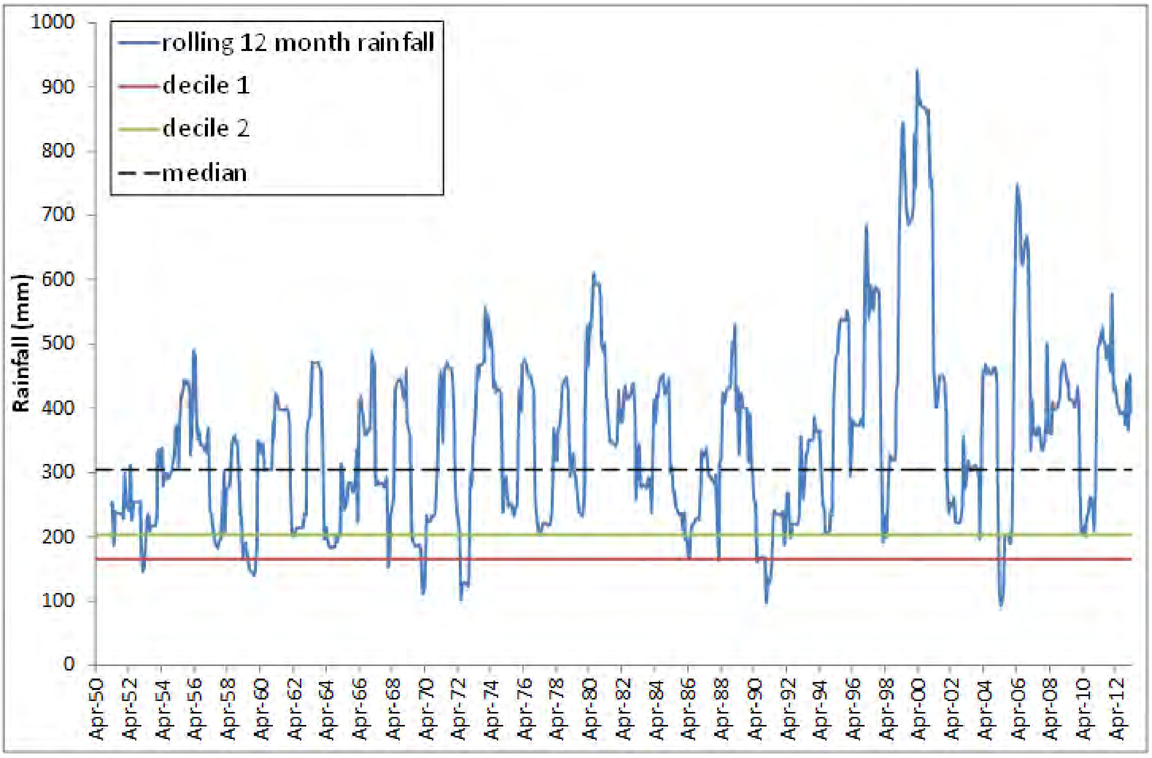

Figure 4.11 Spatially averaged monthly rainfall for the Pilbara pastoral region of the WA Rangelands accumulated on a rolling 12-month basis since April 1950. Horizontal lines show the first, second and fifth deciles for the same region based on April–March rainfall between 1890–91 and 2012–13.

4.6 Key adaptation strategies

Short-term rainfall deficit (up to one year) can occur at any time in the Rangelands Cluster region. Longer term deficits are linked to the major drivers of weather and climate (the well known El Niño Southern Oscillation [ENSO] and the perhaps less familiar Indian Ocean Dipole[5], etc.), and the skill in predicting the timing and consequences of these phenomena is increasing. One anticipated feature of future climate change is that drought will be characterised by a more intense El Niño pattern associated with persistent high pressure systems across much of Australia.

Pastoralists and their advisers should make increasing use of such information and forecasting services in preparing for probable increased frequency and severity of drought. This will likely be more effective if capacity is developed to better interpret probabilistic forecast information and incorporate it into management decisions.

One of the most fundamental adaptation strategies for pastoralists is simply being prepared for drought: that is, to implement drought management strategies promptly as key dates or trigger points for decision-making are reached. An associated adaptation strategy may require the pastoral industry collectively to adopt a more conservative approach to stocking rates and land management so as to better protect the natural resource base where the future location and timing of drought is uncertain.

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[5] The Indian Ocean Dipole (IOD) is an irregular oscillation of sea-surface temperatures in which the western Indian Ocean becomes alternately warmer then colder than the eastern part of the ocean. In this respect, it is analogous to the ENSO in its effect on Australian rainfall. When the IOD is in its negative phase, with cool Indian Ocean water west of Australia and warm Timor Sea water to the north, winds are generated that pick up moisture from the ocean and then sweep down towards southern Australia to deliver higher rainfall. In the IOD positive phase, the pattern of ocean temperatures is reversed, weakening the winds and reducing the amount of moisture picked up and transported across Australia. The consequence is that rainfall in the south-east is well below average during periods of a positive IOD (Wikipedia 2014).

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Australian rangelands and climate change – heatwaves

Gary Bastin

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5. Australian rangelands and climate change – heatwaves

Key points

- It is hot and getting hotter – the regional projections report advises that the Rangelands Cluster region has warmed at a rate of 0.05–0.15°C per decade since 1911 (Watterson et al. 2015). The recent experience of many rangelands communities in coping with increasing summer temperatures provides some foundation for adjusting to what is projected to come. This acknowledged, there will still be a considerable requirement for further adjustment and adaptation (not covered in this short document).
- Most towns in the region have had more hot days and heatwaves, and longer heatwaves, in the recent past, particularly during the first decade of this century. This pattern is consistent with projected hotter temperatures as part of climate change. More recent contributing factors also included low humidity, cloudless days and increased reflected and transmitted heat from areas with low ground cover associated with protracted and widespread drought conditions during much of the 2000s.
- The trend in heatwave conditions appears to be moderated for northern urban centres (Longreach, Mount Isa and Tennant Creek; not so for Newman). Here, the summer monsoon probably has a moderating effect on extreme maximum daily temperatures (i.e. periods of cloud cover, higher humidity, variable rainfall and increased ground cover).
- In this section, we report recent decadal patterns in the number of summer days exceeding a threshold daily maximum temperature (either 36° or 40° C) and the number and length of heatwaves (defined as continuous periods beyond a week when the threshold temperature was exceeded). Temperature data were sourced from the Bureau of Meteorology for 16 towns in (or on the edge of) the Rangelands Cluster.

5.1 Introduction

It is getting hotter and it is predicted that we should prepare for even hotter conditions (Watterson et al. 2015). As context, much of the Rangelands Cluster region is no stranger to extended hot periods through the summer. An analysis of summer maximum temperatures since 1950 for larger towns in, and neighbouring, the Rangelands Cluster reveals some interesting patterns in the frequency and duration of hot spells. Temperature data analysed were downloaded as patched-point datasets from SILO at the Long Paddock web site.[6] This provides a convenient source of data for spreadsheet analysis (i.e. similar to the location-specific rainfall data reported in Bastin 2014).

5.2 Method

1. For this analysis, 'summer' is defined as the warmer (or hotter) months of October to March. The analysis period is the 1950–51 summer through to the 2012–13 summer (i.e. 63 summers).
2. Two regionally different threshold temperatures were used to define a 'hot' day: 36° C for southern centres (Figure 5.1) and 40° C for central and northern centres.
3. A 'heatwave' was defined, for each location, as a week or more of continuous maximum daily temperatures above the specified threshold.
4. Four indices are used to describe hot and heatwave conditions in the recent past:

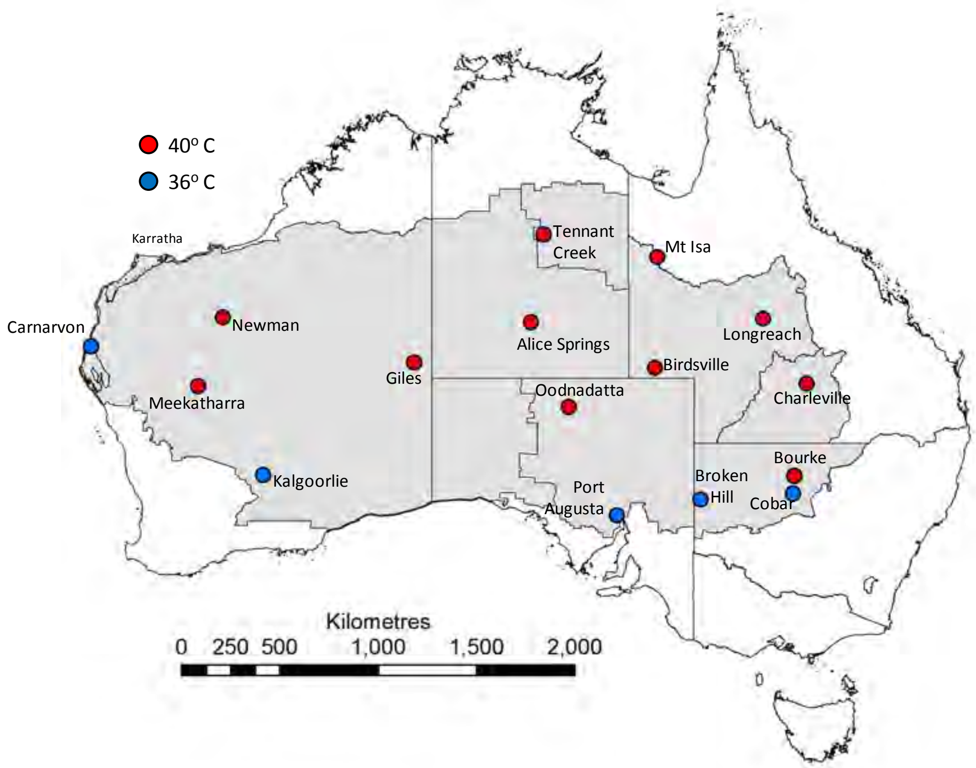

Figure 5.1 Locations and temperature thresholds within the Rangelands Cluster for characterising heatwaves.

Black lines show the boundaries of individual NRM regions within the combined cluster region (shaded in grey).

[6] http://www.longpaddock.qld.gov.au/silo/, accessed 12 February 2014

a. The total number of days in each decade when the threshold temperature was exceeded and the decadal frequency of continuously hot days (following graphs). The statistics for the current, incomplete, decade (with data for only three summers) are not directly comparable with previous decades.
b. The mean annual number of days in each decade when the threshold temperature was exceeded (Table 5.1). This is a way of standardising (or normalising) data for the current decade.
c. The number of heatwaves experienced per decade (Table 5.2), bearing in mind there are only three summers in the current decade.
d. The duration and time of the longest heatwave.

5.3 Data source

Temperature data are readily available for many locations in the Rangelands Cluster. Data files can be downloaded from the SILO URL (http://www.longpaddock.qld.gov.au/silo/) or from the Bureau of Meteorology web site (www.bom.gov.au). The data used in the analyses below were patched-point SILO data for larger towns in the Rangelands Cluster region from October 1950 to March 2013 (63 summers).

5.4 Caveats

- The temperature thresholds defining a 'hot' day are arbitrary.
- The duration of consecutive hot days specifying a heatwave is similarly arbitrary.

5.5 Findings

The regional occurrence of past heatwaves is characterised in the following sub-sections. For ease of formatting, tables and figures for the various NRM regions (Table 5.1 and Table 5.2 and Figures 5.2–5.17) are presented at the end of this section.

5.5.1 NSW: Western CMA

Broken Hill

The 1980s and 2000s were the hottest decades in terms of number of days with a maximum temperature above the threshold (36° C, Figure 5.2 and Table 5.1). Both periods were associated with drought. There were more heatwaves in the last decade compared with the 1980s (Table 5.2). There were two record heatwaves (based on this analysis): 17 days in January–February 1979 and February–March 2004.

Bourke

The 2000s was by far the hottest decade since the 1950s (Figure 5.3, Table 5.1 and Table 5.2). The current decade (2011–2013) has been more moderate (Table 5.1), no doubt due in part to the wetter period at its start (i.e. cloud cover and higher humidity reduce maximum temperatures). The hottest spell over the last 63 summers was 14 consecutive days in February 2004 (i.e. maximum daily temperature ≥40° C).

Cobar

Both the 1950s and 2000s were notably hot decades (Figure 5.4 and Table 5.1), although the last decade had more heatwaves (Table 5.2). Also apparent from Figure 5.4 is that longer heatwaves were slightly more numerous (compared with the 1950s). The longest heatwaves were two periods of ≥36° C over 18 days in January–February 1999 and February–March 2004.

5.5.2 Queensland: South West NRM

Charleville

The last decade was remarkably hotter than preceding ones (Figure 5.5 and Table 5.1), although the 1970s had a small number of longer continuously hot periods (Figure 5.5 and Table 5.2). The longest continuously hot period (≥40° C) was 9 days in December 1972.

5.5.3 Queensland: Desert Channels

Longreach

There does not appear to have been any medium-term change in the decadal frequency of hot days (≥40° C), heatwaves or their duration (Figure 5.6, Table 5.1 and Table 5.2). The 1950s, 1980s and 2000s were similarly hot (Figure 5.6). It may be that monsoonal conditions (particularly cloud cover) in most summers moderate extreme temperatures and their duration. It may also be that early spring (August–September) and later autumn (April–May) are experiencing a higher frequency of maximum daily temperatures close to, but below, the threshold. This phenomenon is unrelated to heatwaves and the analysis has not been conducted.

The longest hot spell for Longreach was 13 days in December 1997.

Mount Isa

This city is on the edge of the Rangelands Cluster. The analysis of temperature data conducted here indicates that the 1980s was the hottest decade although the most recent decade was similar in terms of extended heatwaves (Figure 5.7, Table 5.1 and Table 5.2). As for Longreach, the summer monsoon probably moderates extreme temperatures in most summers. Maximum temperatures continuously exceeded 40° C over 15 days in January 1971.

Birdsville

Birdsville is truly a hot place (Figure 5.8)! It has experienced some very long heatwaves in the 1960s, 1970s and 2000s (Table 5.2) The 1980s were also hot (compared with other decades in the second half of the 20th century) but that decade did not have the extended heatwaves of the more recent past (Figure 5.8). The longest heatwave was quite recent: 37 days between December 2012 and January 2013.

5.5.4 SA: Arid Lands

Port Augusta

The last decade was by far the hottest experienced in the recent past, in terms of individual and cumulative days exceeding 36° C (Figure 5.9, Table 5.1 and Table 5.2). Based on normalised (i.e. per year within decade) data, the start to this decade has also been hot (Table 5.1). The continuously hottest period was 15 days in March 2008.

Oodnadatta

On a decadal time scale, Oodnadatta has, in the main, experienced an increasing number of summer days hotter than 40° C (Figure 5.10). This is also the case for standardised (mean per year) data (Table 5.1). Notably, the last decade and years to date in the current decade have had more and longer heatwaves (Table 5.2 and Figure 5.10). This was not the case for the absolute longest heatwave; it lasted 18 days between December 1978 and January 1979.

5.5.5 NT: Arid Lands and Tablelands sub-regions

Alice Springs

Based on the total number of summer days with temperatures ≥40° C, the last three decades of the 20th century were considerably hotter than the preceding decades (Figure 5.11). This was also the case when the data were normalised to an annual basis (Table 5.1). The first and current decades (to date) of this century have also had more extended heatwaves than previously (Figure 5.11 and Table 5.2), including the longest heatwave (16 days in January 2013).

Tennant Creek

Contrasting with almost all other centres, heatwave conditions in Tennant Creek appear to have progressively moderated on a decadal and standardised year-within-decade basis (Figure 5.12 and Table 5.1). This may be due to a changing monsoonal influence (perhaps more cloud and higher humidity in some recent years), but this has not been investigated. As with the similar northern centres of Longreach and Mount Isa, it is likely that adjacent spring and autumn months are now experiencing hotter temperatures but because such days are unlikely to combine to constitute heatwaves (as defined here), this feature has not been analysed. The hottest continuous summer period since 1950–51 was 19 days in January 2008.

5.5.6 WA: Rangelands

Kalgoorlie

Summers over the last decade in Kalgoorlie were the hottest experienced since the 1950s, both in terms of days exceeding 36° C (Figure 5.13), normalised to a mean per year (Table 5.1) and number of heatwaves (Table 5.2). Both the 1990s and 2000s had increasingly longer heatwaves (Figure 5.13). Against this trend, the longest heatwave was 11 days in February–March 1953.

Meekatharra

Meekatharra experienced more hot days (≥40° C), more heatwaves and longer heatwaves in the last decade compared with previous decades back to the 1950s (Figure 5.14 and Table 5.2). There was a consistent decadal increase in normalised mean annual number of hot days between the 1960s and 2000s (Table 5.1). This trend has abated in the first three summers of the current decade.

The longest heatwave (24 days) extended from December 2007 into January 2008.

Carnarvon

The decadal pattern of an increasing number of hot summer days and heatwaves and progressively longer heatwaves for most towns in the Rangelands Cluster appear not to include Carnarvon (Figure 5.15). It may be that the proximity of the Indian Ocean moderates extremely hot temperatures in this town.

However, this may be about to change. One notable feature of the three summers to date in the current decade is the substantial increase in the normalised value for the annual number of hot days (Table 5.1), record heatwave (12 days in February 2013) and generally longer heatwaves (Figure 5.15), also apparent in the 1980s.

Newman

Like Birdsville, Newman is hot and getting hotter (Figure 5.16). There has been a remarkable increase since the 1970s in (i) the number of summer days per decade exceeding 40° C, (ii) the number of heatwaves (Table 5.2) and (iii) the length of heatwaves (Figure 5.16). This pattern has moderated with the first three summers of the current decade (Table 5.1).

The longest heatwave was 29 days in January–February 2007.

Giles

Although the normalised (mean per year within decade) and total number of days hotter than 40° C was relatively stable between the 1970s and 2000s (Table 5.1), there has been a more recent tendency of longer heatwaves (Figure 5.17). This translates to the highest normalised index value for mean annual hot days in the current decade (Table 5.1). The longest heatwaves have been quite recent: each 17 days, between February–March 2007, January–February 2011 and January–February 2013.

Table 5.1 Mean annual number of days per decade when threshold temperature was exceeded

LOCATION IN NRM REGION (DEGREE THRESHOLD)	DECADE						
	1950s	1960s	1970s	1980s	1990s	2000s	2011–2013
NSW: Western CMA							
Broken Hill (36° C)	25.5	26.4	24.7	36.4	26.0	37.9	25.3
Bourke (40° C)	13.4	9.6	9.0	12.8	12.8	24.7	13.0
Cobar (36° C)	43.5	32.8	26.7	32.7	32.5	45.4	31.3
Queensland: South West NRM							
Charleville (40° C)	5.7	5.4	5.7	7.3	5.3	10.1	6.7
Queensland: Desert Channels							
Longreach (40° C)	29.7	21.7	18.8	25.4	20.6	25.5	15.7
Mt Isa (40° C)	21.4	21.0	12.2	24.5	15.7	20.2	16.3
Birdsville (40° C)	35.6	43.8	37.9	51.5	44.8	55.9	60.3
SA: Arid Lands							
Port Augusta (36° C)	32.0	30.7	25.7	31.7	32.8	43.2	40.0
Oodnadatta (40° C)	31.1	34.8	30.9	41.4	37.9	40.2	40.3
NT: Arid Lands & Tablelands sub-regions							
Alice Springs (40° C)	12.2	13.2	13.5	18.2	19.1	17.2	23.7
Tennant Creek (40° C)	33.2	23.5	14.1	26.1	18.8	18.1	14.0
WA: Rangelands							
Kalgoorlie (36° C)	29.8	31.1	33.3	29.8	32.4	38.8	28.7
Meekatharra (40° C)	24.9	20.0	26.7	29.5	30.2	36.8	23.7
Carnarvon (36° C)	16.8	19.1	21.9	21.2	18.8	17.9	32.0
Newman (40° C)	33.9	40.2	31.7	39.7	44.9	61.8	39.3
Giles	7.7	13.9	15.6	20.7	20.2	17.8	23.7

Table 5.2 Number of heatwaves experienced in each decade since 1950 where a heatwave is defined as >1 week of maximum daily temperature above the specified threshold (Figure 5.1)

LOCATION IN NRM REGION	DECADE						
	1950s	1960s	1970s	1980s	1990s	2000s	2011–2013
NSW: Western CMA							
Bourke	1	0	0	1	3	17	0
Broken Hill	3	11	21	5	2	25	0
Cobar	42	15	10	13	21	58	8
Queensland: South West NRM							
Charleville	0	0	2	0	0	0	0
Queensland: Desert Channels							
Birdsville	29	43	48	27	26	75	46
Longreach	8	13	7	6	11	12	0
Mt Isa	5	4	10	10	5	8	0
SA: Arid Lands							
Oodnadatta	7	10	32	11	21	58	13
Port Augusta	0	0	2	6	4	20	2
NT: Arid Lands & Tablelands sub-regions							
Alice Springs	0	1	9	4	1	8	10
Tennant Creek	15	8	6	15	14	18	0
WA: Rangelands							
Carnarvon	1	0	0	3	0	0	7
Giles	1	0	13	3	8	11	20
Kalgoorlie	5	3	0	1	5	6	0
Meekatharra	17	10	19	16	21	53	3
Newman	52	49	28	53	96	138	9

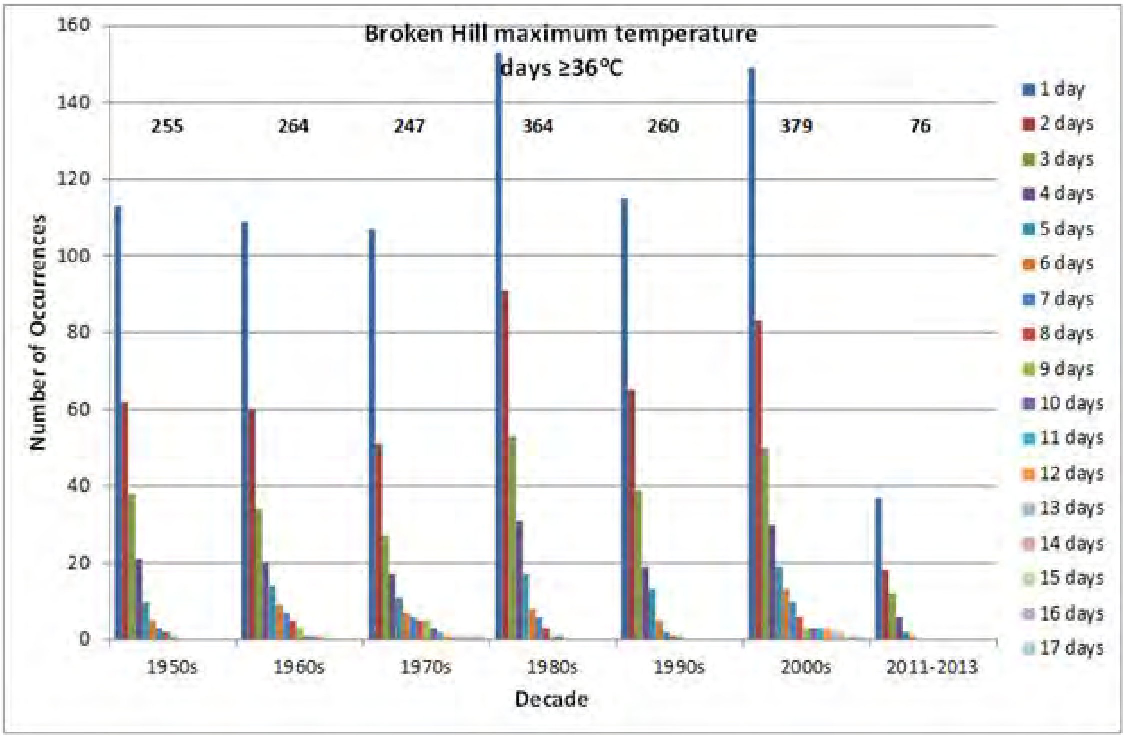

Figure 5.2 Broken Hill: total number of summer days per decade hotter than 36° C and the decadal frequency of continuously hot days.

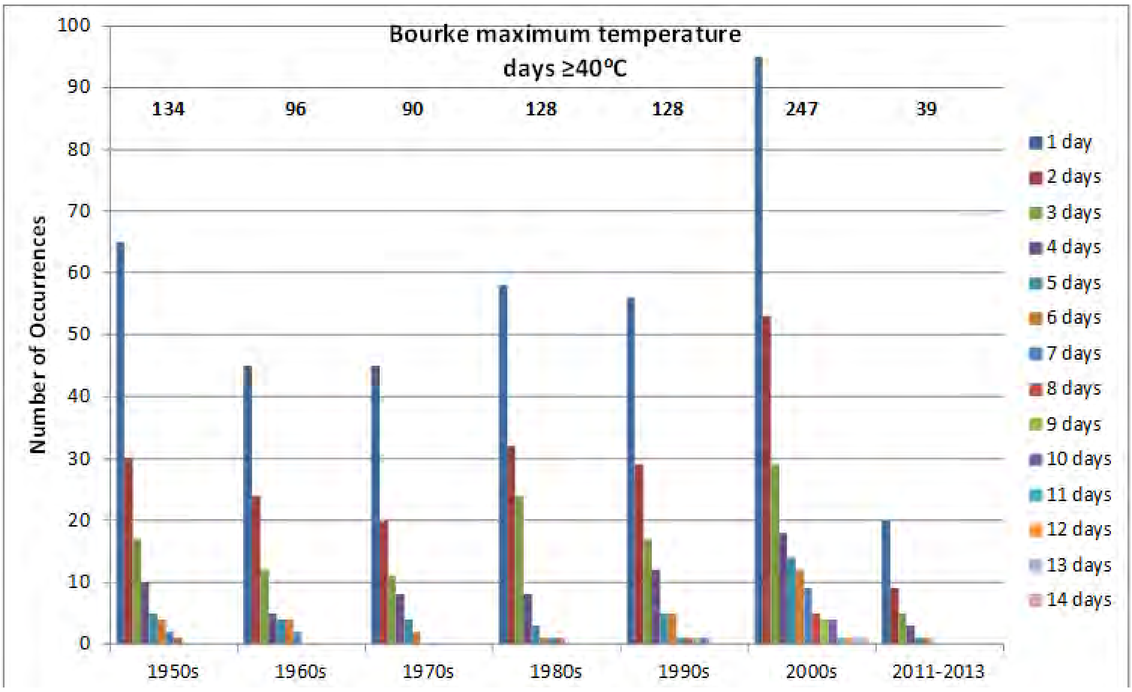

Figure 5.3 Bourke: total number of summer days per decade hotter than 40° C and the decadal frequency of continuously hot days.

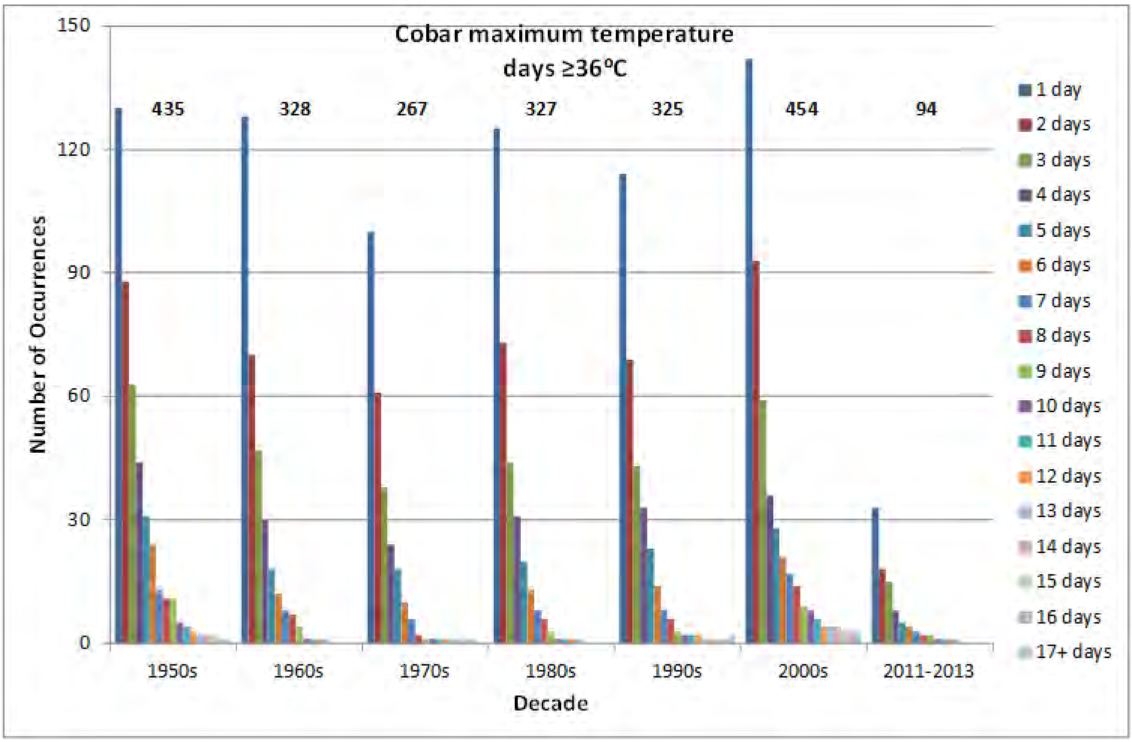

Figure 5.4 Cobar: total number of summer days per decade hotter than 36° C and the decadal frequency of continuously hot days.

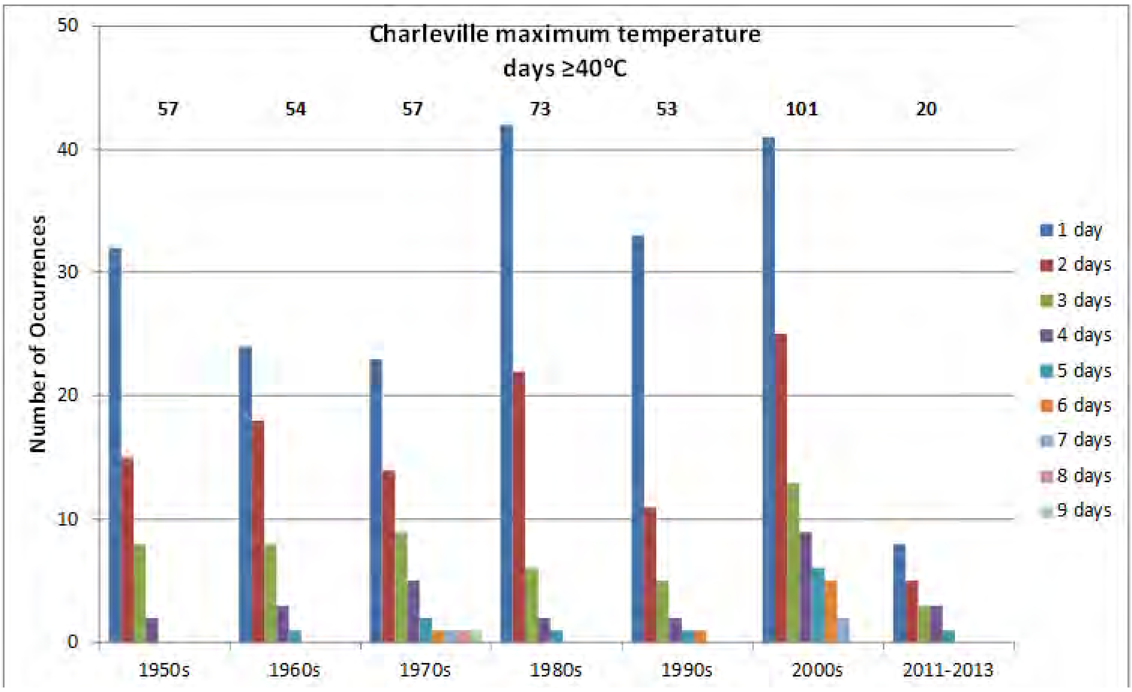

Figure 5.5 Charleville: total number of summer days per decade hotter than 40° C and the decadal frequency of continuously hot days.

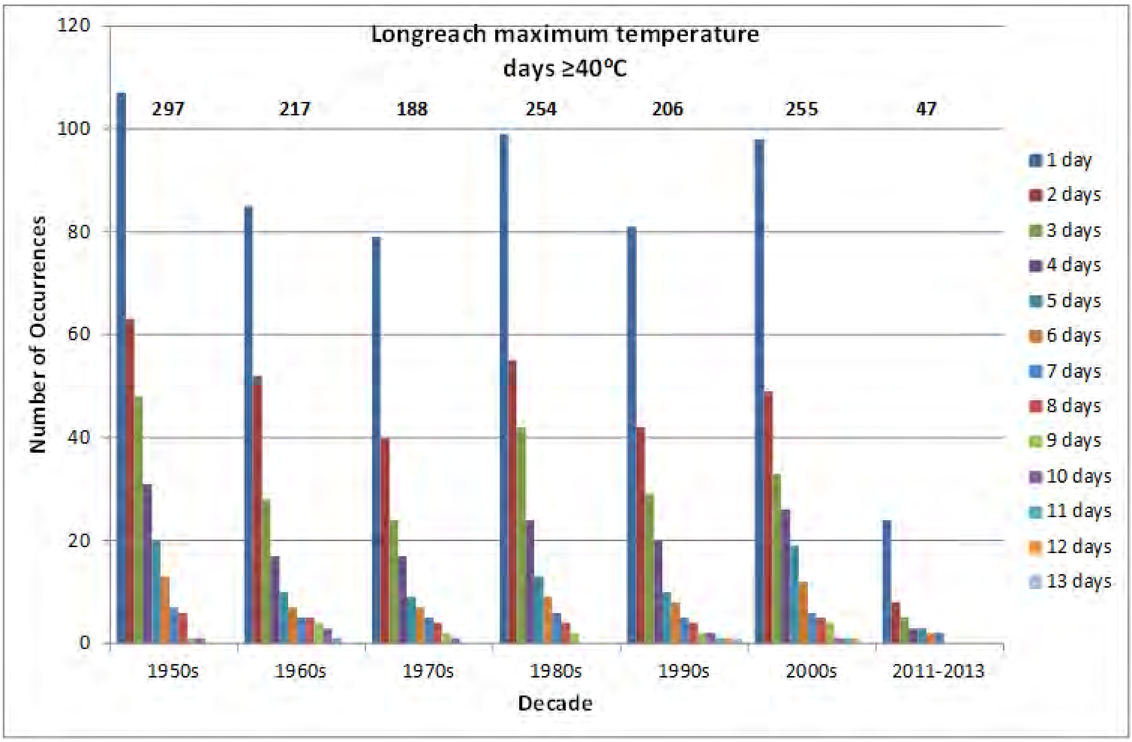

Figure 5.6 Longreach: total number of summer days per decade hotter than 40° C and the decadal frequency of continuously hot days.

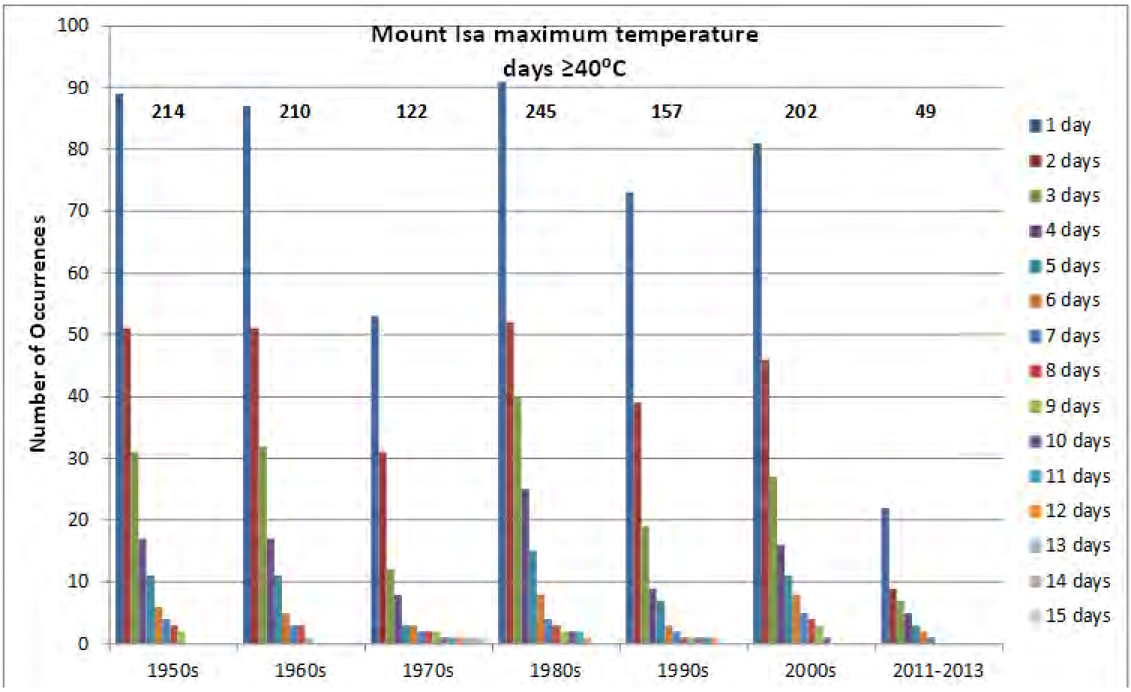

Figure 5.7 Mount Isa: total number of summer days per decade hotter than 40° C and the decadal frequency of continuously hot days.

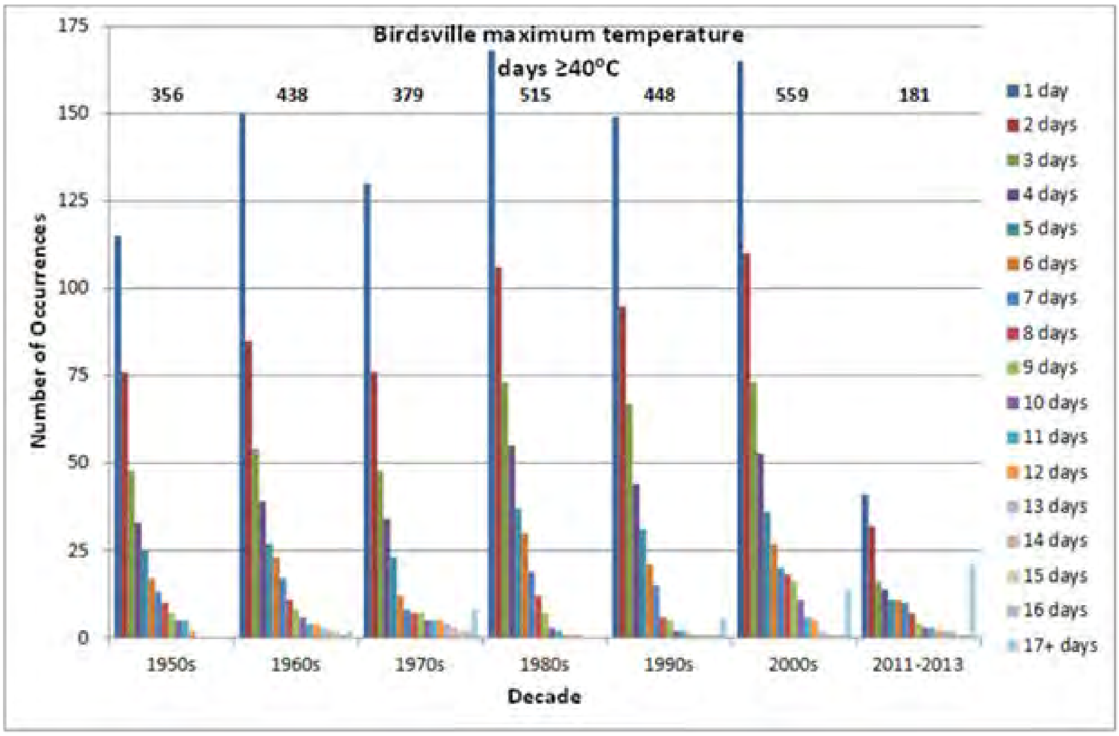

Figure 5.8 Birdsville: total number of summer days per decade hotter than 40° C and the decadal frequency of continuously hot days

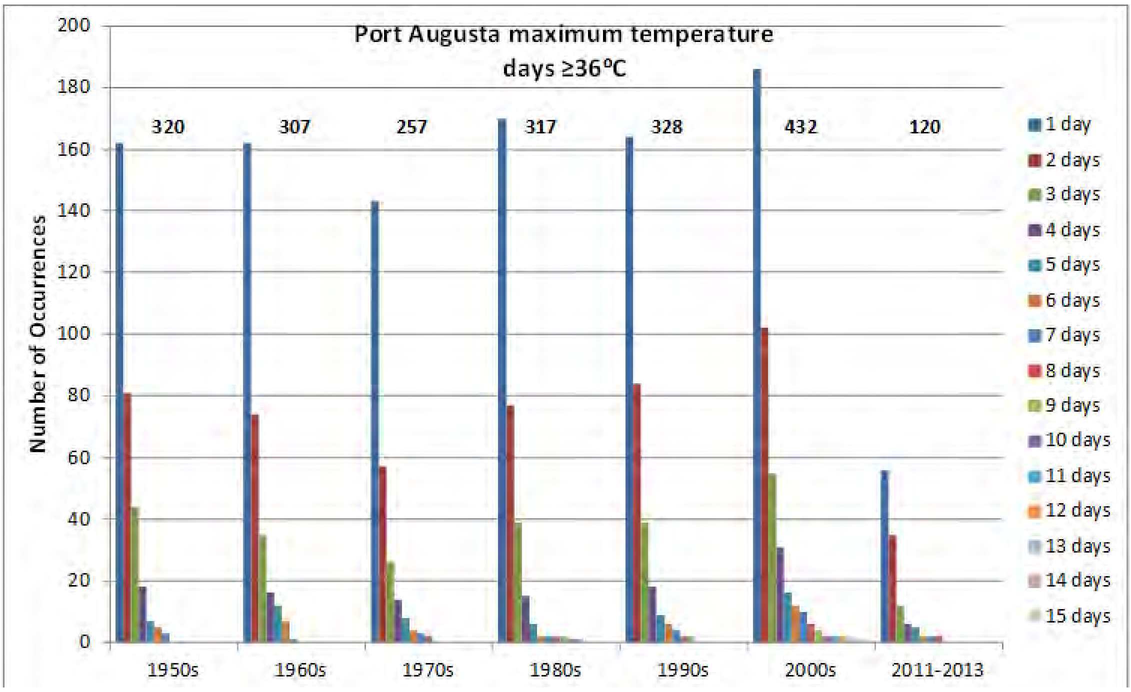

Figure 5.9 Port Augusta: total number of summer days per decade hotter than 36° C and the decadal frequency of continuously hot days.

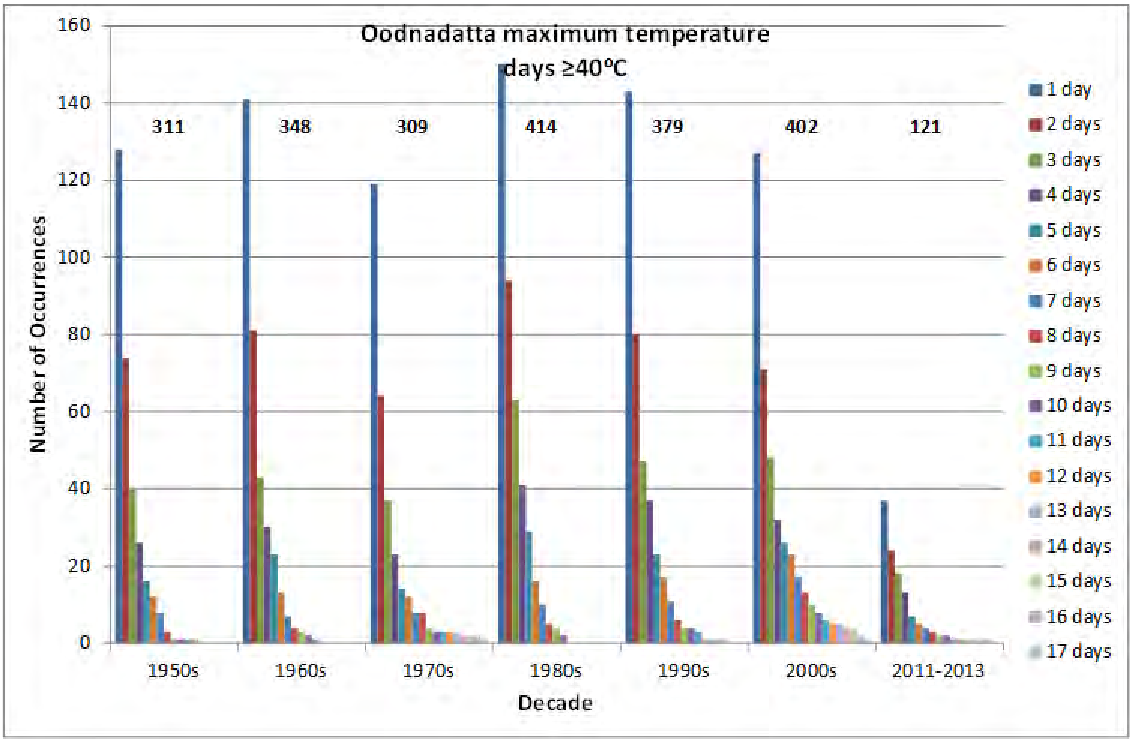

Figure 5.10 Oodnadatta: total number of summer days per decade hotter than 40° C and the decadal frequency of continuously hot days.

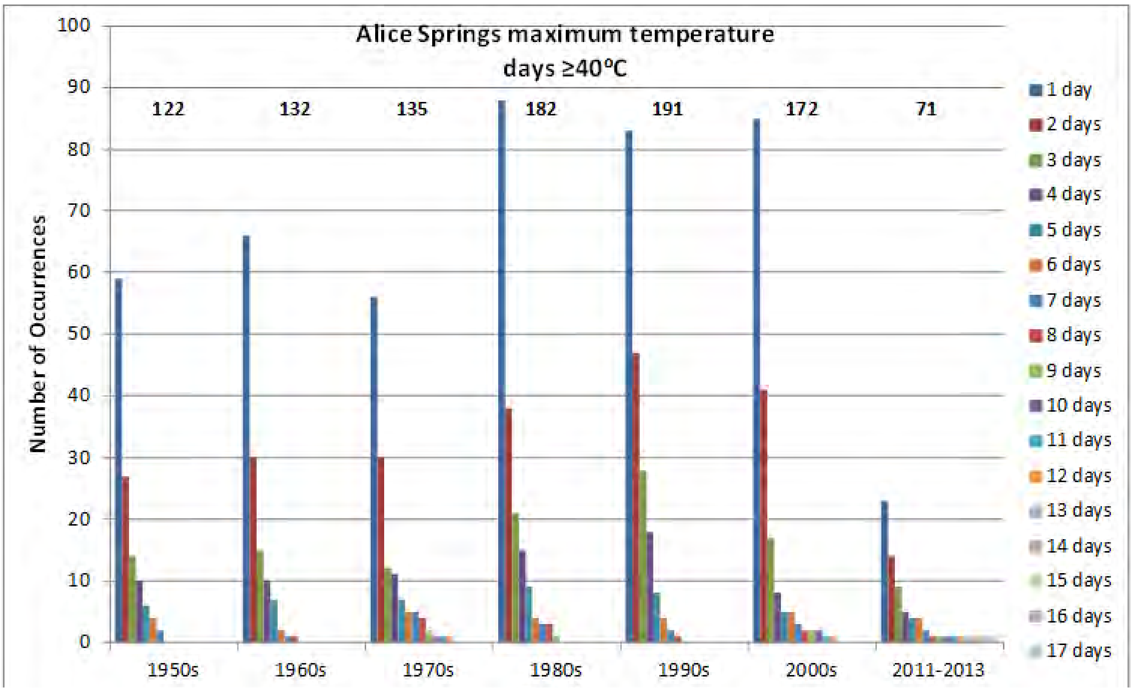

Figure 5.11 Alice Springs: total number of summer days per decade hotter than 40° C and the decadal frequency of continuously hot days

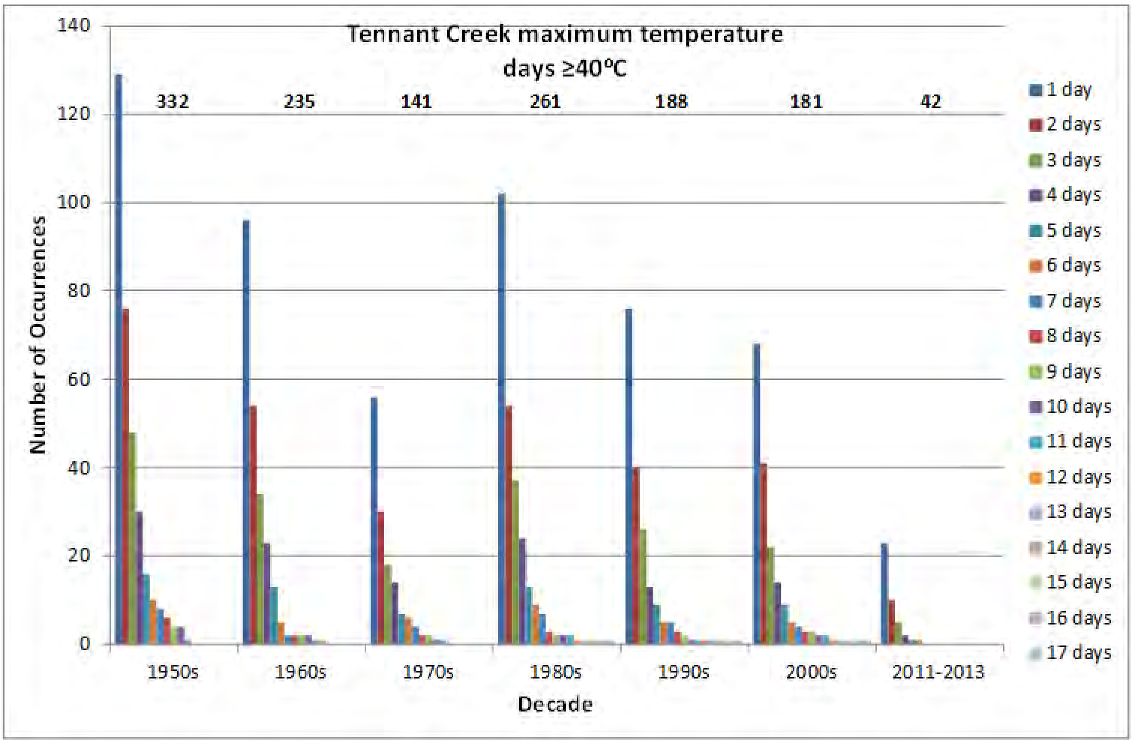

Figure 5.12 Tennant Creek: total number of summer days per decade hotter than 40° C and the decadal frequency of continuously hot days.

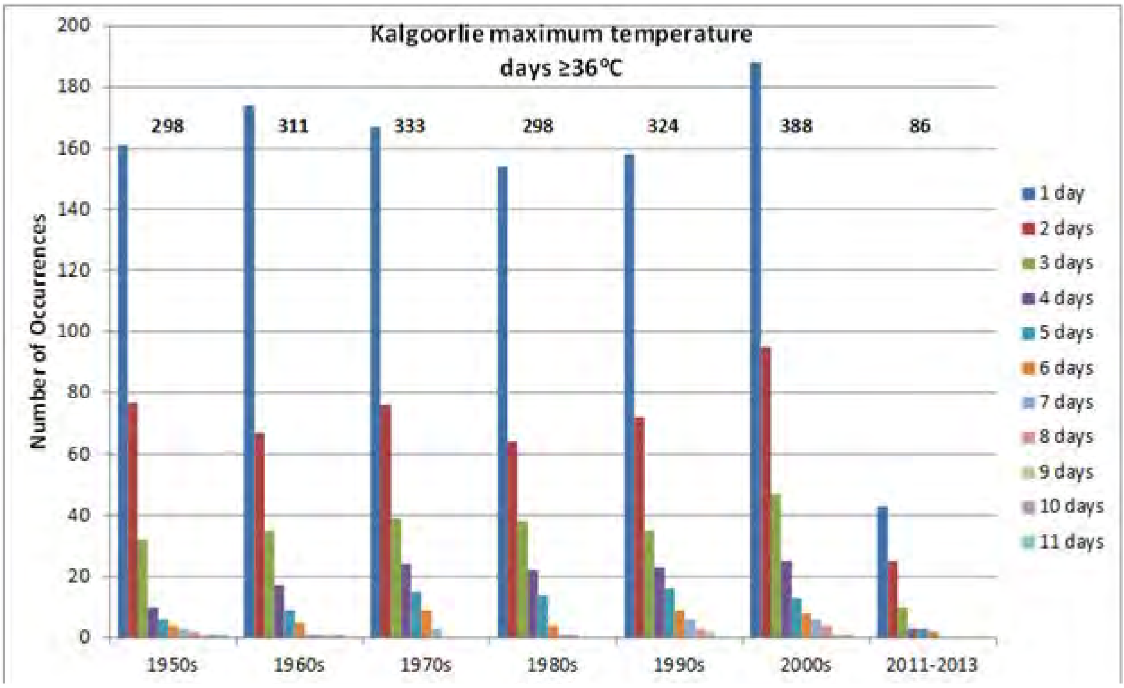

Figure 5.13 Kalgoorlie: total number of summer days per decade hotter than 36° C and the decadal frequency of continuously hot days.

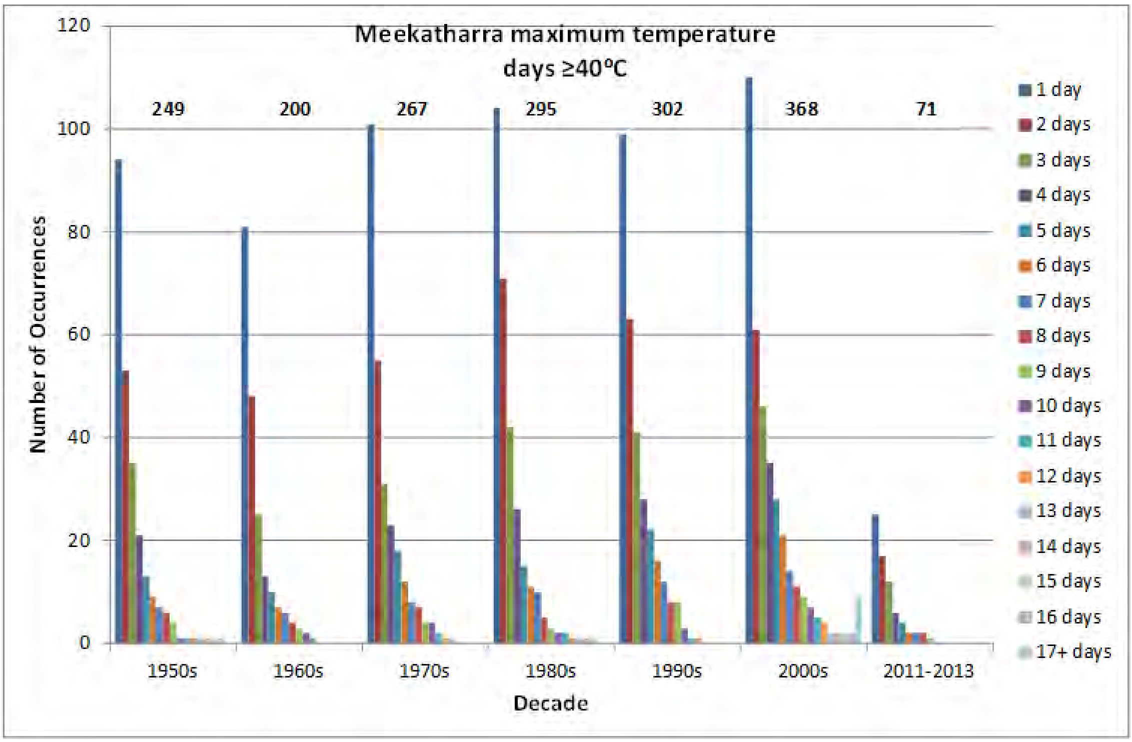

Figure 5.14 Meekatharra: total number of summer days per decade hotter than 40° C and the decadal frequency of continuously hot days.

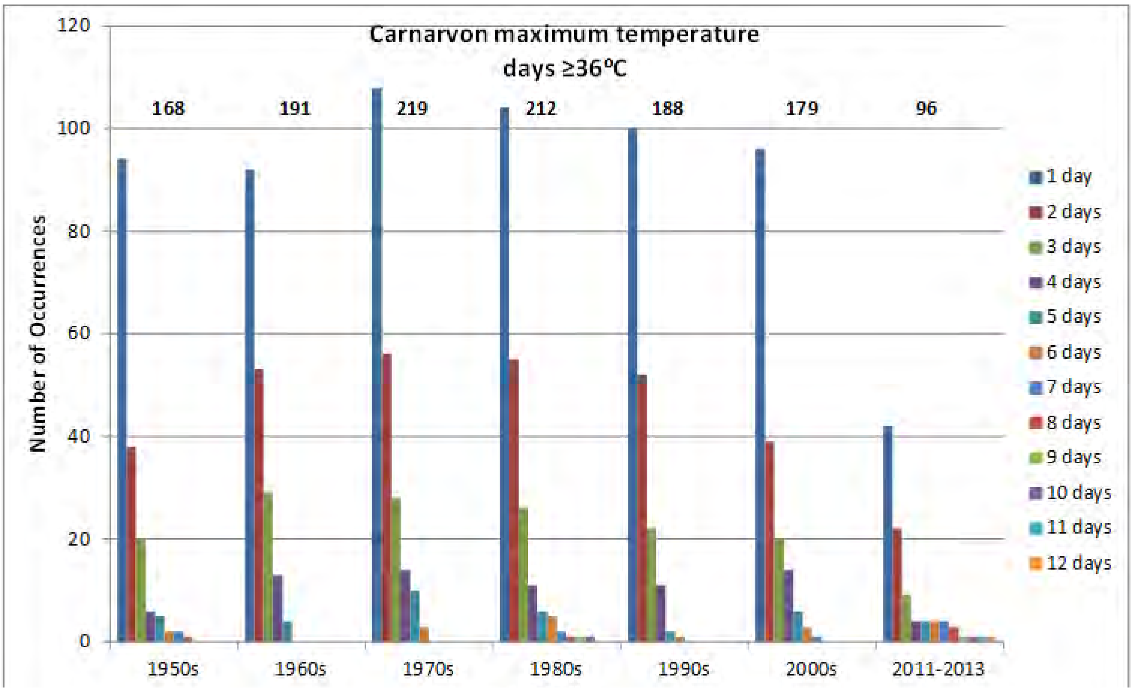

Figure 5.15 Carnarvon: total number of summer days per decade hotter than 36° C and the decadal frequency of continuously hot days

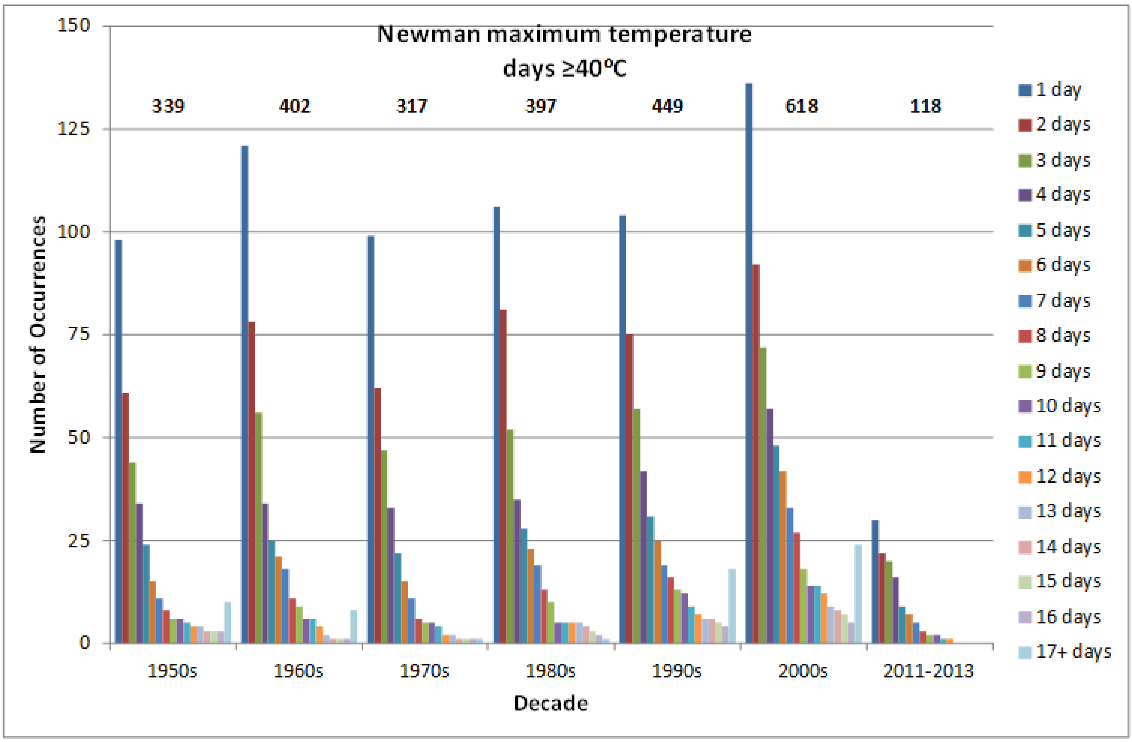

Figure 5.16 Newman: total number of summer days per decade hotter than 40° C and the decadal frequency of continuously hot days.

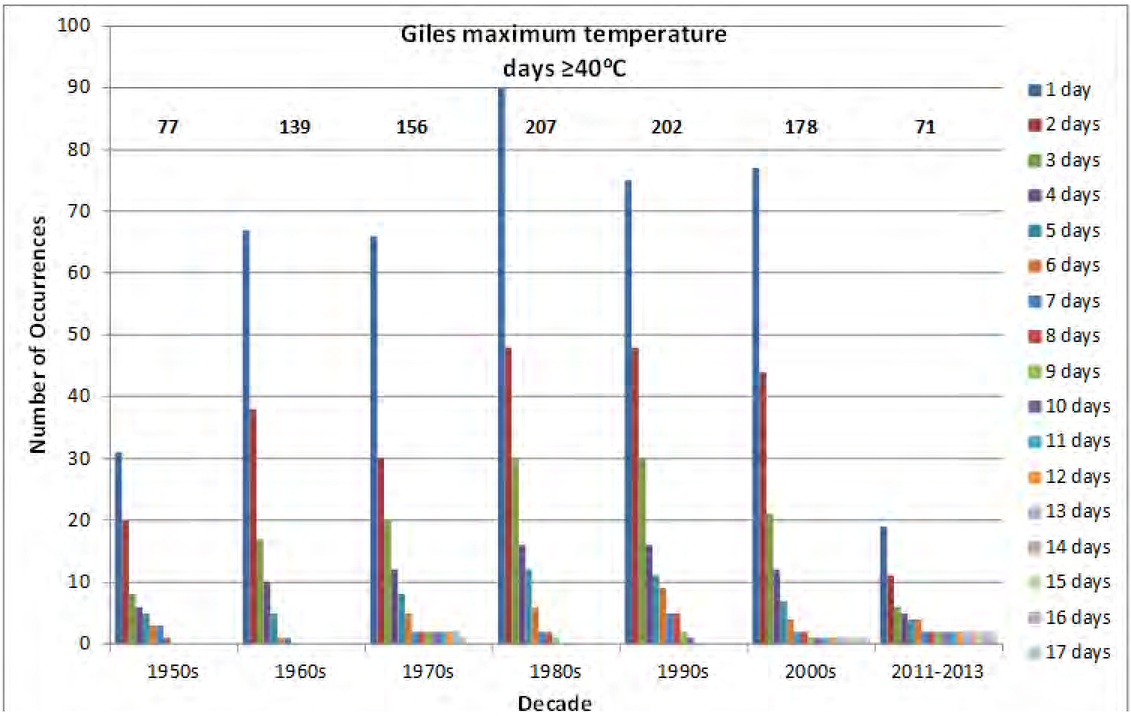

Figure 5.17 Giles: total number of summer days per decade hotter than 40° C and the decadal frequency of continuously hot days

5.6 Key adaptation strategies

Urban rangeland communities in the Rangelands Cluster will probably cope with rising temperatures with increased use of air conditioners, at least into the medium term (e.g. next 30 years). Remote communities and the pastoral industry face particular challenges.

Measham (2014) describes how a vulnerability framework may assist remote communities to adapt to the expected increased frequency and intensity of heatwaves (his information adapted from Maru et al. 2014).

Information relevant to the pastoral industry is provided in Bastin et al. (2014).

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Australian rangelands and climate change – remotely sensed ground cover

Gary Bastin

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6. Australian rangelands and climate change – remotely sensed ground cover

Key points

- Targets specifying the maintenance of minimum levels of ground cover are a common feature of regional NRM plans. Setting realistic targets for broadly different land types within each region is a challenge. Targets should be set and reviewed with climate variability, and change, in mind.
- National remote sensing capability now means that fractional cover derived from 500 m MODIS imagery, extending back to late 2000, is available. The bare soil component of fractional cover can potentially assist in setting, monitoring and reviewing regional cover targets. Knowing how amounts of bare soil have varied under recent climate variability, fire regime and grazing management provides some basis for specifying appropriate targets for broadly different land types under continuing rainfall variability and possible long-term change.
- Fractional cover images for mid-March and mid-September 2001 to 2013 were analysed to determine how the percentage area of bioregions within NRM regions varied for different threshold levels of bare soil. Threshold values of bare soil within 25 ha MODIS pixels were ≥0.7, ≥0.6, ≥0.5, ≥0.4 and ≥0.3. The mid-March date represents likely maximal yearly bare soil in the southern part of the Rangelands Cluster, and the mid-September date is its equivalent in the central and northern cluster region.
- Using the former NSW Western CMA as an example, the analysis suggests that threshold levels of allowable bare soil should vary with land type (e.g. bioregion). A blanket target for an entire NRM region is not appropriate, particularly where mean annual rainfall, soil and vegetation type vary spatially within the region. Maximum allowable levels of bare soil should be lower in areas receiving higher or more reliable rainfall and where more perennial vegetation should be present. Conversely, more bare soil is permitted in arid parts of the Rangelands Cluster and where predominantly annual vegetation naturally occurs.
- Maximum threshold levels of bare soil are nominated for major bioregions within all NRM regions of the Rangelands Cluster. If the method demonstrated here for setting and monitoring maximum allowable levels of bare soil has merit, then these targets should be further investigated before being accepted.
- Targets should be periodically reviewed, as they may need to be adjusted under continuing climate variability and projected change. This will be the case where perennial grasses with the C_4 photosynthetic pathway (including buffel grass) displace existing C_3 herbage species due to atmospheric CO_2 enrichment and continued warming. Elsewhere in the near to medium term, strategies such as patch burning to reduce extensive wildfire, improved grazing land management and control of feral herbivores should increase vegetation cover in most years. Both scenarios (climate change and improved land management) should warrant a regional lowering of the permissible level of bare soil.

6.1 Introduction

Rainfall, fire and grazing are the principal drivers of ground cover. Fire is a more regular feature in the northern part of the Rangelands Cluster region, and its widespread occurrence in the central and southern rangelands generally follows successive wetter years (see Bastin 2014). There is little that land managers can do about the timing and amount of rainfall, but they can take steps to maximise its effectiveness when received and to manage subsequent grazing pressure so as to maintain acceptable levels of ground cover and thereby minimise the risk of erosion.

Maintaining a minimum level of ground cover is a common target in regional NRM plans. For example, the former Western CMA in NSW had a target of 40% ground cover based on soil conservation principles. This target was useful for focusing the attention of graziers and their advisers towards good grazing management.

Setting an ecologically sensible target that can be achieved on-ground by most land managers most of the time has been a challenge. This is further complicated by practical and cost-effective monitoring methods that indicate where and when regional targets are being met. A further technical issue is defining exactly what constitutes 'ground cover': is it just plant matter (alive and dead), does it include cryptogams or should it include stone mantling? (Gibber may be a legitimate 'ground cover' component because it protects the soil surface from wind erosion and raindrop impact.)

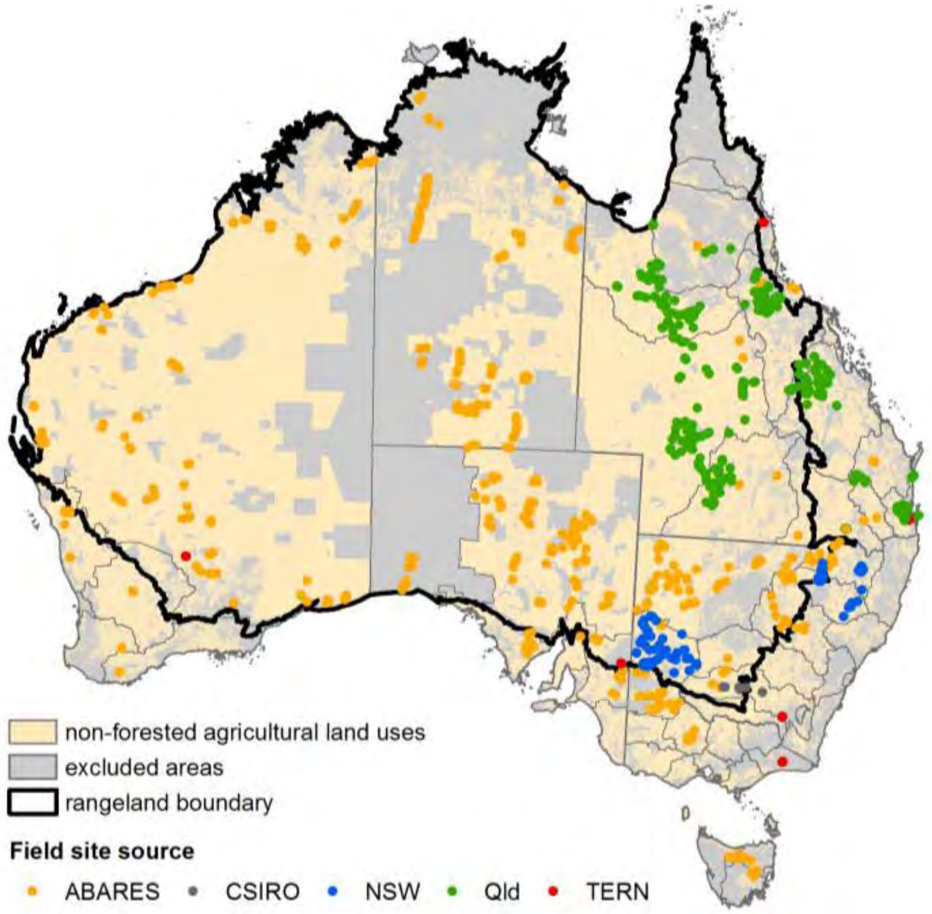

Figure 6.1 Locations of the ~1500 ground sites used to calibrate and validate remotely sensed fractional cover.

Source: Map courtesy of the Australian Bureau of Agricultural and Resource Economics and Sciences

Remote sensing methods now allow vegetation cover to be routinely monitored across Australia at two spatial and temporal scales. Methods are based on:

1. Landsat Thematic Mapper (TM): 30 m pixel resolution and potentially every 16 days since 1987. Some images are missing in the archive and others are unsuitable due to cloud cover and other forms of contamination, or more recent issues of malfunctioning by the TM instrument. In effect, the Landsat record is generally used for detailed monitoring of cover at specific times, for example, recovery following wetter periods or at the driest time of the year. Techniques for deriving and validating reliable cover indices are most advanced in Queensland and NSW and are currently being extended to the NT.
2. MODIS: at 500 m pixel resolution, cloud-free composite images are available for most of Australia every eight days since late 2000.

We use MODIS imagery for this analysis because a nationally led effort in recent years has collected ground data using consistent methods to suitably calibrate and validate cover estimates across the country (Figure 6.1). Also, for convenience, the larger pixel size of MODIS means smaller and more manageable image files when analysing cover dynamics across the large area covered by the Rangelands Cluster.

An unmixing technique is used to generate three components of fractional cover for each MODIS pixel: photosynthetic vegetation (PV: green), non-photosynthetic vegetation (NPV: senescent pasture and litter) and bare soil (BS) (Figure 6.2). The three components sum to one (or 100%) meaning that each 500 m by 500 m (25 ha) pixel has some proportion of PV, NPV and BS (see the legend below the example fractional cover image in Figure 6.2). This mixing is analogous to the soil texture triangle, where every soil is some mixture of sand, silt and clay.

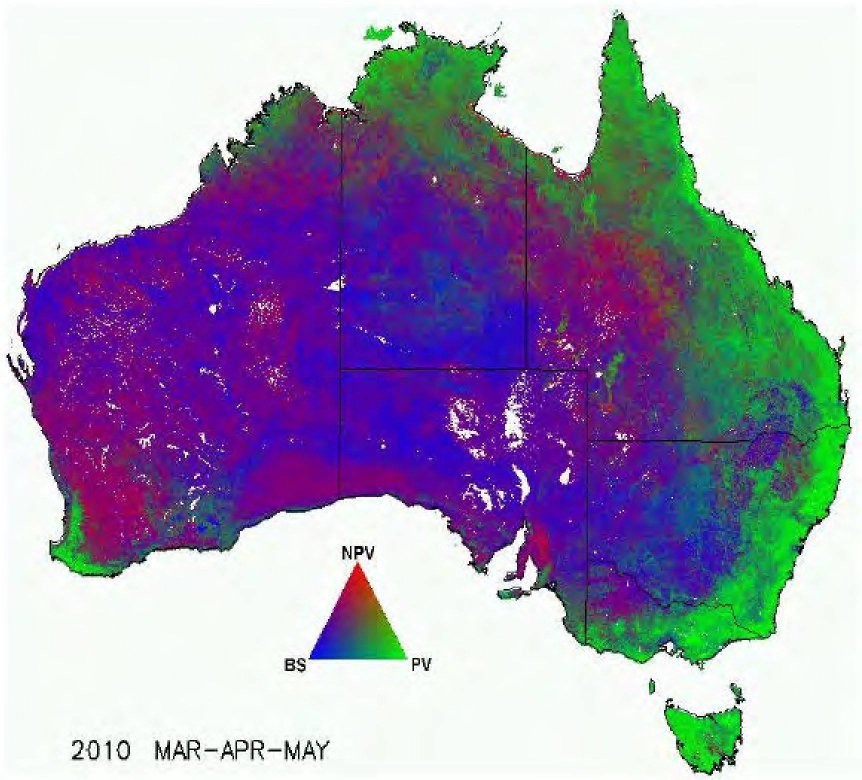

Figure 6.2 The autumn 2010 seasonal composite of fractional cover for Australia derived from MODIS imagery.

The photosynthetic (PV), non-photosynthetic (NPV) and bare soil (BS) components of fractional cover for each 500 m pixel are indicated by the mixing of primary colours shown in the triangle legend below the map.

Bare soil is effectively the converse of vegetation cover; that is, the more bare soil in a 500 m pixel, the less vegetation cover. An example bare-soil image is shown in Figure 6.3.

More information about fractional cover and the unmixing method is available in Guerschman et al. (2009), Stewart et al. (2013) and Malthus et al. (2013).

Images of fractional cover (bare soil, photosynthetic vegetation, non-photosynthetic vegetation) are available through TERN AusCover (http://www.auscover.org.au/xwiki/bin/view/Product+pages/Fractional+Cover+MODIS+CLW).

6.2 Setting a cover target

Vegetation cover or its converse, bare soil, varies spatially (Figure 6.3) and temporally, within years and between years (Figure 6.4). At specific locations, ground cover varies over time in response to rainfall (or lack of it, i.e. drought), grazing and fire. Sensible analysis of cover (or bare soil) dynamics over a large area and decadal time scales requires appropriate spatial and temporal stratification.

The spatial unit for this analysis is bioregions (IBRA v7, Department of the Environment n.d.) within NRM regions (Figure 6.5). A bioregion is a large, geographically distinct area of land that has groups of ecosystems forming recognisable patterns within the landscape. For our purpose, bioregions group broadly similar landform, soil and vegetation types. Fractional bare soil for nominated times of the year (next paragraph) were spatially averaged for each bioregion

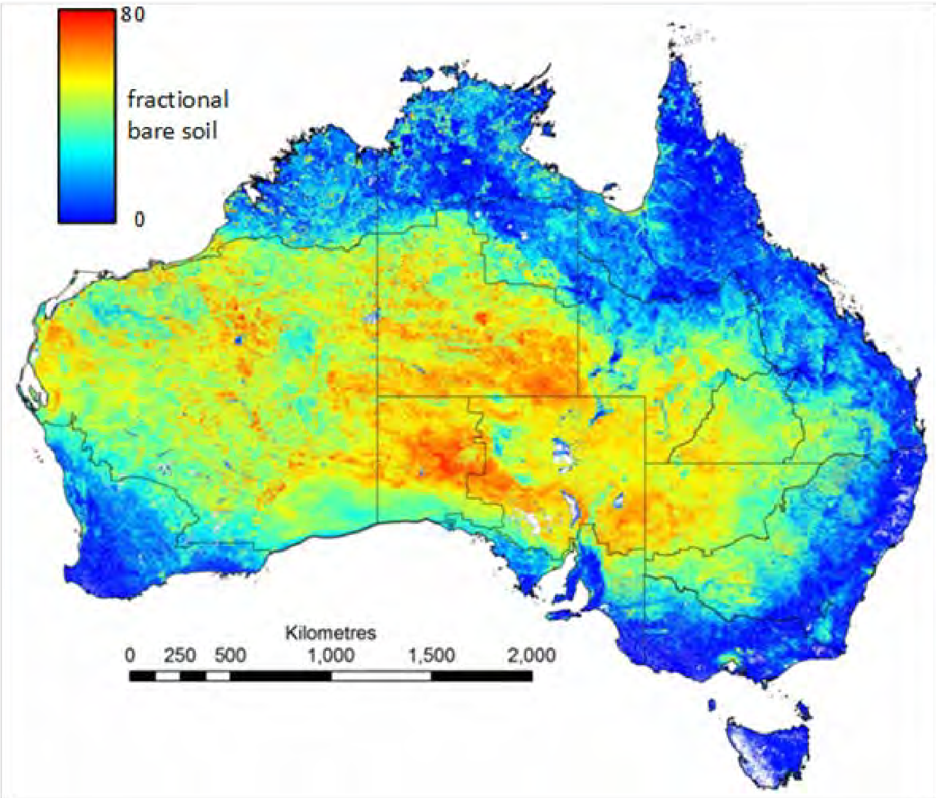

Figure 6.3 The percentage bare soil within 500 m MODIS pixels, mid-September 2009 (a particularly dry time for much of inland Australia). NRM regions within the Rangelands Cluster are also shown.

More bare soil means less vegetation cover.

in each NRM region. This stratification still has considerable internal landscape variability, but less so than averaging across the whole of each NRM region.

The soil surface is more vulnerable to erosion in dry times, notwithstanding the effects of grazing and fire. Thus it seems sensible to examine trends in bare soil at the probable driest time of each year. We have arbitrarily defined this as the middle of September for northern NRM regions (Table 6.1) where summer rainfall is more common and mid-March elsewhere where there is some chance of winter rain (but rainfall is essentially aseasonal).

The amount of bare soil also varies from year to year depending on seasonal quality (a general descriptor of yearly rainfall). This means there are two approaches to specifying a regional target: either (i) an amount of bare soil that should not be exceeded in most years, or (ii) the maximum level permissible in dry or drought years.

In this section we demonstrate the first approach and show how a regionally appropriate target varies for bioregions within NRM regions. The success in meeting our nominated regional targets between 2001 and 2013 is reported as *the percentage of bioregion area exceeding the agreed bare-soil target*.

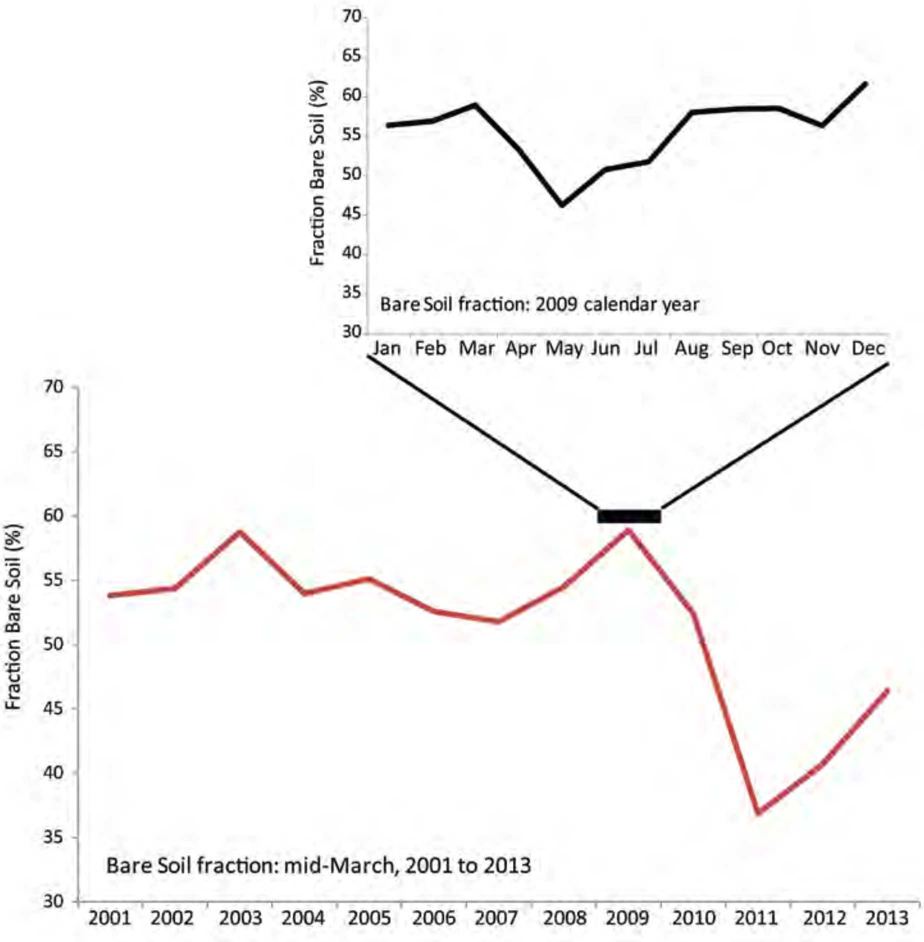

Figure 6.4 Temporal variation in the fraction of bare soil within MODIS pixels for a 1° block (approximately 10,000 km^2) centred on Broken Hill.

The top graph shows monthly variation throughout 2009; the bottom shows variation, for mid-March, between 2001 and 2013.

Note that more bare soil means less vegetation cover (including ground cover).

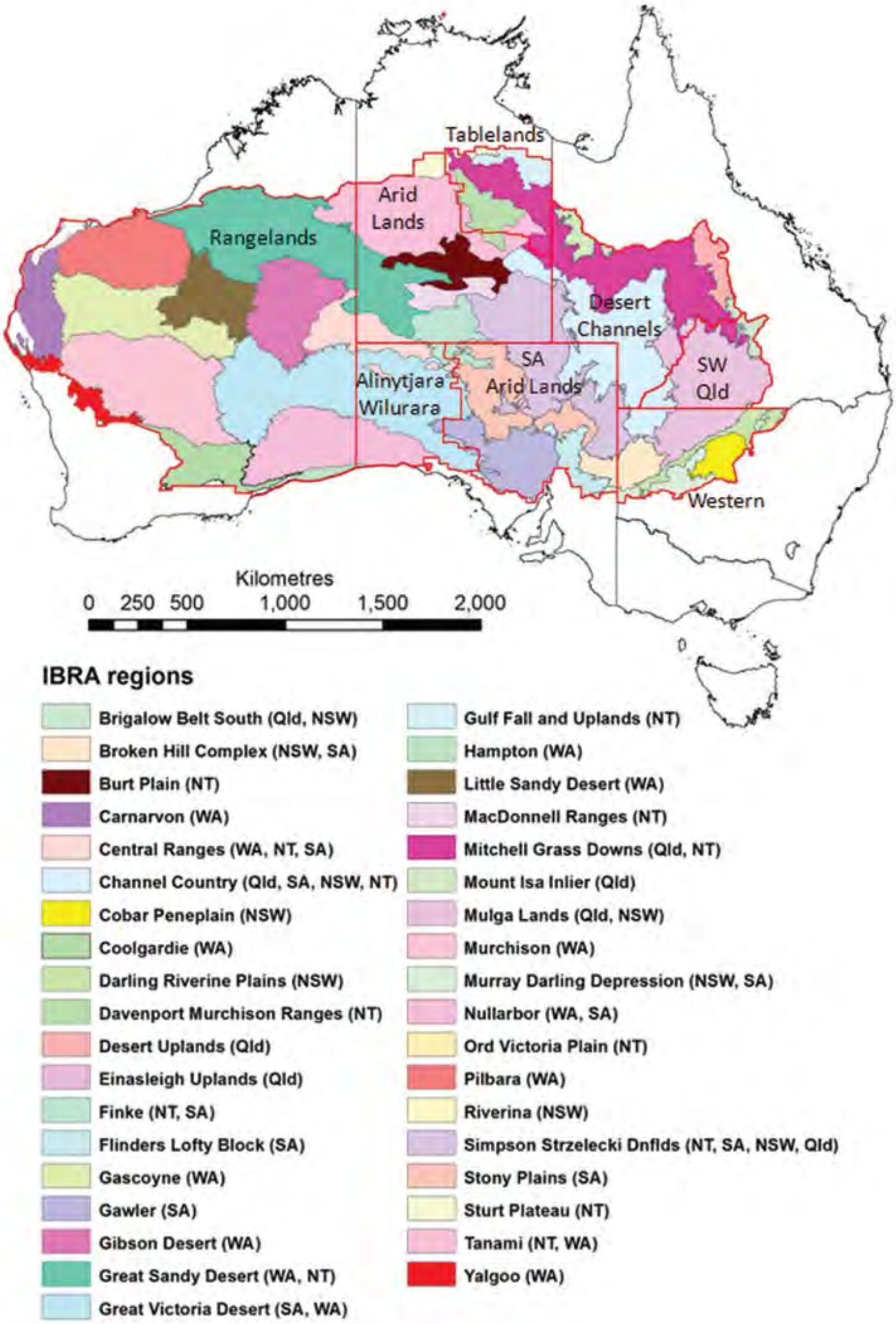

Figure 6.5 NRM regions and IBRA v7 bioregions in the Rangelands Cluster.

Bioregions are briefly described in Appendix A.

Table 6.1 Assignment of bioregions and NRM regions to summer and aseasonal rainfall zones. Bare soil levels in mid-September are analysed for summer-rainfall regions, and mid-March image dates are used elsewhere.

MID-SEPTEMBER (SUMMER RAINFALL)		MID-MARCH (ASEASONAL/WINTER RAINFALL)	
NRM region	**Bioregion**	**NRM region**	**Bioregion**
		NSW: Western	All
Desert Channels Queensland	All		
Queensland: South West NRM	All		
SA: Arid Lands	Simpson Strzelecki Desert, Finke, Stony Plain, Channel Country	SA: Arid Lands	Broken Hill Complex Gawler Flinders Lofty Block
SA: Alinytjara Wilurara	Central Ranges	SA: Alinytjara Wilurara	Great Victoria Desert Nullarbor
NT: Arid Lands sub-region	All		
NT: Tablelands sub-region	All		
WA Rangelands	Pilbara, Tanami Great Sandy Desert Little Sandy Desert Gibson Desert Gascoyne, Carnarvon Central Ranges	WA Rangelands	Nullarbor, Yalgoo Coolgardie Murchison Great Victoria Desert Hampton

6.3 Method

Datasets accessed and the procedure used to (i) nominate regionally appropriate maximum levels of bare soil and then (ii) monitor the success of these targets follows.

- Download archived fractional bare-soil images from the TERN AusCover portal and uncompress each image. Images included mid-March (Julian day 073) and mid-September (day 257) from 2001 to 2013.
- For each NRM bioregion, determine the number of 500 m pixels in each image having greater than 30%, 40%, 50%, 60% or 70% bare soil within the pixel (spatial analysis done in a GIS).
- Import spatial statistics to Excel and convert the pixel counts to the percentage area of corresponding bioregions within NRM regions.
- Based on the criteria in Table 6.1 and the temporal pattern of percentage area for each bare-soil category by NRM bioregion, assign the most appropriate category as the nominated target.
- Summarise the above analysis by tabulating the percentage area of each NRM bioregion exceeding the nominated target level of bare soil between 2001 and 2013.

6.4 Data source

Analyses below used MODIS-derived images (500 m pixels) of fractional bare soil downloaded from the TERN AusCover portal. Images are available on a 16-day basis from late 2000 to 2014.

6.5 Caveats

- The algorithm for calculating fractional cover has been calibrated and validated according to rigorous ground data collected at ~1500 sites across Australia (Figure 6.1). Fractional bare soil at the scale of individual MODIS pixels may not be accurate everywhere.
- Nominated regional targets are suggestions only and should be set for the broad land types within NRM regions using the best available scientific information and stakeholder consultation.

6.6 Findings

Broken Hill Complex, Western CMA as an example

The percentage area of the Broken Hill Complex having different levels of fractional bare soil between 2001 and 2013 is shown in Figure 6.6. This is based on a mid-March image for each year. Rainfall for the preceding 12 months (March to February) is also shown. Not surprisingly, a larger proportion of the bioregion area had intermediate levels of bare soil after the dry years of the mid to late 2000s (up to 2009), and the percentage area exceeding each bare-soil threshold declined substantially following the wetter years of 2011 and 2012. The time traces of percentage area suggest that fractional bare-soil thresholds of ≥0.6 and

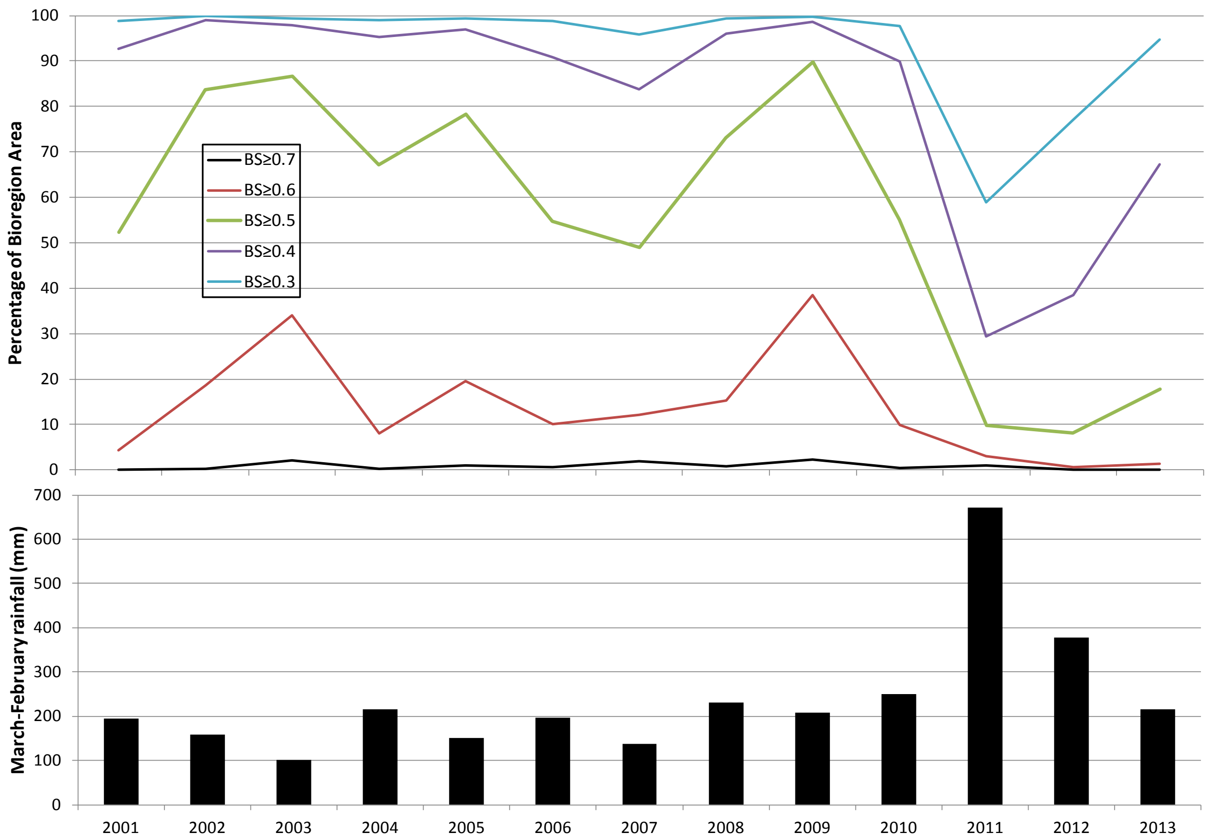

Figure 6.6 Spatially averaged March-February rainfall between 2001 and 2013 for the Broken Hill Complex, Western CMA, and corresponding percentage areas of the bioregion exceeding specified thresholds of fractional bare soil.

≥0.5 for each MODIS pixel (i.e. 25 ha area) are useful as regional targets for this land type. Correspondingly, for planning purposes, this means that we expect most of the area to have at least 50% or 60% vegetation cover (including trees and shrubs), and we will use fractional cover to monitor how much of the Broken Hill Complex achieves this target in March each year.

The spatial representation of three bare-soil thresholds is shown for mid-March of the very dry year, 2009, in Figure 6.7. Part (a) of the figure shows that fractional bare soil was between 0.4 and 0.6 in most pixels (i.e. green and yellow colours). Small areas were largely bare (i.e. red dots in parts of the image). Correspondingly for this dry time, much of the area exceeded the 0.5 and 0.6 fractional bare-soil targets (green and red colouring in part (b) of Figure 6.7).

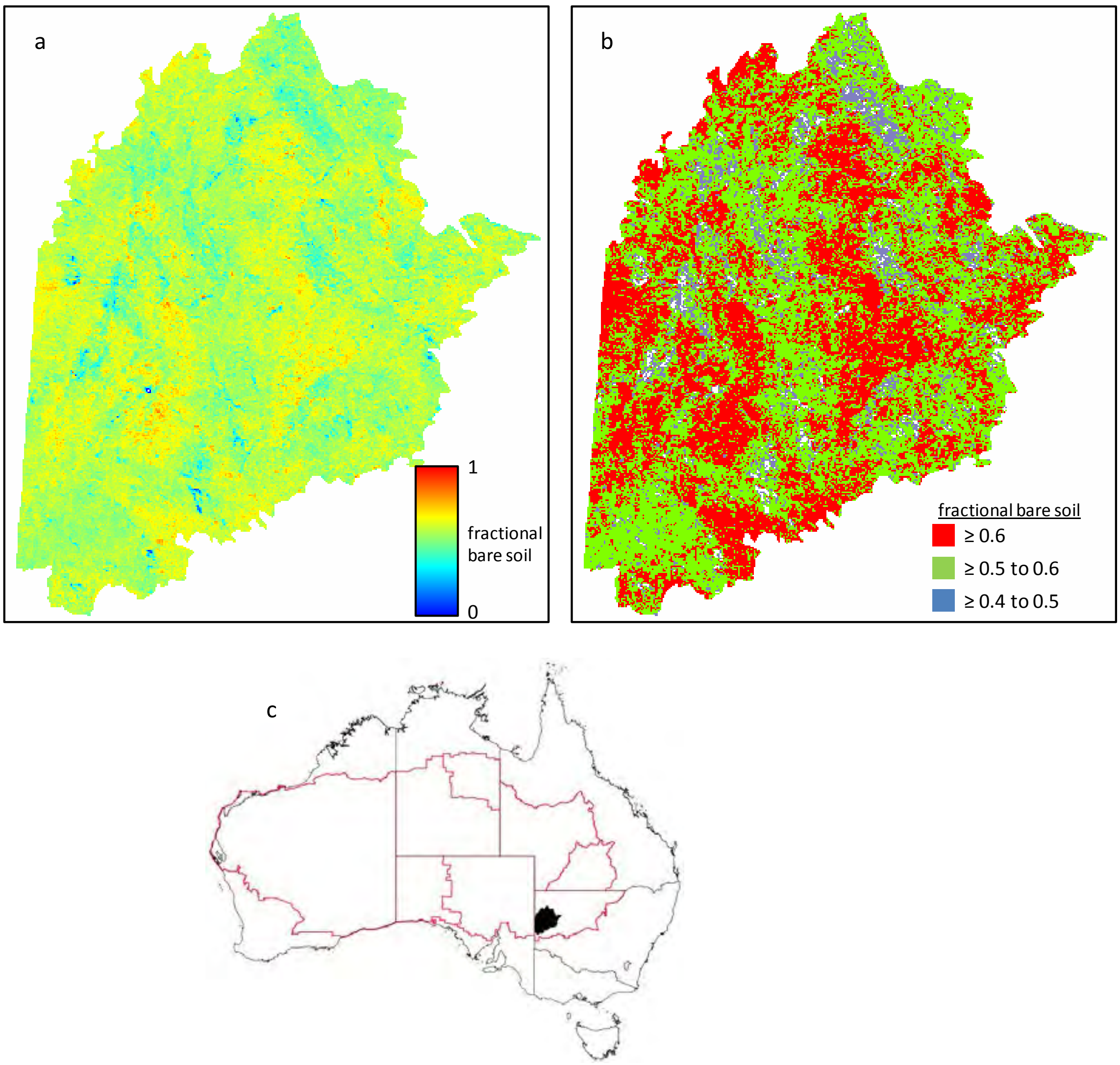

Figure 6.7 (a) Fractional bare soil in March 2009 for the Broken Hill Complex, Western CMA, (b) categories of bare soil mapped from the same image and (c) the location of the Broken Hill Complex in the Western CMA.

Bare-soil targets for Western CMA bioregions

Nominated target thresholds for maximum levels of bare soil in each bioregion are highlighted near the top of Table 6.2. The percentage area of bioregions exceeding nominated targets in mid-March 2001 to 2013 is then listed in following rows of the table and graphed in Figure 6.8. (See Figure 6.5 for the location of bioregions within the Western CMA.)

The area of bioregions, along with their brief description, is available in Appendix A.

It should be clearly understood that the bare-soil thresholds listed in Table 6.2 are indicative only. If regional planners consider that the method demonstrated in this section for specifying targets and monitoring their outcomes has merit, they should undertake further evaluation to that presented here. Such evaluation could usefully include stakeholder consultation to gain consensus for sensible bare-soil targets for regional land types.

Table 6.2 Nominated bare-soil thresholds for Western CMA bioregions and the percentage area exceeding each threshold in mid-March 2001 to 2013.

	BIOREGION							
	Brigalow Belt South	Broken Hill Complex	Channel Country	Cobar Peneplain	Darling Riverine Plains	Murray–Darling Depression	Mulga Lands	Simpson Strzelecki Dunefields
Bare soil threshold	≥40	≥60	≥50	≥40	≥40	≥50	≥50	≥60
2001	8.1	4.3	21.2	1.6	21.5	9.0	4.9	1.1
2002	37.0	18.5	64.6	25.8	42.3	35.3	33.3	37.3
2003	36.5	31.9	64.3	35.0	26.5	43.2	44.1	39.8
2004	24.2	7.8	56.5	36.2	32.3	28.4	41.0	9.6
2005	25.9	18.7	45.5	34.4	32.6	41.6	36.5	22.4
2006	32.0	9.5	40.7	22.7	35.1	7.4	27.7	15.6
2007	31.5	10.1	14.7	27.7	31.9	16.6	26.1	5.8
2008	20.1	14.3	32.4	31.9	26.6	35.8	23.8	8.5
2009	23.6	36.2	58.8	31.2	29.6	56.9	48.8	21.3
2010	5.1	9.4	2.9	32.0	18.2	28.3	15.5	0.2
2011	3.5	2.0	2.6	10.0	6.3	4.0	2.5	0.1
2012	1.2	0.6	2.2	7.6	5.3	2.1	1.6	0.2
2013	9.4	1.2	8.1	19.9	18.6	6.8	7.3	1.2

6.6.1 Bare soil targets for other Rangelands Cluster bioregions

The percentage area of major bioregions exceeding threshold levels of bare soil in other NRM regions in the Rangelands Cluster is tabulated in Appendix B. These data can be explored graphically to decide appropriate targets (e.g. Figure 6.6) and the results between 2001 and 2013 evaluated as shown in Figure 6.8.

Appendix B is in two parts: the first table lists percentage areas of southern bioregions based on analysis of fractional bare soil in mid-March of each year; the second table presents corresponding results for northern bioregions using the mid-September image date. Highlighted rows in each table are our suggested threshold level of maximum bare soil for that bioregion and NRM region.

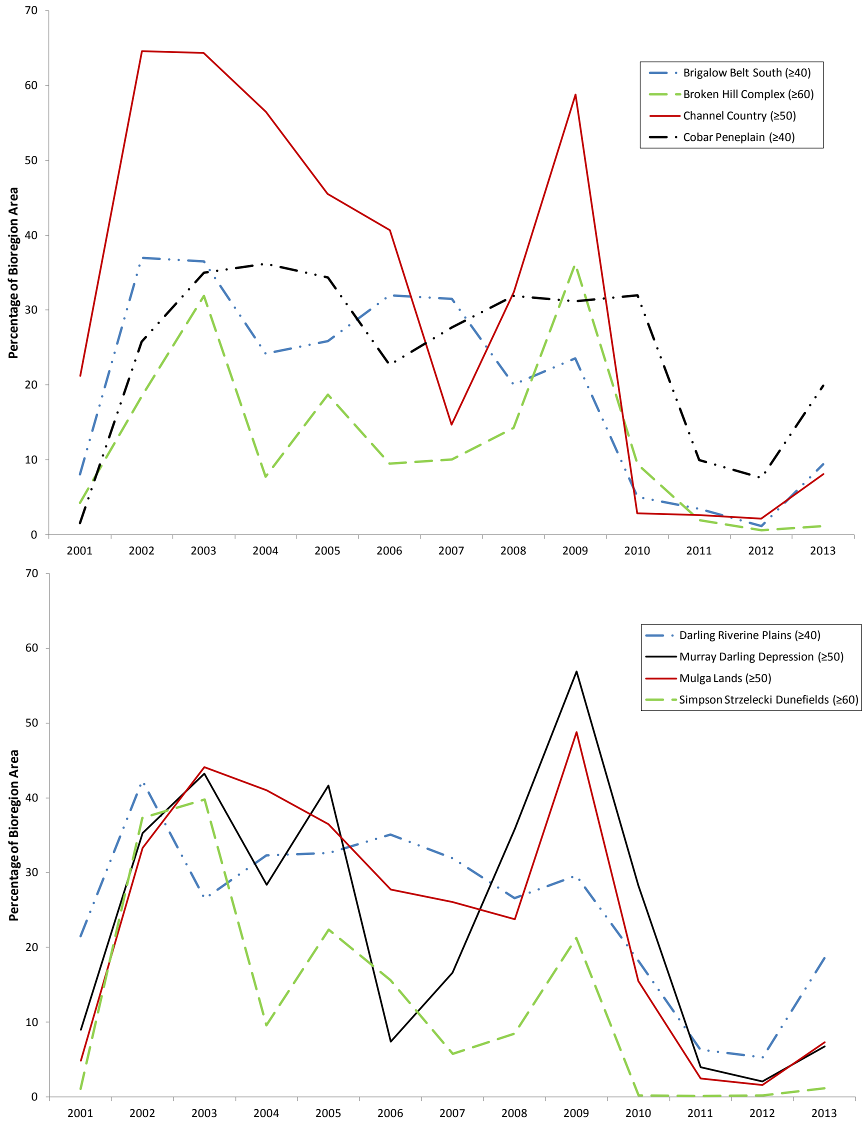

Figure 6.8 The percentage area of bioregions in the Western CMA exceeding nominated target levels of bare soil in mid-March 2001 to 2013.

Target levels of maximum bare soil are shown in brackets in the legend of each graph (see also Table 6.2).

6.7 Key adaptation strategies

- Use the best sources of information, including remote sensing, and a stakeholder consultation process to set thresholds for maximum acceptable levels of bare soil (conversely, minimum vegetation cover) for the broadly different land types in each NRM region. These targets should seek to minimise the area of each land type (e.g. bioregion) that exceeds the nominated threshold in most years. Alternatively, set a target for dry/drought years that allows more bare soil, but ensure that the area exceeding this specified level of bare soil is minimised in such years. It certainly should not be approached at other times when more normal rainfall is received.
- Encourage land managers to meet these targets, perhaps by providing appropriate incentives.
- Use the now-available MODIS or Landsat TM fractional cover products to monitor the extent to which regional land-type (or bioregional) targets are being met.
- Be mindful that target values will need reviewing if vegetation composition, structure and function changes under projected climate change. Possible examples include:
  - an increased perennial component in the herbage layer as C_4 grasses (particularly buffel) establish: then decrease the level of acceptable bare soil
  - reduced opportunities for pasture growth with increased warming due to greater evapotranspiration: then possibly increase acceptable levels of bare soil.
- The need for revised targets will be clearer where the vegetation is changing relatively rapidly (e.g. establishment of buffel grass) but will be a much more difficult decision where slower change is immersed in year-to-year variability associated with the amount and timing of rainfall.

Appendix A Bioregions and their areas

A brief description of bioregions (IBRA v7) present in the Rangelands cluster region and the area in each in each NRM region is provided in the following table.

BIOREGION	DESCRIPTION	NRM REGION	AREA (KM^2)
Brigalow Belt South	The region contains mixed landscapes including undulating to hilly areas with low ridges and deep valleys as well as flat alluvial plains in the south. There is a large distance between the extreme southern sections in northern NSW and those parts in rangeland Queensland. Vegetation is predominantly mixed eucalypt woodland with areas of brigalow scrubs and open Mitchell grasslands. Tenure is mostly leasehold with cattle grazing being the major land use. Relatively small outliers of the bioregion occur in northern NSW.	Western (NSW) SW NRM (Qld) Desert Channels (Qld)	3,630 14,599 4,726
Broken Hill Complex	Land types include low ranges, rounded hills and gently undulating downs. Chenopod downs country occupies the majority of this bioregion. Tenure is mostly pastoral leasehold with some nature reserves. Grazing, by sheep and increasingly cattle, is the most extensive land use. Mining for silver, lead, zinc and copper is still important to the region's economy and tourism has grown in recent years. Broken Hill is the major population centre.	Western (NSW) Arid Lands (SA)	37,665 18,687
Burt Plain	Landscapes characterised by plains and low rocky ranges. Vegetation is predominantly mulga and other acacia woodlands with short grasses and forbs, and spinifex grasslands. The predominant land use is cattle grazing with some Aboriginal land. Communities include Aileron, Barrow Creek, Ti Tree and Yuendumu.	Arid Lands (NT)	73,797

BIOREGION	DESCRIPTION	NRM REGION	AREA (KM^2)
Carnarvon	Low gently undulating landscape with open drainage. Vegetation is mainly Acacia shrublands and saltbush/bluebush shrublands with areas of tussock grassland in the north. Major land tenure is pastoral leasehold, with some conservation reserves, such as the Cape Range National Park. The region has a range of industries including extensive cattle and sheep grazing, salt mining, tourism and fishing. Major population centres are Carnarvon, Denham, Exmouth and Coral Bay.	WA Rangelands	84,302
Central Ranges	Landforms dominated by rugged ranges and red sandplains. The vegetation is predominantly mulga open woodland over spinifex grasslands. The entire bioregion is Aboriginal land and there are many small Aboriginal communities in this area. Larger communities include Warburton and Warakurna in WA; Ernabella, Kaltjiti (Fregon) and Amata in SA; and Kaltukatjara (Docker River) in the NT.	WA Rangelands Arid Lands (NT) Arid Lands (SA) Alinytjara Wilurara	47,015 26,196 453 27,977
Channel Country	Vast braided, flood and alluvial plains surrounded by gravel or gibber plains, dunefields and low ranges. Vegetation is predominantly Mitchell grass, gidgee and spinifex. Major population centres are Birdsville, Windorah and Innaminka.	Desert Channels SW NRM (Qld) Arid Lands (SA) Arid Lands (NT) Western (NSW)	189,998 15,867 51,597 23,276 23,355
Cobar Peneplain	Landscapes include undulating low rounded ridges, rolling downs and plains. A large area of the bioregion is rangeland, where land tenure is predominantly leasehold (Western Division) and vegetation consists of poplar box woodlands, mulga communities and white cypress pine. The eastern-most part of the bioregion has freehold title (Central Division) and has largely been cleared for cereal cropping. The dominant land use (in terms of area) in the rangelands is sheep and goat grazing with some cattle production. Dryland cropping is also important within the eastern margins of the rangeland zone and becomes dominant further to the east. Copper mining occurs around Cobar, the major population centre.	Western (NSW)	37,037

BIOREGION	DESCRIPTION	NRM REGION	AREA (KM^2)
Coolgardie	Landforms include granite rocky outcrops, low greenstone hills, laterite uplands and broad plains. Numerous salt lakes also occur through the bioregion. The Coolgardie bioregion covers the interzone between mulga/spinifex country and eucalypt environments. Land tenure includes pastoral lease, Aboriginal land and several National Parks and reserves. Gold and nickel mining are very important to the region's economy. Regional income is supplemented by pastoral activity and tourism. Major population centres are Kalgoorlie, Coolgardie and Norseman.	WA Rangelands	84,857
Darling Riverine Plains	The bioregion includes the extensive alluvial plains of the network of rivers and creeks that flow into the Darling River together with its floodplain. Vegetation includes river red gum, blackbox and coolibah woodlands with inliers of poplar box, belah, redbox and ironbark woodlands on higher parts of the landscape. Major tenure is leasehold in the Western Division and freehold in the Central Division of NSW. Sheep and cattle grazing is the main land use; other land uses include dryland cropping, irrigated cotton, horticulture, and at Lightning Ridge, black opal mining. Major population centres are Wilcannia, Bourke, Brewarrina, Nyngan (all in NSW) and St George (Qld).	Western (NSW) SW NRM (Qld)	38,656 539
Davenport Murchison Ranges	The bioregion is characterised by a chain of rocky ranges surrounded by lowland plains. Vegetation is predominantly eucalypt low open woodland and acacia sparse shrubland over hummock grassland. Land tenure includes Aboriginal land, pastoral leases and the Davenport-Murchison National Park. Mining for gold production occurs at Tennant Creek. Major population centres are Tennant Creek and Warrego.	Tablelands (NT) Arid Lands (NT)	49,654 8,397
Desert Uplands	Upland landforms dominated by sandstone ranges and sand plains, thickly vegetated with eucalypt woodlands with a spinifex understorey as well as acacia woodlands. Most of the bioregion is under leasehold tenure and is used for cattle grazing and some sheep grazing in the west. Major population centres are Barcaldine and Pentland.	Desert Channels (Qld)	42,146
Einasleigh Uplands	Landforms consist of a series of rugged hills and ranges, dissected plateaus and alluvial and sand plains. The bioregion is dominated by eucalypt woodlands. Land is used extensively for grazing with some mining, cropping and horticulture. There are several nature reserves. Major population centres are Charters Towers, Georgetown and Mareeba.	Desert Channels (Qld)	48

BIOREGION	DESCRIPTION	NRM REGION	AREA (KM^2)
Finke	The main land types are arid sand plains with dissected uplands and valleys, including some major rivers (Finke, Hugh and Palmer). The bioregion is dominated by mulga with various Senna, Eremophila and other Acacia species present over short grasses and forbs. Major land uses are cattle grazing and Aboriginal land management. Major population centres are Finke and Imanpa.	Arid Lands (NT) Arid Lands (SA) Alinytjara Wilurara	53,520 12,322 6,833
Flinders Lofty Block	The bioregion has a general pattern of mountain ranges, ridges and wide flat plains. Vegetation types are related to landforms with eucalypts on hills and ranges that receive higher rainfall, mulga in the drier areas, and sparse low shrubs or spinifex on stony areas. The area is mainly used for sheep and cattle grazing. Conservation reserves and associated tourism are also important. Coal is mined at Leigh Creek and there is limited dryland agriculture in the south and east. Major population centres are Olary, Hawker, Quorn, and Leigh Creek.	Arid Lands (SA)	38,661
Gascoyne	Low rugged ranges and broad flat valleys. Open mulga low woodlands dominate. Extensive sheep and cattle grazing is the dominant land use on pastoral leasehold in the bioregion. Mining is important to the region’s economy. There are no major population centres in the bioregion. Aboriginal communities include Jigalong and Burringurrah.	WA Rangelands	180,753
Gawler	Characteristic landscapes are rounded, rocky hills, plains and salt-encrusted lake beds. Vegetation types include spinifex grasslands, open woodlands and chenopod shrubs. Sheep and some cattle grazing is the most extensive industry (in terms of area) but mining, particularly copper, uranium and gold at Olympic Dam, provides the main source of revenue. Iron ore is also extracted in the Iron Knob area. Major population centres are Whyalla, Port Augusta, Roxby Downs and Woomera.	Arid Lands (SA) Alinytjara Wilurara	113,022 4,508
Gibson Desert	Vast undulating sand plains, dunefields, and lateritic gibber plains. The vegetation is mainly mulga and other mixed shrubs over spinifex. The bioregion includes Aboriginal land, Unallocated Crown Land and conservation reserves. Conservation and Aboriginal land are the main land uses. The bioregion has a very low population with the major centres being the Kanpa, Patjarr and Tjirrkarli Aboriginal communities.	WA Rangelands	156,289
Great Sandy Desert	Red sandplains, dunefields and remnant rocky outcrops. Vegetation is predominantly spinifex grasslands, low woodlands and shrubs. Tenure comprises Unallocated Crown Land, conservation reserves and Aboriginal land, with the main industries being tourism, mining and mineral exploration. Major population centres are Telfer (WA) and Yulara (NT).	WA Rangelands Arid Lands (NT)	295,396 99,465

BIOREGION	DESCRIPTION	NRM REGION	AREA (KM^2)
Great Victoria Desert	A desert region characterised by dunefields with playa lakes and lunettes. Vegetation is predominantly marble gum, mulga and yarldarlba over spinifex grassland. Most of the bioregion is Unallocated Crown Land, conservation reserves and Aboriginal land. As such, it has very low pastoral value and is little developed. There are no major population centres in the bioregion but there are a number of small Aboriginal communities. Cosmo Newberry is probably the best known.	WA Rangelands Alinytjara Wilurara Arid Lands (SA)	217,942 186,133 16,360
Gulf Fall and Uplands	Landscapes include spectacular gorges, water holes and dissected sandstone plateaus. Vegetation is predominantly eucalypt woodlands over spinifex grasslands. Cattle grazing and mining are the main industries. Other land uses include Aboriginal land and conservation reserves. Major population centres are Borroloola and Ngukurr.	Tablelands (NT)	37,259
Hampton	Landforms include marine dunes and limestone escarpments. Vegetation is a mix of mallee, eucalypt and myall woodlands. Tenure is mainly pastoral leasehold and Unallocated Crown Land with pastoralism as the main industry. The main population centre is Eucla.	WA Rangelands Alinytjara Wilurara	10,430 452
Little Sandy Desert	This desert region is characterised by dunefields and low ranges. Vegetation is mainly a shrub steppe of acacia over spinifex. Tenure is predominantly Aboriginal land with some Unallocated Crown Land, conservation reserves and the eastern margins of several pastoral leases. Mineral exploration is also an important industry. There are no major population centres in the bioregion. Parnngurr is one of the smaller Aboriginal communities in the region.	WA Rangelands	110,899
MacDonnell Ranges	Landforms characterised by high-relief ranges and foothills. Spinifex and acacias, particularly mulga, occur throughout the region. Land tenure is pastoral leasehold, conservation reserve and Aboriginal freehold. The main industries are cattle grazing and tourism. Alice Springs is the major population centre.	Arid Lands (NT)	39,294

Appendix B Threshold levels of bare soil for bioregions within NRM regions

The percentage area of major bioregions (by area) exceeding threshold levels of bare soil in Rangelands cluster NRM regions is listed in the following two tables. The first table provides the percentage area of southern bioregions exceeding specified levels of bare soil based on analysis of mid-March images from 2001 to 2013. The second table presents corresponding results for northern bioregions using the mid-September image date. Highlighted rows suggest the appropriate target for each bioregion and NRM region.

B1. Mid-March analysis

IBRA	Bare soil threshold	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
NSW Western														
Brigalow Belt South	≥70	0.1	0.1	1.5	1	0.1	1.2	1.4	0.5	0.3	0.1	0.2	0	0.4
	60.0-69.9	0.7	2.6	7.8	3	0.7	4.5	8.7	1.8	1	0.4	0.4	0.1	0.9
	50.0-59.9	3.5	13.9	25.9	10.3	7.4	16.2	22.9	5.6	6.3	1.7	1.1	0.3	3.2
	40.0-49.9	8.1	37	36.5	24.2	25.9	32	31.5	20.1	23.6	5.1	3.5	1.2	9.4
	30.0-39.9	23.1	34.9	21.7	32.4	37.3	30.1	26.5	37.8	44.1	20	11.8	6.1	23.2
Broken Hill Complex	≥70	0	0.2	2.1	0.2	0.9	0.6	1.9	0.9	2.3	0.5	0.9	0	0.1
	60.0-69.9	4.3	18.5	31.9	7.8	18.7	9.5	10.1	14.3	36.2	9.4	2	0.6	1.2
	50.0-59.9	48.1	65	52.6	59.2	58.7	44.6	36.9	57.8	51.4	45.1	6.9	7.5	16.6
	40.0-49.9	40.3	15.4	11.2	28.1	18.6	36.1	34.8	23.1	8.8	34.8	19.5	30.5	49.4
	30.0-39.9	6.3	0.9	1.6	3.9	2.5	7.9	12.1	3.3	1.1	7.9	29.6	38.5	27.5
Channel Country	≥70	0	0.2	0.2	0.1	0.1	0.3	1.1	0.1	0.2	0.2	0.1	0.1	0
	60.0-69.9	0.3	2.6	12	3.2	2.6	3.7	2.8	1.7	4.9	0.3	0.4	0.3	0.3
	50.0-59.9	21.2	64.6	64.3	56.5	45.5	40.7	14.7	32.4	58.8	2.9	2.6	2.2	8.1
	40.0-49.9	60.9	25.3	15	28.7	40.3	40.5	39.3	46.6	27.1	25.5	14.6	20	51.8
	30.0-39.9	10.4	4.7	4.4	6.2	7.2	9.5	25.7	13	6.2	45.7	34.5	44.8	31

IBRA	Bare soil threshold	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Cobar Peneplain	≥70	0	0	0.5	0.1	0.1	0.1	0.4	0.2	0.8	0.1	0.3	0	0
	60.0-69.9	0	0.3	4.7	1.3	2.2	0.6	1.6	1.9	7.5	0.9	1	0.1	0.3
	50.0-59.9	0.3	4.2	19.8	11.9	15.8	5.2	9	13.3	22.8	10.5	3	0.8	3.8
	40.0-49.9	1.6	25.8	35	36.2	34.4	22.7	27.7	31.9	31.2	32	10	7.6	19.9
	30.0-39.9	9.5	51.4	31	38.4	33.1	39	38.3	35.8	27.6	41.6	27.2	29.1	38.2
Darling Riverine Plains	≥70	0.1	0.7	1.6	1.1	0.6	1.5	2.6	0.4	0.4	0.1	0.5	0.3	0.1
	60.0-69.9	0.4	5.6	15.6	7.4	6.6	8	12.7	2.3	5.7	0.7	0.8	0.5	0.5
	50.0-59.9	6.7	33.5	46.2	31.6	33.3	25.6	34.7	13.2	29.3	6.5	2.2	1.7	4.8
	40.0-49.9	21.5	42.3	26.5	32.3	32.6	35.1	31.9	26.6	29.6	18.2	6.3	5.3	18.6
	30.0-39.9	31.9	13.2	7.4	15.6	17.5	20.8	13.2	24.1	22.8	18.4	14.2	13.7	26.7
Murray Darling Depression	≥70	0	0.2	1.1	0	0.4	0.1	0.9	0.3	0.4	0	0.5	0	0.1
	60.0-69.9	0.2	8.2	21.9	1.6	6.8	0.7	3.4	6.1	15	1.7	1.3	0.1	0.4
	50.0-59.9	9	35.3	43.2	28.4	41.6	7.4	16.6	35.8	56.9	28.3	4	2.1	6.8
	40.0-49.9	34.7	30.5	22.1	48	34.9	33.6	36.5	40.4	21.5	53	13.8	20.1	38.5
	30.0-39.9	27.9	20.4	9.1	17.4	12.6	40.3	30.3	14.9	5.4	15.6	28.6	44.1	40
Mulga Lands	≥70	0	0.1	0.3	0.2	0.2	0.3	1.7	0.3	0.2	0.2	0.2	0.1	0.1
	60.0-69.9	0.1	1.5	8.3	3.2	4.1	3	5.6	2.2	8	1.1	0.6	0.2	0.4
	50.0-59.9	4.9	33.3	44.1	41	36.5	27.7	26.1	23.8	48.8	15.5	2.5	1.6	7.3
	40.0-49.9	29.4	46.1	34.1	42.5	42	46.7	43	44	29.4	40.3	10.5	13.1	38.7
	30.0-39.9	37.9	17.3	10.8	10.5	14	17.5	17.7	19.9	10.3	22.8	28.7	37.5	34.4
Simpson Strzelecki Dunefields	≥70	0	0	0.2	0	0.2	0.5	0.7	0.3	0.3	0	0	0	0.1
	60.0-69.9	1.1	37.3	39.8	9.6	22.4	15.6	5.8	8.5	21.3	0.2	0.1	0.2	1.2
	50.0-59.9	63.5	59.4	56.1	79	71.6	63.8	47.4	60.5	64.7	4.8	0.6	1.7	9.2
	40.0-49.9	33.7	3.1	3.3	10.5	5.2	18.3	38	27.9	12.6	46.7	6.3	17.9	61
	30.0-39.9	1.3	0.1	0.5	0.7	0.4	1.6	6.7	2.6	0.9	42.8	31.1	54.7	27.2
SA Arid Lands														
Broken Hill Complex	≥70	0.1	0.1	3	1.3	1.3	0.3	1.5	2.2	3.5	0.7	2.2	0.1	0.2
	60.0-69.9	8.2	16.5	47.6	35.6	35.1	11.4	13.5	29.8	47.7	16.4	6.6	2.5	8.8

IBRA	Bare soil threshold	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
	50.0-59.9	69.9	63.5	44.4	55.9	59.6	64.2	51.9	53.3	44.6	57.5	21.5	26.1	51.6
	40.0-49.9	21.5	19.5	4.1	6.5	3.6	22.1	28.3	13	3.8	22.1	35.6	48.9	33.5
	30.0-39.9	0.4	0.5	0.6	0.5	0.3	1.7	4.1	1.5	0.3	2.8	22.9	19.4	5.5
Flinders Lofty Block	≥70	0.5	0.5	3.9	2.6	2.7	2.1	4	2.4	3.1	2.4	2.6	1.2	0.6
	60.0-69.9	7.7	5.4	22.9	18.6	19.5	14	15.7	17.2	22.6	22.1	8.1	6.8	7.9
	50.0-59.9	40.6	37.5	41.8	43.1	43.3	39.5	36.5	44.5	43.2	42.5	22.5	24.8	34.9
	40.0-49.9	36.5	35.8	19.3	22	20.4	26.8	26.1	23	19.7	21.5	33	37	37.1
	30.0-39.9	9.1	11.9	8.2	8.9	9.1	11.2	11.3	8.4	7.5	8.3	22	21.5	14.2
Gawler	≥70	4.5	0.5	7.4	1.8	1.3	5.8	4.9	2.7	6.1	1.5	1.9	1.8	1.6
	60.0-69.9	24.1	12.3	31.5	28.4	21.2	27.9	14.3	26.1	30.6	23.6	10.6	16.7	21.3
	50.0-59.9	30.8	33.8	33.4	37.8	42.5	31.5	31.2	35.9	32	35.8	31.5	39	41.2
	40.0-49.9	17.5	26.7	10.9	14	15.4	14.5	22.9	17.1	14	15.6	27.1	19.8	16.2
	30.0-39.9	7.7	11.6	4.5	5.1	6.2	5.9	10.2	5.9	4.3	7.5	11.2	7.2	6.1
Alinytjara Wilurara														
Great Victoria Desert	≥70	9.1	0.1	7.6	6.6	2.5	9.9	10	5.5	7	2.9	3.3	2.6	6.8
	60.0-69.9	22.7	10.4	30.5	35.5	22.4	34.2	25.2	25.4	28.7	21.4	17.7	13.1	22.9
	50.0-59.9	36.5	52.2	41.4	35.5	40.3	32.6	31.1	33.9	39.2	37.4	40.7	26.4	37.5
	40.0-49.9	25.1	27.9	18.4	18.9	28.4	19.5	21.7	28.2	21.9	27.7	29	37.9	27.5
	30.0-39.9	5.6	7.8	1.7	3	5.6	3.2	8.7	6.3	2.6	8.7	7.5	17.5	4.6
Nullarbor	≥70	0.1	0	0.1	0.2	0.1	0.1	1.3	0.1	0.2	0.8	0.3	0.1	0.2
	60.0-69.9	2.2	1.1	0.7	2.4	0.5	0.6	2.2	1.4	4.7	4.7	0.9	0.2	1.1
	50.0-59.9	10.8	7.7	9.4	10.6	6.6	7	6.9	8.9	11.5	9.6	4.5	0.9	10
	40.0-49.9	38.9	22.3	38.1	38.6	19.1	20.5	16.9	23.7	48.9	26.6	12.3	6.9	29.3
	30.0-39.9	45.1	59.6	49.3	46.2	61.3	59.1	33.5	53.1	32.8	47.4	36.7	31.6	49
WA Rangelands														
Coolgardie	≥70	0.7	0.1	0.8	0.2	1.5	0.9	0.5	0.8	0.1	1	0.5	0.4	0.4
	60.0-69.9	1.8	0.5	2.3	1.3	1.5	3	3.2	3.2	1.2	2.1	2.9	1.5	1.2
	50.0-59.9	1.8	4.4	7.4	6.9	4.2	9.1	10	10.4	7.5	7.6	11.7	6.1	5.7

IBRA	Bare soil threshold	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
	40.0-49.9	5.9	14.2	18.1	17.4	12.1	19.3	20.6	20.2	17.3	16.2	23.1	18	19
	30.0-39.9	28.3	33.8	30.5	34.9	22.8	32.6	32.4	33.4	31	25.4	35.3	33.5	35.1
Great Victoria Desert	≥70	4.8	1.9	6.2	2	1.4	0.8	3.8	2.3	1.6	1.8	2.1	0.5	7.8
	60.0-69.9	10.2	6.8	13.2	9.9	5.2	5.1	8.4	5.5	7.7	7.8	9.8	1.4	12
	50.0-59.9	21	26.1	26.6	33.1	21	23.5	21.4	16.5	28.7	23.2	28.6	7.1	22.9
	40.0-49.9	34.7	36.6	33.7	35.5	38.4	43.5	33.8	34.8	41.7	36.2	39.3	26.8	33.3
	30.0-39.9	24.2	22.6	15.4	15.6	23.4	22.1	22.8	28.8	16.7	23.3	16.2	40.6	17.8
Murchison	≥70	1	0.2	1.3	0.4	0.3	0.2	0.2	0.5	0.3	0.4	0.6	0.3	0.2
	60.0-69.9	1.7	1	3.4	2.6	1.6	1.4	1.2	1.9	2.2	2.3	3	1.4	1.2
	50.0-59.9	3.3	10.2	13	16	10	9	7.9	10.4	13.4	12.7	11.7	6.7	9.3
	40.0-49.9	23.6	45.2	33.7	39.3	33	33.1	30.9	37.2	38.2	34.5	29.1	22	34.8
	30.0-39.9	47.6	33	30.3	29.5	34.2	39.6	40.3	35.2	32.4	31.2	36	38.6	36.4
Nullarbor	≥70	0	0	0	0	0.1	0	0.6	0.1	0	0.4	0.1	0.2	0.5
	60.0-69.9	0.6	0.5	0.5	0.8	0.5	0.2	1.6	0.7	1.6	3	0.6	0.9	2.4
	50.0-59.9	10.4	10.9	11.5	14.1	6.3	5.2	8.6	6.9	15.1	15.1	4.3	3.5	10.3
	40.0-49.9	16.7	26	48.7	56	37.1	32.8	30.8	34.7	49.7	37.2	17.8	12.4	32.4
	30.0-39.9	43	55.8	37	27.7	47.1	40.4	36.1	47.9	31.4	34.2	27.3	26.1	38

B2. Mid-September analysis

IBRA	Bare soil threshold	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
South West NRM														
Brigalow Belt South	≥70	0.1	0.3	0.2	0.1	0.1	0.2	0.2	0.0	0.0	0.0	0.1	0.0	0.0
	60.0-69.9	0.3	0.9	0.9	0.5	0.5	3.1	3.5	0.0	0.1	0.0	0.2	0.0	0.2
	50.0-59.9	1.1	5.6	8.0	3.8	4.2	17.9	18.9	0.7	2.5	0.1	0.3	0.1	1.0
	40.0-49.9	8.4	19.5	22.7	16.0	20.2	23.4	26.0	7.5	14.8	0.9	0.7	0.5	6.0
	30.0-39.9	24.7	24.4	23.8	22.6	31.6	19.2	21.1	22.8	21.8	4.9	4.6	3.4	24.1
Channel Country	≥70	0.0	0.8	0.1	0.2	0.1	0.4	0.1	0.1	0.5	0.4	0.0	0.0	0.0
	60.0-69.9	0.0	14.8	6.8	3.0	1.6	11.9	3.8	3.1	18.9	1.2	0.1	0.1	1.0
	50.0-59.9	17.4	50.1	63.4	58.2	49.4	62.8	49.1	53.4	57.1	7.6	0.9	2.4	18.6
	40.0-49.9	58.8	24.3	23.4	30.4	39.7	18.2	33.2	32.5	16.7	37.3	8.9	19.0	49.3
	30.0-39.9	18.5	6.5	4.6	5.5	6.4	4.7	8.5	6.1	4.6	34.6	34.5	42.3	26.0
Mitchell Grass Downs	≥70	0.0	0.0	0.3	0.1	0.1	0.5	0.3	0.0	0.0	0.0	0.0	0.0	0.0
	60.0-69.9	0.1	1.5	6.6	3.9	1.7	8.5	8.0	0.2	0.8	0.2	0.0	0.1	0.6
	50.0-59.9	6.3	16.0	37.7	28.8	18.3	37.5	47.7	6.3	18.3	1.0	0.1	0.3	7.3
	40.0-49.9	39.7	39.2	38.3	39.9	44.1	38.4	37.0	29.8	45.7	4.7	1.8	3.6	30.5
	30.0-39.9	35.8	31.6	13.5	19.8	26.8	12.1	6.0	35.5	26.9	15.0	14.7	20.2	35.9
Mulga Lands	≥70	0.0	0.2	0.3	0.1	0.2	0.3	0.5	0.0	0.1	0.1	0.1	0.0	0.2
	60.0-69.9	0.1	3.1	8.9	3.6	3.9	6.7	12.3	1.6	3.4	0.3	0.1	0.0	1.3
	50.0-59.9	5.2	22.4	38.3	34.9	32.2	37.4	46.7	19.7	27.9	2.4	0.7	0.5	10.0
	40.0-49.9	37.2	36.9	33.0	39.0	40.9	37.4	29.7	39.8	41.0	14.4	9.1	7.4	38.4
	30.0-39.9	40.1	23.1	14.0	16.3	17.2	13.5	7.9	28.0	21.5	29.7	34.1	32.3	34.3
Desert Channels Queensland														
Channel Country	≥70	0.5	1.1	0.6	0.5	0.5	0.6	0.2	0.2	0.1	0.5	0.1	0.2	0.4
	60.0-69.9	0.8	6.2	7.4	8.4	5.6	10.6	5.5	5.6	5.9	2.3	0.7	2.6	5.2

IBRA	Bare soil threshold	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
	50.0-59.9	12.7	34.0	39.3	39.5	38.1	43.7	34.5	41.9	36.2	14.2	5.6	14.8	29.8
	40.0-49.9	34.2	32.6	30.3	26.9	34.9	25.9	34.6	31.8	27.0	33.6	18.3	30.9	37.2
	30.0-39.9	27.2	15.2	13.8	14.2	13.4	10.4	14.6	11.7	15.2	26.5	30.7	30.1	15.9
Desert Uplands	≥70	0.1	0.2	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.2
	60.0-69.9	0.2	1.8	4.5	0.7	0.9	0.6	0.7	0.2	0.2	0.1	0.2	0.1	1.4
	50.0-59.9	2.1	8.4	17.2	7.5	13.8	8.6	10.2	1.9	1.6	0.5	0.6	0.4	5.5
	40.0-49.9	8.7	21.4	36.4	26.9	38.6	34.5	34.6	13.0	8.3	2.0	2.5	3.1	15.0
	30.0-39.9	26.1	30.6	27.2	37.1	30.5	38.6	34.4	32.4	20.8	7.8	9.3	12.7	28.2
Mitchell Grass Downs	≥70	0.0	0.1	0.1	0.0	0.1	0.1	0.2	0.1	0.0	0.2	0.0	0.0	0.1
	60.0-69.9	0.1	1.7	3.1	1.2	2.9	4.2	6.5	4.6	0.7	1.1	0.1	0.7	2.9
	50.0-59.9	1.4	16.5	28.4	18.0	33.8	28.4	36.1	34.6	8.4	8.5	2.6	9.6	25.9
	40.0-49.9	13.6	35.6	39.7	34.7	44.4	30.5	35.6	33.2	18.3	23.0	14.2	27.4	37.9
	30.0-39.9	26.6	26.7	20.7	26.9	13.6	17.0	14.9	16.3	18.5	28.3	25.1	26.3	20.5
Mount Isa Inlier	≥70	0.2	1.7	0.1	0.0	0.1	0.1	0.1	0.7	0.0	0.1	0.0	0.9	1.6
	60.0-69.9	0.4	6.6	2.7	0.9	3.3	1.8	2.4	6.0	0.0	0.5	0.0	4.5	9.7
	50.0-59.9	1.4	14.6	19.0	9.6	20.3	11.3	14.8	23.9	0.1	4.3	0.4	13.3	25.9
	40.0-49.9	4.2	25.3	34.9	26.5	30.9	22.7	27.6	27.6	1.9	19.5	2.9	27.1	28.2
	30.0-39.9	16.9	25.1	25.3	32.0	23.9	29.2	27.9	20.8	12.6	35.0	17.3	26.2	19.6
Mulga Lands	≥70	0.0	0.1	0.2	0.1	0.0	0.1	0.2	0.1	0.1	0.3	0.0	0.0	0.0
	60.0-69.9	0.1	2.0	3.3	2.5	1.4	2.6	5.8	2.7	2.5	1.2	0.0	0.1	0.5
	50.0-59.9	5.8	20.4	26.1	24.3	21.4	24.8	33.2	25.8	26.4	8.1	0.4	1.7	9.3
	40.0-49.9	38.7	36.0	35.6	37.8	40.2	35.9	32.0	36.4	37.1	29.6	9.1	20.0	38.7
	30.0-39.9	30.9	22.6	19.8	21.6	22.9	21.5	17.5	21.3	21.0	35.1	39.0	42.3	27.3
Simpson Strzelecki Dunefields	≥70	0.0	7.1	4.7	5.3	1.0	1.7	0.1	0.2	0.2	0.2	0.1	1.1	2.3
	60.0-69.9	0.1	18.5	22.5	25.8	28.6	43.7	8.9	16.6	20.9	1.3	0.3	15.5	32.3
	50.0-59.9	27.4	48.9	62.6	65.2	63.3	50.9	48.1	68.8	57.2	25.9	1.5	38.5	43.4
	40.0-49.9	49.2	23.7	9.2	3.5	6.4	3.4	38.8	13.8	20.1	57.9	19.0	30.2	19.8
	30.0-39.9	22.2	1.6	0.6	0.2	0.4	0.2	3.7	0.4	1.5	12.5	50.5	12.3	1.9

IBRA	Bare soil threshold	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
SA Arid Lands														
Channel Country	≥70	0.1	0.6	0.3	0.5	0.2	0.4	0.3	0.2	0.3	1.5	0.3	0.2	0.3
	60.0-69.9	3.5	13.8	9.3	11.2	6.5	15.1	9.8	9.0	14.3	5.8	2.4	3.3	6.9
	50.0-59.9	42.1	52.2	59.3	61.2	62.5	63.6	47.4	55.5	55.9	20.3	8.8	16.3	37.1
	40.0-49.9	41.2	24.3	25.7	19.0	25.9	17.5	32.0	27.9	17.6	34.1	18.7	33.7	39.8
	30.0-39.9	6.9	5.2	3.7	3.7	3.3	2.3	5.4	5.0	4.0	16.8	27.8	31.3	11.6
Finke	≥70	0.0	0.0	0.0	0.1	0.6	0.6	2.3	4.7	1.6	0.2	0.4	0.0	2.7
	60.0-69.9	6.1	0.0	5.4	15.4	29.4	30.6	53.7	67.4	45.7	12.2	2.9	1.2	24.6
	50.0-59.9	45.4	14.1	64.4	63.7	59.4	57.9	41.8	27.1	48.6	61.2	13.9	16.1	59.9
	40.0-49.9	45.2	48.3	28.3	20.1	10.1	10.2	2.1	0.7	3.9	24.4	48.3	56.4	12.5
	30.0-39.9	3.2	30.0	1.7	0.5	0.4	0.5	0.1	0.0	0.2	1.8	31.1	23.6	0.2
Simpson Strzelecki Dunefields	≥70	0.0	0.2	0.1	0.1	0.1	0.3	0.2	0.5	0.5	1.3	0.1	0.0	0.1
	60.0-69.9	0.7	13.3	6.7	9.0	6.2	18.2	17.9	21.3	20.4	9.7	0.5	0.9	7.5
	50.0-59.9	38.3	57.5	52.0	62.0	56.4	61.2	47.4	60.9	56.9	38.3	9.6	24.2	47.9
	40.0-49.9	45.8	17.4	27.3	16.4	23.7	9.5	22.5	6.3	9.9	30.5	28.5	43.5	30.3
	30.0-39.9	3.2	3.3	3.4	2.3	3.0	2.9	4.5	3.1	2.1	6.1	28.6	18.9	5.8
Stony Plains	≥70	0.4	0.5	0.6	0.2	0.7	1.3	0.7	1.6	0.9	1.4	0.1	0.1	0.1
	60.0-69.9	4.4	9.1	7.9	7.3	11.1	13.8	14.9	16.8	9.2	13.1	2.4	2.9	5.7
	50.0-59.9	37.7	43.4	47.6	44.1	50.3	52.7	54.3	54.4	51.2	44.9	23.5	26.4	44.4
	40.0-49.9	39.7	29.5	30.5	33.5	26.5	21.9	20.3	17.9	26.7	25.2	39.9	43.1	36.4
	30.0-39.9	12.7	12.5	9.4	10.5	7.6	6.8	6.5	6.0	7.8	9.5	23.6	19.3	9.3
Alinytjara Wilurara														
Central Ranges	≥70	1.2	12.1	7.7	0.8	3.2	1.8	3.6	12.3	0.9	6.4	3.4	9.4	2.7
	60.0-69.9	8.6	10.7	28.0	13.1	20.4	25.8	30.8	34.1	20.5	35.0	5.9	10.3	11.5
	50.0-59.9	30.4	19.8	42.7	44.7	46.2	43.2	40.4	35.6	54.1	40.4	24.7	22.0	39.1
	40.0-49.9	37.7	29.4	16.6	28.2	21.6	18.6	17.2	12.6	17.7	11.9	39.5	36.6	33.9
	30.0-39.9	16.7	18.1	4.0	10.5	6.3	7.7	6.1	3.9	5.0	4.5	18.5	16.7	10.1
NT Arid Lands														

IBRA	Bare soil threshold	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Burt Plain	≥70	6.5	1.9	2.2	1.4	2.8	2.5	1.5	8.0	5.1	0.1	3.2	1.9	5.6
	60.0-69.9	5.4	2.9	8.9	9.3	17.6	11.7	8.0	20.7	18.9	2.5	3.5	7.1	19.3
	50.0-59.9	8.0	10.6	25.1	34.5	45.5	27.4	26.8	39.5	41.8	18.1	5.1	17.1	37.7
	40.0-49.9	13.3	24.3	35.7	37.6	26.5	33.5	32.3	23.3	25.6	43.4	9.0	32.0	27.9
	30.0-39.9	29.6	35.3	21.1	14.4	5.9	20.0	24.0	6.4	6.7	28.4	23.7	30.2	7.4
Central Ranges	≥70	2.3	17.7	22.1	1.4	1.9	1.9	2.6	3.3	2.7	7.2	1.4	6.5	7.1
	60.0-69.9	11.4	10.1	34.0	14.5	25.0	19.2	28.7	22.3	36.3	47.5	3.8	9.6	19.9
	50.0-59.9	25.8	12.3	27.9	41.5	50.3	43.5	47.5	45.4	46.4	36.5	35.5	23.3	45.4
	40.0-49.9	44.7	25.0	12.7	34.1	18.3	29.1	17.5	23.2	11.3	6.5	48.6	44.1	23.7
	30.0-39.9	14.6	25.3	2.8	7.7	3.7	5.3	3.0	4.7	2.5	1.8	8.9	14.4	3.1
Channel Country	≥70	3.1	1.1	1.4	4.0	2.4	1.5	0.0	0.4	0.2	0.0	1.7	1.5	4.8
	60.0-69.9	1.8	4.7	11.6	39.4	40.0	31.8	1.6	15.8	7.7	0.1	2.0	12.1	32.2
	50.0-59.9	1.8	12.8	34.1	41.3	45.0	51.2	18.6	52.6	43.7	4.0	4.3	31.7	39.0
	40.0-49.9	4.2	23.3	34.7	12.4	10.4	13.0	43.0	26.1	37.7	33.9	4.6	33.9	18.5
	30.0-39.9	21.2	27.7	13.7	2.5	1.9	2.0	26.9	4.4	9.2	44.4	15.3	16.1	4.6
Finke	≥70	0.2	6.9	10.4	5.7	5.9	8.7	7.0	19.7	5.3	3.6	4.2	1.1	2.4
	60.0-69.9	1.3	5.3	27.6	36.3	39.7	42.0	45.4	49.9	43.2	28.0	5.4	5.4	29.3
	50.0-59.9	22.4	10.7	39.9	44.6	41.5	39.0	41.1	27.1	44.1	43.5	16.3	26.3	51.3
	40.0-49.9	63.0	28.8	19.0	12.0	11.3	9.2	5.9	2.8	6.6	19.6	38.6	43.6	15.6
	30.0-39.9	11.9	37.6	2.6	1.0	1.2	0.8	0.4	0.4	0.6	4.5	28.4	20.2	1.0
Great Sandy Desert	≥70	7.6	12.2	14.2	2.7	4.6	1.2	1.9	3.3	3.2	3.5	11.2	5.1	7.3
	60.0-69.9	9.6	14.0	24.2	16.1	24.7	14.1	21.1	25.1	25.0	24.2	8.9	10.2	28.4
	50.0-59.9	16.8	20.3	27.7	44.2	46.0	41.4	43.9	45.5	44.9	45.0	22.1	24.5	46.8
	40.0-49.9	38.8	25.7	21.2	28.2	18.7	32.3	26.3	20.5	21.4	20.6	37.1	40.4	13.5
	30.0-39.9	20.5	20.0	8.6	5.7	3.5	7.3	4.5	3.3	3.2	4.1	15.0	16.1	1.8
MacDonnell Ranges	≥70	0.7	5.4	2.5	2.2	2.8	4.6	3.3	6.0	4.5	0.3	6.7	0.9	2.0
	60.0-69.9	1.4	5.9	12.4	16.4	18.0	21.3	20.1	23.7	22.0	3.4	6.7	3.5	14.4
	50.0-59.9	4.6	11.7	27.4	35.7	33.3	31.1	33.7	30.7	33.9	19.9	7.0	15.8	35.1

IBRA	Bare soil threshold	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
	40.0-49.9	23.4	26.0	31.1	31.2	26.4	24.6	27.8	23.2	25.8	37.8	11.5	33.1	31.0
	30.0-39.9	47.4	33.7	19.2	11.9	14.1	13.7	12.1	12.5	11.1	29.4	25.8	30.9	14.1
Simpson Strzelecki Dunefields	≥70	0.0	14.0	16.2	15.8	8.4	17.3	2.1	5.2	7.9	0.2	2.5	5.5	11.8
	60.0-69.9	7.7	27.6	46.9	68.9	71.7	64.9	41.9	61.2	61.7	9.9	4.1	25.6	54.7
	50.0-59.9	34.3	34.9	30.6	13.5	17.6	16.0	42.5	31.0	27.6	50.8	12.8	43.0	27.4
	40.0-49.9	34.9	17.0	5.3	1.5	1.8	1.6	11.6	2.3	2.6	30.1	29.2	20.5	5.4
	30.0-39.9	18.6	5.3	0.9	0.3	0.3	0.2	1.6	0.2	0.2	7.1	35.7	4.3	0.7
Sturt Plateau	≥70	34.5	0.0	0.1	0.0	11.5	0.0	0.1	3.4	0.0	0.1	24.5	4.5	0.4
	60.0-69.9	10.6	0.4	0.7	0.0	29.1	0.0	0.4	26.6	0.0	0.4	16.6	5.1	2.9
	50.0-59.9	10.7	4.7	4.1	0.2	22.8	0.3	1.0	30.6	5.2	8.3	13.3	11.7	8.8
	40.0-49.9	12.0	22.3	12.6	1.9	16.9	9.8	3.0	12.8	37.0	37.3	9.5	30.6	21.2
	30.0-39.9	11.9	23.9	29.2	11.7	14.9	31.9	16.2	10.2	23.4	32.5	12.0	25.1	32.0
Tanami	≥70	15.5	4.8	2.4	1.9	10.7	0.8	12.8	7.5	1.5	0.8	25.6	6.2	5.7
	60.0-69.9	8.5	6.8	11.1	6.0	24.0	3.0	9.0	22.2	11.0	4.9	9.5	15.7	19.8
	50.0-59.9	16.1	15.0	24.4	21.8	31.9	14.7	18.2	32.0	31.1	28.3	9.6	26.6	31.2
	40.0-49.9	19.6	24.8	31.5	33.8	25.0	32.0	29.4	26.1	35.0	43.2	16.8	25.1	28.4
	30.0-39.9	17.6	24.7	21.4	25.4	7.3	30.6	22.8	9.7	17.3	18.8	20.6	16.6	11.8
NT Tablelands														
Davenport Murchison Ranges	≥70	13.3	1.5	0.3	0.3	9.1	0.3	7.3	9.7	0.1	0.0	8.6	0.9	2.6
	60.0-69.9	10.1	3.0	2.1	1.2	15.2	1.5	6.9	16.4	2.9	0.9	5.9	3.6	7.7
	50.0-59.9	12.3	10.0	8.8	7.0	27.0	6.3	8.5	20.8	12.3	7.9	7.2	17.8	23.4
	40.0-49.9	16.1	22.1	25.3	23.9	28.4	16.9	17.3	24.0	21.1	27.8	7.4	26.3	34.6
	30.0-39.9	14.8	28.7	33.4	35.8	15.8	36.5	30.1	20.4	30.6	42.5	11.7	22.1	20.9
Gulf Fall & Uplands	≥70	0.7	0.0	0.1	0.1	0.2	0.0	0.2	0.1	0.0	0.1	0.1	1.3	0.1
	60.0-69.9	2.5	0.3	0.4	0.3	2.8	0.0	0.9	1.8	0.0	0.3	0.4	3.0	0.9
	50.0-59.9	6.5	1.7	1.7	0.7	10.0	0.0	3.5	8.2	0.4	0.6	1.2	6.7	3.6
	40.0-49.9	9.6	8.5	4.2	1.9	19.1	0.4	7.9	15.8	2.1	2.3	3.3	10.2	10.3
	30.0-39.9	8.7	21.2	12.3	7.0	25.7	5.7	15.5	21.7	11.8	8.4	6.6	14.5	23.3

IBRA	Bare soil threshold	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Mitchell Grass Downs	≥70	0.5	0.1	0.0	0.1	0.3	0.0	0.1	0.2	0.0	0.0	0.1	0.1	0.3
	60.0-69.9	0.6	0.4	0.5	1.3	3.6	0.4	0.6	6.0	0.0	0.5	0.7	0.8	5.8
	50.0-59.9	0.8	2.9	2.6	8.3	19.6	6.1	8.0	32.6	0.3	4.3	1.8	4.8	25.5
	40.0-49.9	1.0	8.6	7.7	12.6	27.5	7.9	26.3	30.4	3.0	14.4	1.2	12.4	29.4
	30.0-39.9	1.6	16.8	17.4	12.4	22.1	10.2	28.0	16.0	7.1	25.2	2.2	20.9	19.2
WA Rangelands														
Carnarvon	≥70	2.2	2.9	4.4	3.4	1.0	1.4	3.0	0.6	1.6	4.4	0.2	2.6	3.0
	60.0-69.9	6.1	15.7	19.0	12.9	5.5	13.6	13.2	6.1	13.8	25.6	4.1	11.0	16.4
	50.0-59.9	31.3	43.7	43.1	33.4	20.3	41.3	37.2	17.9	41.2	44.9	15.9	32.6	42.9
	40.0-49.9	37.6	24.4	21.8	34.5	42.1	28.2	30.7	32.4	28.8	14.8	25.7	32.8	24.0
	30.0-39.9	14.4	7.3	5.9	9.6	20.7	8.7	9.1	28.6	7.8	4.5	27.0	12.7	6.8
Central Ranges	≥70	1.7	9.5	18.0	1.0	3.7	0.2	1.4	3.0	3.8	15.0	0.2	3.7	5.5
	60.0-69.9	12.2	11.0	33.1	10.5	22.6	5.5	11.4	20.9	25.5	39.6	7.2	3.7	18.7
	50.0-59.9	22.3	21.5	32.3	39.7	46.2	34.0	41.1	42.1	43.9	34.3	42.8	11.8	45.4
	40.0-49.9	35.8	31.6	12.1	34.4	21.1	40.7	34.9	25.8	20.5	7.9	37.9	40.3	24.9
	30.0-39.9	22.6	19.5	3.3	11.6	5.1	15.7	9.4	6.3	4.9	2.5	9.4	32.1	4.4
Gascoyne	≥70	0.6	0.9	1.3	0.8	1.6	0.1	0.6	0.9	1.0	2.4	0.6	0.5	1.0
	60.0-69.9	2.6	7.8	9.1	6.8	11.0	2.5	6.8	8.6	10.3	16.7	5.2	5.3	9.2
	50.0-59.9	13.3	28.7	28.9	26.4	35.4	14.3	27.0	30.0	34.6	37.8	23.0	17.9	31.9
	40.0-49.9	44.7	38.8	39.0	41.0	35.0	35.0	44.0	40.0	37.0	30.9	43.6	37.4	39.3
	30.0-39.9	31.5	18.1	17.1	19.8	13.3	32.1	17.7	16.7	13.7	9.8	22.0	29.9	15.0
Gibson Desert	≥70	0.7	2.5	3.9	0.4	0.7	0.1	1.0	1.5	1.1	1.6	0.1	2.3	2.2
	60.0-69.9	7.7	4.7	11.1	4.9	6.3	0.8	4.8	7.1	7.2	12.7	2.0	2.9	11.6
	50.0-59.9	15.0	16.0	23.7	21.8	25.6	9.8	13.9	22.7	26.2	32.4	17.4	7.7	28.6
	40.0-49.9	29.8	30.1	28.7	33.7	35.1	30.6	31.3	31.9	34.0	29.5	34.7	26.0	32.2
	30.0-39.9	27.5	28.0	21.2	25.4	22.5	33.1	28.2	22.7	21.6	17.9	26.8	29.5	17.5
Great Sandy Desert	≥70	2.2	5.2	3.2	0.3	2.5	2.4	1.9	2.2	2.1	3.2	1.8	6.9	3.3
	60.0-69.9	7.6	11.1	12.2	3.6	11.9	2.5	9.9	9.3	10.5	16.3	3.4	7.9	14.3

IBRA	Bare soil threshold	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
	50.0-59.9	20.8	19.3	26.2	22.2	32.7	14.6	21.5	27.8	31.5	41.2	16.9	16.7	34.5
	40.0-49.9	31.2	29.7	32.6	37.9	36.4	35.0	34.2	34.9	35.1	29.6	37.3	28.4	30.7
	30.0-39.9	23.7	24.0	18.7	25.6	12.9	29.9	23.8	18.7	15.7	7.0	28.5	24.6	12.5
Little Sandy Desert	≥70	5.4	3.1	4.6	0.9	2.6	0.4	1.7	3.4	4.1	4.7	0.4	3.0	3.6
	60.0-69.9	18.0	13.5	20.8	11.6	17.1	6.4	7.6	11.7	18.2	26.1	6.3	3.1	16.2
	50.0-59.9	25.5	27.4	36.7	41.5	43.9	36.7	35.7	40.9	44.0	45.1	36.7	11.5	33.1
	40.0-49.9	33.2	31.8	24.9	30.6	25.3	36.0	38.5	33.1	25.4	18.0	42.7	37.7	34.4
	30.0-39.9	13.8	18.1	9.3	11.3	7.9	14.7	12.4	7.9	5.9	4.0	10.8	33.7	9.6
Pilbara	≥70	1.7	4.1	4.5	1.8	2.5	0.5	2.8	2.3	1.8	6.5	1.2	1.5	1.3
	60.0-69.9	5.4	11.8	13.7	7.7	12.0	1.9	9.0	10.4	9.7	20.4	7.2	4.2	6.5
	50.0-59.9	15.1	20.8	25.0	20.3	29.7	8.7	19.2	23.6	22.3	27.3	20.6	13.0	18.2
	40.0-49.9	24.1	24.0	26.9	30.1	28.8	23.2	25.6	27.7	27.2	23.4	31.3	25.6	29.8
	30.0-39.9	25.9	20.2	18.1	24.3	17.5	31.3	24.5	21.3	21.8	14.4	24.9	28.7	27.0

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Australian rangelands and climate change – fire

Gary Bastin

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7. Australian rangelands and climate change – fire

Key points

- We anticipate that fire regimes in the Rangelands Cluster region will be modified by climate change in three main ways:
  - Although annual rainfall will continue to be highly variable, a greater summer component may increase grass biomass and thereby fire risk, particularly following extended wetter periods.
  - Warmer temperatures will extend the meteorological fire season and greatly increase fire danger following successive wetter years. Within the fire season, increased periods of very high temperature and low humidity will increase periods of potential very high fire danger. This may translate to widespread intense wildfire where fuel loads are sufficient, ignition occurs and there is limited capacity to implement prior strategic controlled burning and other fuel reduction practices to reduce this risk.
  - The predicted continued spread and thickening of buffel grass will exacerbate this risk.
- Analysis of the recent fire record available from satellite-based fire-scar mapping can provide useful context for predicting what may occur under climate change. Here we use data supplied to the Australian Collaborative Rangelands Information System (ACRIS) by WA Landgate to describe the recent fire regime (extent and frequency) for bioregions within Rangelands Cluster NRM regions.
- Extensive wildfire is more common in the spinifex-dominant deserts and following two or more years of above average rainfall. This feature was last experienced in central Australia in 2011 and 2012.
- Buffel grass can greatly change the fire regime at local scale: it increases fuel loads, responds readily to fire disturbance and has the capacity to make local environments in which it thrives much more fire-prone.

7.1 Introduction

Fire is extensive and common in northern Australia, particularly the tropical savanna (Figure 7.1). In the Rangelands Cluster region, extensive fire is more common in the spinifex-dominant deserts and following two years of above average rainfall. This phenomenon was last seen in central Australia in 2011 and 2012 (Figure 7.2) and, prior to that, 2002 (see Figure 3.41 in Bastin and ACRIS Management Committee 2008, p. 72). Extensive wildfire also occurred in 1976 following the wet years of the mid-1970s.

The majority of fires in the arid and semi-arid rangelands do not re-burn country that was burnt in the previous year. Thus the pattern of fire shown in Figure 7.2 was complementary in 2011 and 2012, that is, concentrated in the central and southern NT in 2011 and in the western deserts (WA and part SA) in 2012.

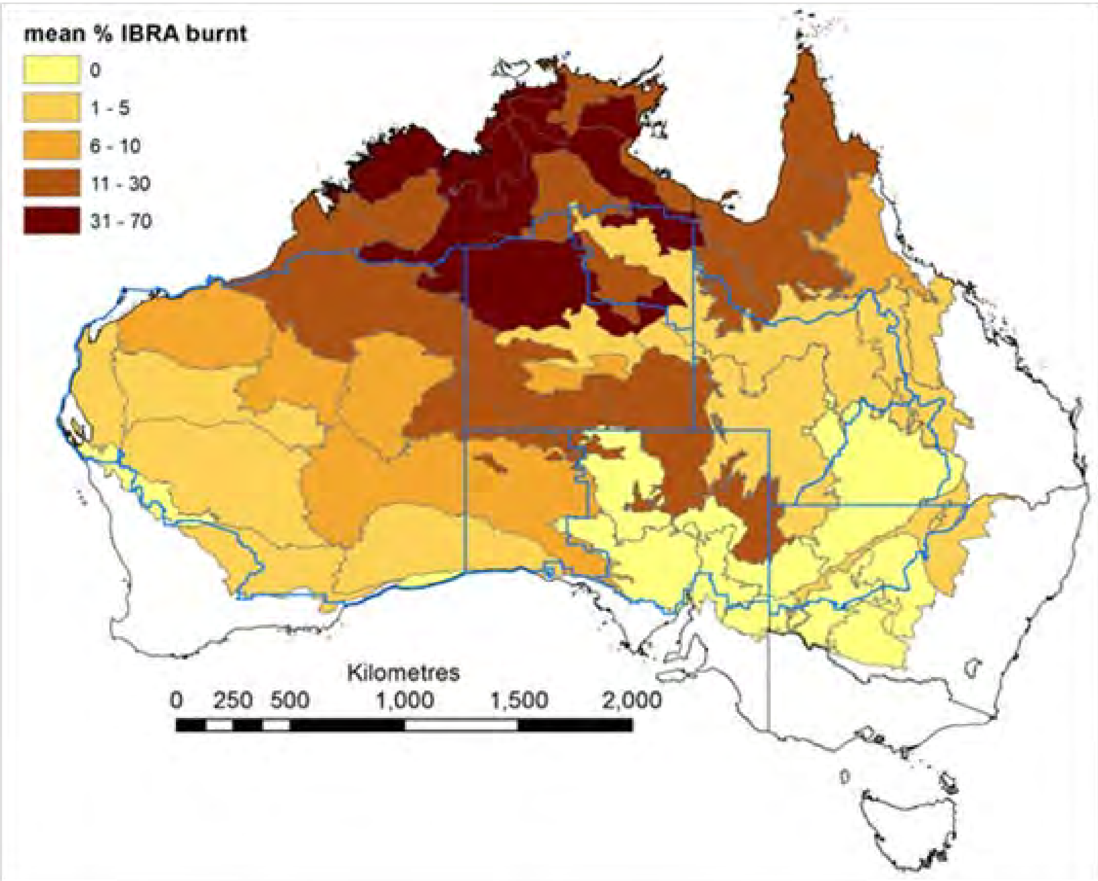

Figure 7.1 Mean percentage area of bioregions (IBRA v7) in the rangelands burnt between 1997 and 2012.

Black and blue lines show IBRA and Rangelands Cluster NRM boundaries respectively.
Source: Annual fire extent data were supplied to ACRIS by WA Landgate.

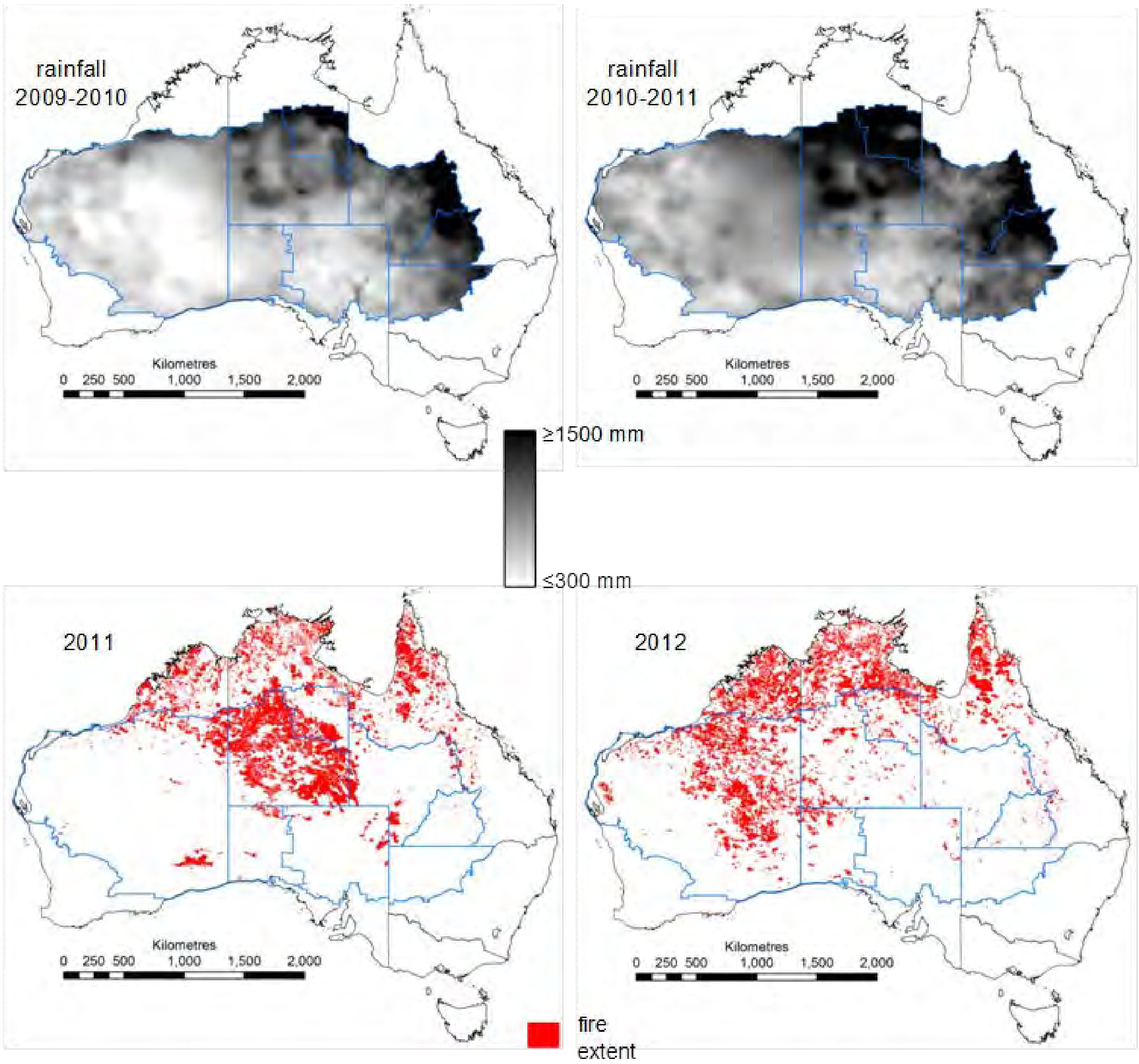

Figure 7.2 Cumulative rainfall within the Rangelands Cluster region for 2009–10 and 2010–11 (top) and area burnt in the following two years (bottom).

The paired maps (i.e. left and right) show, for the more arid rangelands, spatial correspondence between two-yearly cumulative rainfall and subsequent fire extent. Blue lines show NRM regions within the Rangelands Cluster.

Source: Maps produced from data held by ACRIS: fire data obtained from WA Landgate and rainfall data from the Bureau of Meteorology.

7.2 Method

Here, we briefly describe the recent fire history (1997–2012) for NRM regions in the Rangelands Cluster and comment on how this may alter with projected climate change.

7.3 Data sources

Fire information presented here is based on data held by the Australian Collaborative Rangelands Information System (ACRIS). ACRIS, in turn, sourced fire data from the WA Land Information Authority (WA Landgate). This agency maps fire scars monthly across all of Australia as detected in NOAA AVHRR imagery (1.1 km x 1.1 km pixel resolution). The large pixel size means that small fires and some patchy burns may be missed, but the data are ideal for detecting large-scale fire patterns across very large areas.

Maps of past fires in northern Australia are also available from the North Australian Fire Information (NAFI) web site (http://www.firenorth.org.au/nafi2/). These fire scars are mapped from 250 m MODIS imagery extending back to late 2000 and can be downloaded as monthly images (GeoTIFF) or shapefiles of burnt area.

We use the WA Landgate data for fire history because their mapping is national and for a slightly longer period (1997 compared to late 2000 for the MODIS record). The Landgate data for fire extent and frequency are also readily available within ACRIS.

Landgate has provided ACRIS with statistics on the monthly and annual extent of fire scars in each rangelands[7] bioregion (IBRA v7, Department of the Environment n.d.) between 1997 and 2012. Fire frequency is a spatial averaging of the number of times an area (pixels in a satellite image) burnt over the 16 years between 1997 and 2012 (further detail in Appendix A).

[7] The rangelands boundary as defined by ACRIS covers approximately 80% of Australia, including the savanna region (see Figure 1.3 in Bastin and ACRIS Management Committee 2008).

ACRIS reports fire history by bioregion (see www.environment.gov.au/resource/fire-product-update-2011-12 for the most recent information). Here, we adapt bioregion-level information on fire extent and frequency to the NRM regions within the Rangelands Cluster. We retain bioregions as the reporting unit because of the considerable variation in fire regime from north to south and between broadly different landscapes within larger NRM regions.

7.4 Findings

7.4.1 Regional fire statistics

Extent

The average percentage area of bioregions burnt in each NRM region between 1997 and 2012 is listed in Table 7.1. The minimum and maximum percentage area burnt for each bioregion during the period is also listed; this serves to show the highly variable nature of fire in some regions. Figure 7.3 contrasts the mean percentage area burnt between 1997 and 2012 for a fire-prone region (the NT part of the Tanami bioregion) and a largely fire-protected bioregion (the Nullarbor in the WA Rangelands). Yearly percentages for other bioregions are listed in Appendix B – similar comparative graphs to that shown in Figure 7.3 can be constructed from these data.

Important features are:

- Fire is more extensive and common in northern desert country within the cluster region.
- Fire is largely absent in southern pastorally dominant bioregions and particularly those with lower total biomass and/or a significant chenopod component, that is, essentially less grass and therefore less flammable fuel.
- Fire follows substantial and extended periods of rainfall (as illustrated in Figure 7.2), but burnt areas do not burn again until sufficient grass has accumulated as fuel. This is probably a shorter period (5+ years) where spinifex readily regenerates in desert bioregions, although post-fire floristic changes such as the establishment of shrubby wattles in the Pilbara may alter the return period of

the next fire. In mid-latitude pastoral bioregions (i.e. the northern part of the Rangelands Cluster) where native grasses dominate in the pasture, sufficient fuel for another fire may require >10 years – but is determined both by much above-average rainfall and grazing pressure.

- Buffel grass (*Cenchrus ciliaris*) can greatly change the fire regime at local scale, particularly in central Australia. It increases fuel loads, responds readily to fire disturbance and has the capacity to make local environments in which it thrives much more fire-prone. There is insufficient evidence yet at regional scale, but the continued spread and thickening of buffel grass may mean that less rainfall, and maybe one wet year by itself, will generate sufficient fuel to considerably increase the risk of future extensive fire.

Table 7.1 The average, minimum and maximum percentage areas of bioregions burnt within Rangelands Cluster NRM regions between 1997 and 2012. Data are adapted from burnt-area statistics supplied to ACRIS by WA Landgate.

BIOREGION	FIRE EXTENT STATISTIC		
	MEAN (%)	MIN. (%)	MAX. (%)
NSW: Western			
Brigalow Belt South	1.4	0.0	4.7
Broken Hill Complex	0.0	0.0	0.1
Channel Country	0.4	0.0	1.3
Cobar Peneplain [1]	0.1	0.0	0.2
Mulga Lands	0.1	0.0	0.4
Simpson Strzelecki Dunefields	2.2	1.2	3.2
Queensland: South West NRM			
Mulga Lands	0.3	0.0	2.2
Queensland: Desert Channels			
Channel Country	1.0	0.0	7.6
Desert Uplands [1]	3.6	0.1	21.1
Mitchell Grass Downs	0.4	0.0	1.8
Simpson Strzelecki Dunefields	14.2	2.4	52.4
SA: Arid Lands			
Broken Hill Complex	0.2	0.2	0.2
Channel Country	1.0	0.0	3.0
Finke	7.9	0.0	23.3
Flinders Lofty Block [1]	0.1	0.0	0.2
Gawler	0.1	0.0	0.3
Simpson Strzelecki Dunefields	2.8	0.0	8.9
Stony Plains	0.2	0.0	0.4
SA: Alinytjara Wilurara			
Central Ranges	7.5	0.1	25.8
Great Victoria Desert	1.6	0.0	6.6
Nullarbor	2.0	0.1	3.4
NT: Arid Lands sub-region			
Burt Plain	5.1	0.0	31.6
Central Ranges	8.8	0.1	32.9
Channel Country	14.8	0.0	63.3
Finke	7.9	0.0	31.0
Great Sandy Desert	7.9	0.2	35.5
MacDonnell Ranges	6.0	0.0	34.9
Simpson Strzelecki Dunefields	9.4	0.0	63.6
Tanami	16.9	0.6	64.5
NT: Tablelands sub-region			
Davenport Murchison Ranges	13.9	0.0	56.8
Mitchell Grass Downs	3.7	0.1	20.9
WA: Rangelands			
Carnarvon	1.2	0.0	8.4
Central Ranges	6.7	0.0	39.2

BIOREGION	FIRE EXTENT STATISTIC		
	MEAN (%)	MIN. (%)	MAX. (%)
Coolgardie	1.4	0.0	5.3
Gascoyne	0.9	0.1	4.4
Gibson Desert	7.1	0.1	35.7
Great Sandy Desert	11.8	0.5	35.3
Great Victoria Desert	4.2	0.0	24.2
Hampton	0.6	0.1	1.2
Little Sandy Desert	5.5	0.1	38.1
Murchison	0.7	0.0	1.9
Nullarbor	1.4	0.0	11.3
Pilbara	8.5	1.1	25.8
Tanami	18.3	0.9	52.5

BIOREGION	FIRE EXTENT STATISTIC		
	MEAN (%)	MIN. (%)	MAX. (%)
Yalgoo	0.2	0.0	0.7

[1] Rangelands component of bioregion extends beyond the NRM region. Percentage area burnt may be influenced by the area outside the NRM region.

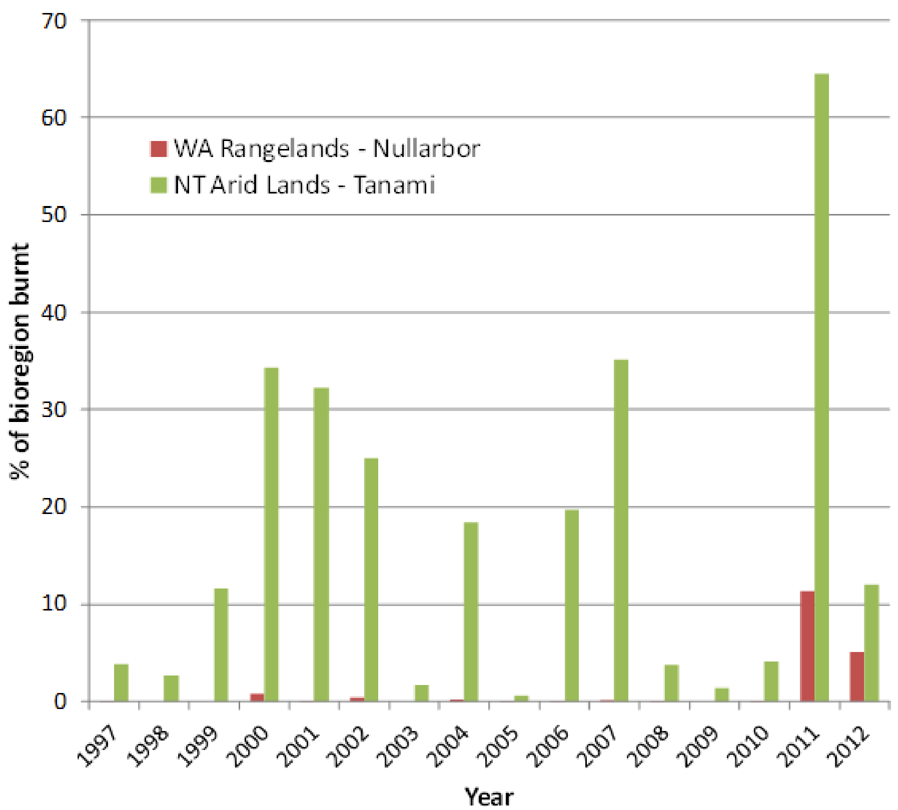

Figure 7.3 Mean percentage area burnt between 1997 and 2012 in the Tanami bioregion of the NT Arid Lands sub-region and the Nullarbor bioregions in the WA Rangelands.

Fire is much more extensive and recurrent in the northern desert country within the Rangelands Cluster.

Frequency

Fire frequencies are reported as the average number of fire scars, per 1.1 km x 1.1 km pixel, across each bioregion between 1997 and 2012. The arithmetic procedure for calculating fire frequency is described in Appendix A.

Where extensive fire occurred in the Rangelands Cluster region between 1997 and 2012, most areas were burnt once or twice (on average) (Figure 7.4). Fire was most frequent in the Tanami, Davenport Murchison Ranges and Gulf Fall and Uplands regions of the NT and the Mount Isa Inlier area of north-west Queensland. Fire was slightly less frequent in the Pilbara and Great Sandy Desert. As noted before, fire is much more frequent in northern Australia where, for example, all of the Pine Creek and Daly Basin bioregions have burnt 7–8 times in the 16-year period (and parts of each region burn every year).

7.5 Rangeland fire and climate change

There are four major biophysical factors that will contribute to any change in the future fire regime under climate change.

1. Rainfall variability is predicted to continue, although the winter component may decrease. A higher proportion of summer rainfall may increase grass biomass in the pasture and thereby increase potential fuel loads. However, continuing rainfall variability will likely mean that fuel accumulation sufficient to carry extensive wildfire will likely continue to require two (or more) years of above-average rainfall. This is particularly expected to be the case in pastoral bioregions, where varying levels of grazing intensity reduce fuel loads and their continuity in most years.

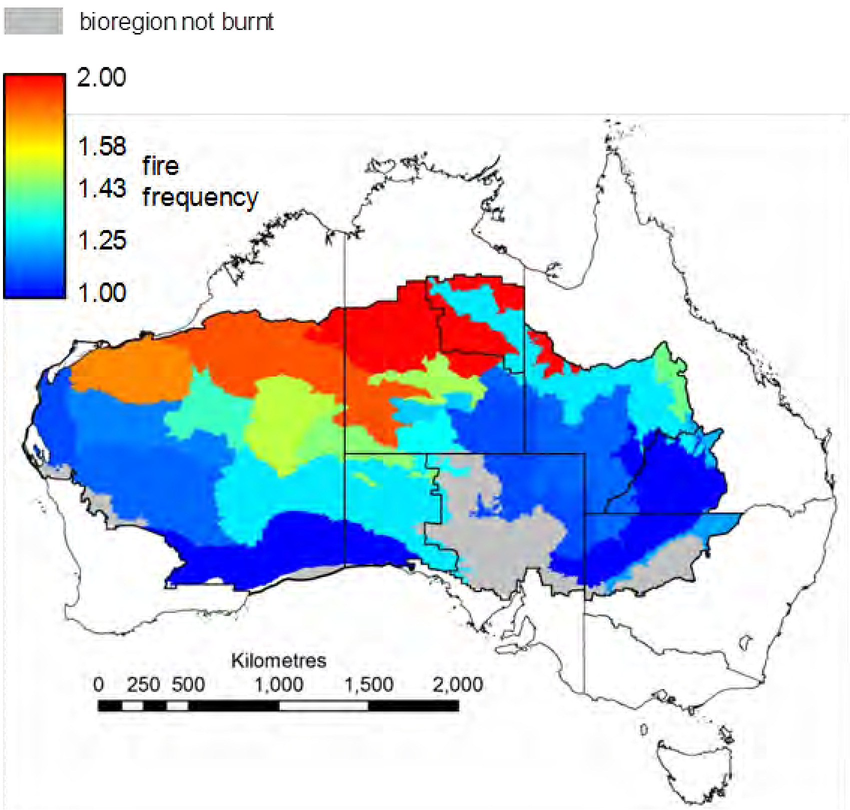

Figure 7.4 Fire frequency for bioregions within the Rangelands Cluster region burnt between 1997 and 2012. The blue lines show NRM regions (or sub-regions).

Source: Fire frequency data were supplied to ACRIS by WA Landgate.

The ‘two-year rule’ may be modified in pastoral areas of central and northern parts of the cluster region where C_4 grasses progressively replace C_3 species in the pasture. Grasses with the C_4 photosynthetic pathway grow more rapidly, accumulate greater biomass and are more flammable than C_3 species. Increase in C_4 grasses, including buffel grass, may mean that sufficient fuel accumulates to carry fire following one wet year.

Reduced winter rainfall and warmer temperatures throughout may see the present central Australian fire regime of decadal (plus) extensive fire move south into the northern parts of South Australia and the southern WA Rangelands.

2. Warmer temperatures will likely extend the length of the meteorological fire season and greatly increase fire danger following successive wetter years. This is more likely in the central and southern parts of the cluster region; fire risk in the north will continue to be associated with the northern monsoon and related to amount and timing of wet-season rainfall. The central Australian fire season may increase to cover the August to May period and expand by a month (or more) either side of the current summer period further south.

   Conversely, these changes will reduce the window of opportunity to safely use fire for hazard reduction burning in the relatively cooler months. This, in turn, will necessitate enhanced logistical capacity (including mobility) to best utilise suitable times for the safe use of fire.

   Increased periods of higher temperature and lower humidity will likely considerably increase periods of potential very high fire danger throughout the cluster region, and this may translate to extensive wildfire where fuel loads are sufficient, ignition occurs and there is limited capacity to implement prior strategic controlled burning and other fuel reduction practices to reduce wildfire risk.

3. At a more local scale, the continued spread and thickening of buffel grass can considerably change the fire regime. The distribution of buffel grass is likely to expand with climate change (see Scott 2014), and its colonising success and consequent likely thickening will be facilitated by recurrent fire as a disturbance factor. Where dominant in the pasture, buffel grass will fuel hotter fires with potential intensity further increased by the increased likelihood of hotter and less humid days (and nights). Buffel grass and associated intense fires will probably continue to be a greater threat on non-pastoral land but, even here, it has the potential to increase fire risk in future wetter years.

4. Vegetation productivity (and hence fuel loads) is expected to increase due to the combined effects of trends in atmospheric CO_2 (i.e. enrichment), rainfall and temperature on plant growth and shifts in species composition.

7.6 Adaptation strategies

Required adaptation strategies will vary with NRM region and associated land use. Likely responses will include:

1. Learn from past experience in managing and controlling episodic extensive wildfire. Widespread fire will continue to follow wetter periods, so preparing for increased fire activity is essential. This likely means implementing more of current procedures: hazard reduction burning to break up extensive fuel loads, protecting fire-sensitive habitats and other high-value assets, etc.

   Increased fire danger associated with hotter temperatures and reduced humidity may mean that larger areas burn following one wet year rather than successive years as is currently the case in much of central Australia. Fuel loads and flammability at such times may also increase with enhanced growth of C_4 grasses due to atmospheric CO2 enrichment. Thus the extent and timeliness of controlled burning and other fuel reduction mechanisms will become more critical.

   Regional knowledge and experience in managing extensive wildfire should be transportable. It is likely that the current appropriate fire management strategy for the southern NT will extend south into much of northern SA, particularly the Alinytjara Wilurara NRM region, and the southern deserts of the WA Rangelands NRM region.

2. Use prescribed fire to maximise the area it can protect. There is evidence that fuel-reduction burning in southern Australian eucalypt forests protects about one quarter of the area burnt, whereas this increases to an equal area protected in the northern savanna (Bradstock et al. 2012). The leverage factor across the fire-prone vegetation types in the Rangelands Cluster region is unknown but could be similar to (or even greater than) that for savanna.

   Local experience in prescription burning combined with temporal statistics of subsequent area burnt (derived from fire-scar mapping) should help to implement spatial and temporal burning patterns that maximise the leverage value of such programs.

3. Increased warming with associated lower humidity combined with continuing rainfall variability should present more frequent opportunities to use managed fire to control woody thickening (invasive native scrub) in pastoral country. This should be the case in parts of central Australia, south-western Queensland, western NSW, the Gascoyne–Murchison in the WA Rangelands and possibly parts of the Flinders Ranges (SA Arid Lands).

4. As highlighted above, continued spread and thickening of buffel grass will greatly alter the fire risk at a more local scale. Increased resources (labour and equipment) will be required to adequately protect vulnerable infrastructure and natural assets as this vegetation change occurs.

Appendix A Calculating fire frequency

The following notes and illustrations briefly describe how WA Landgate calculates fire frequency from mapped fire scars.

Assume that a 3 x 3 array of pixels and lines (below table) represents the area extending across a region. Burnt pixels were represented by the value '1' and unburnt pixels by '0'. In the year 1999, two-thirds of the array was burnt, and in 2000 a little more than one-third was burnt. The fire frequency across the two years is calculated by summing pixel values.

Year 1999			Year 2000			Fire frequency		
0	1	1	0	0	0	0	1	1
0	1	1	0	1	1	0	2	2
0	1	1	0	1	1	0	2	2

Two examples of calculating fire frequencies are presented.

In Example 1, the region is represented by four pixels within the solid line.

0	1	1
0	2	2
0	2	2

The average fire frequency for this example region is (2+2+2+2)/4 = **2.0**

In Example 2, the region is represented by six pixels.

0	1	1
0	2	2
0	2	2

The average fire frequency for this region is (0+0+2+2+2+2)/6 = **1.3**

Appendix B Yearly percentage of bioregion burnt

The following table lists the percentage area of bioregions in Rangelands Cluster NRM regions burnt between 1997 and 2012. Data supplied to ACRIS by WA Landgate.

BIOREGION	AREA (KM^2)	PERCENTAGE OF BIOREGION AREA BURNT															
		1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
NSW: Western																	
Brigalow Belt South	3,630		4.73						0.97		0.01		0.12				1.08
Broken Hill Complex	37,665								0.02	0.06			0.03		0.02		0.05
Channel Country	23,355		0.43	0.06			0.03	0.61	0.29	0.22							1.34
Cobar Peneplain	37,037		0.22	0.01		0.02		0.07	0.01	0.05	0.05	0.01	0.04	0.01		0.15	0.1
Darling Riverine Plains	38,656		0.52	0			0.1	0.13	0.39	0.96	0.11		0.14	0.08		0.14	0.07
Mulga Lands	65,823		0			0.02	0.05	0.04	0.02	0.04						0.01	0.42
Murray Darling Depression	33,888		0.06		0.01	0.04		0.07	0.01	0.01	0.06	0.05	0.04			0.1	0.25
Simpson Strzelecki Dunefields	10,936															1.24	3.16
Queensland: South West NRM																	
Brigalow Belt South	14,599		0.11	1.67	0.04	1.93	1.19	0.95	3.74	0.94	1.34	0.2	0.73	15.06	0.1	7.08	14.45
Mulga Lands	145,677	0.02	0.13	0.24	0.01	0.03	0.04	0.01	0.14	0.14	0.05	0.01	0.12	0.1		0.92	2.21
Queensland: Desert Channels																	
Channel Country	189,998		0.02	0.36		0.7	0.34	0.13	0.21	0.09	0.02	0.03				7.6	1.37
Desert Uplands	42,146	2.83	2.88	1.88	3.06	5.25	0.07	0.14	0.32	0.74	0.11	1.1	4.94	6	1.85	21.12	5.05
Mitchell Grass Downs	192,524	1.78	0.04	0.08	0.04	1.02	0.2	0.05	0.15	0.24	0.17	0.07	0.05	0.05	0.03	1.75	0.35

BIOREGION	AREA (KM^2)	PERCENTAGE OF BIOREGION AREA BURNT															
		1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Mount Isa Inlier	26,296	1.1	6.48	4.42	2.17	19.11	2.41	1.11	3.32	0.86	13.74	5.46	3.4	1.35	5.79	19.88	21.73
Simpson Strzelecki Dunefields	26,219			2.35		7	4.43									52.41	4.6
SA: Arid Lands																	
Broken Hill Complex	18,687								0.2								
Channel Country	51,597			0.18			0.26		0.01						0.03	2.73	3
Finke	12,322				0		11.27	0.71								23.29	4.04
Flinders Lofty Block	38,661													0.09		0.02	0.15
Gawler	113,022				0								0.01	0		0.29	0.11
Simpson Strzelecki Dunefields	136,933			0.01			0.03									8.94	2.09
Stony Plains	129,597				0.39		0.04									0.14	0.05
SA: Alinytjara Wilurara																	
Central Ranges	27,977			5.58	25.81	5.89	19.83	0.07	0.19	0.6	0.07	0.2		0.77	0.22	16.31	22.48
Great Victoria Desert	186,133			0.23	4.29	4.12	4.73	0.29	0.04	0.53	0.01	0.63	0.09	0	0.01	1.49	6.6
Nullarbor	55,603										2.24	3.39	0.07			1.8	2.38
NT: Arid Lands																	
Burt Plain	73,797	0.1	0.02	0.3	2.42	26.43	8.08	0.17	1.8	0.22	1.63	4.72	0.06	0.08	0.31	31.56	3.93
Central Ranges	26,196			0.57	25.18	16.18	32.94	2.83	1.32	0.23	0.07	0.56		0.24	0.55	6.06	27.36
Channel Country	23,276					15.77	8.76	0							0.09	63.29	1.07
Finke	53,520	0.04		0.03		0.92	30.96	0.05			0.01					25.4	6.01
Great Sandy Desert	99,465	0.29	0.19	0.43	5.64	29.16	31.54	0.85	2.98	0.87	3.66	1.04	0.19	0.31	1.02	35.53	12.89
MacDonnell Ranges	39,294		0.01	0.01	0.24	4.71	20.08	0.41	0.03		0.02			0.02		34.9	5.64

BIOREGION	AREA (KM²)	PERCENTAGE OF BIOREGION AREA BURNT															
		1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Simpson Strzelecki Dunefields	105,748	0.08	0.19			19.77	6.59	1.24	0.12			0.01			0.14	63.61	2.01
Sturt Plateau	16,946	7.93	13.25	41.44	20.21	62.55	26.99	18.25	63.65	2.08	31.66	42.8	10.95	39.27	8.61	37.25	43.27
Tanami	203,026	3.85	2.66	11.64	34.28	32.23	25.02	1.72	18.38	0.6	19.7	35.17	3.78	1.4	4.13	64.51	12.02
NT: Tablelands																	
Davenport Murchison Ranges	49,654	0.85	1.62	0.89	30.7	48.63	9.37	2.66	16.85	0.04	10.35	19.04	4.77	0.49	4.41	56.8	15.22
Gulf Fall and Uplands	37,259	26.01	22.59	34.68	24.28	57.2	17.25	9.95	56.09	4.82	21.2	50.63	13.54	31.98	16.53	23.22	49.68
Mitchell Grass Downs	86,375	0.29	1.46	0.58	1.65	20.92	2.23	1.78	7.84	0.09	0.9	3.13	0.38	0.42	0.98	9.46	6.37
WA: Rangelands																	
Carnarvon	84,302	1.49	0.23	1.52	3.4	1.4	0.22	0.76	0.3	0.11	0.56	0.16	0.09	1.07	0.07	0.04	8.4
Central Ranges	47,015	0	0.09	10.96	39.2	4.75	14.27	0.86	0.82	0.41	4.26	1.8	0.32	0.06	0.71	0.4	28.13
Coolgardie	84,857		3.69	0.08	0.11	5.26	2.05	1	1.76	3	0.22	0.68	0.52	0.27	2.02	0.03	0.19
Gascoyne	180,753	0.8	0.48	1.25	4.36	1.88	1.34	0.41	0.23	0.26	0.44	0.18	0.15	0.19	0.05	0.09	1.6
Gibson Desert	156,289	0.71	0.15	11.44	30.83	4.61	5.75	0.78	0.87	0.57	12.99	5.73	1.12	0.43	0.42	0.98	35.74
Great Sandy Desert	295,396	16.94	0.55	18.79	23.82	12.57	7.25	2.6	10.71	1.52	25.67	6.69	5.69	4.28	0.47	16.28	35.31
Great Victoria Desert	217,942	0.33	3.85	1.57	11.96	4.5	4.29	1.33	0.72	1.1	5.8	5.52	0.51	0.73	0.25	0.04	24.17
Little Sandy Desert	110,899	4.29	0.29	5.6	18.55	0.48	2.79	0.62	0.27	1.77	6.85	7.08	0.92	0.4	0.12	0.19	38.11
Murchison	280,842	0.99	1.67	0.65	1.88	1.95	1.09	0.25	0.16	0.26	0.32	0.72	0.16	0.06	0.02	0.23	0.66
Nullarbor	137,360	0.02			0.78	0.1	0.44		0.27	0.04	0.1	0.14	0.01	0	0.02	11.33	5.16
Pilbara	178,112	20.08	2.51	9.69	25.77	9.36	9.99	3.05	3.08	1.15	15.29	8.3	4.36	7.03	3.19	1.48	10.97
Tanami	30,161	5.55	1.88	27.71	33.44	33.09	15.35	7.01	21.58	0.92	38.87	18	4.72	2.59	3.56	52.48	26.25
Yalgoo	34,726		0.15	0.01	0	0.36	0.15	0.01			0.07		0.03	0.65	0.32	0.57	0.04

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Australian rangelands and climate change – *Cenchrus ciliaris* (buffel grass)

John K Scott

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Figures

8. Australian rangelands and climate change – *Cenchrus ciliaris* (buffel grass)

Key points

- Buffel grass (*Cenchrus ciliaris*) has been shown to acclimate to higher temperatures and to maintain competitiveness and response to fire under increased CO_2, conditions expected under climate change.
- Distribution modelling and plant physiological studies indicate that the current region of buffel grass presence in Australia will remain suitable under future climates, thus maintaining or increasing (due to loss of other palatable grasses) its importance for agriculture.
- Modelling the distribution of buffel grass indicates a southward spread in Australia by 2070. This represents a particular threat to the high value nature conservation in areas such as the Great Western Woodlands, the Alinytjara Wilurara Natural Resources Management Region and the Great Victoria Desert bioregion.
- Containment strategies for buffel grass are required for high value environmental assets, given that eradication will be impossible without unsustainable resources. Likewise control is likely to be very difficult, if not impossible, in areas where the plant is already widespread. This makes containment the best strategy for new infestations, given that reinvasion is highly likely.
- There is a risk that many plant species will not survive in a future climate that is hotter and drier. If buffel grass proves to have greater resilience than other plant species then it might form the basis for a novel ecosystem. Research is needed into ways that buffel grass can be managed to maximise its value to other components of the ecosystem.

Research is also needed into the genetic diversity in buffel grass with a view to identifying genotypes that are invasive and/or suitable for pasture improvement under climate change.

8.1 Introduction

Anthropogenic climate change will lead to ecosystem changes in worldwide arid and semi-arid rangelands by the influence changed climate has on invasive plants. For example, in the western USA rangelands invasive grasses are currently transforming native ecosystems by changing fire regimes. Climate change projections for rangelands indicate that with respect to invasive plants:

- warmer conditions will favour cold-intolerant annual grasses
- changes in frequency of wet winters may alter the establishment of invasive annual grasses
- the fire season will start earlier and be longer, furthering the weed–fire invasion process (Abatzoglou and Kolden 2011)
- a reduction in precipitation in drier areas, given the low base typical of deserts, may lead to loss of grasses.

In Australia, invasive plants in the rangelands region are characterised by a wide distribution and the ability to respond to a variable climate marked by hot temperatures and extensive drought. Invasive plants are already responding to climatic extremes and consequently are likely to be pre-adapted to future climate change. Not only will rangelands invasive plants persist within the changed climate of the rangelands region, but they will spread southwards as the more southerly regions become hotter and drier. Buffel grass is a species that exemplifies this pattern.

Buffel grass (*Cenchrus ciliaris*) (Figure 8.1) is one of the most widespread exotic grasses in Australia. It is native to tropical Africa and Asia and has been planted widely in central, tropical and sub-tropical Australia as a pasture species. It has also naturalised throughout this range, invading areas reserved for nature conservation. This 'contentious' species presents special challenges for determining the adaptation response to climate change, because it is both a threat and a beneficial species. This case study will examine the issues related to buffel grass in the context of a changing climate. General aspects of the reaction of weeds to climate change are covered in Module 2: Weeds and climate change of the National AdaptNRM project (https://research.csiro.au/adaptnrm/)

8.2 Methods

Buffel grass was chosen as the exemplar weed to show the impacts of climate change in rangelands regions because it is:

- the most widespread weed/pasture species of concern to rangelands in Australia
- a relatively well-studied species for its reaction to climate change
- important to both agriculture and the environment.

This case study takes a national approach. While buffel grass occurs throughout the Rangelands Cluster region, the implications of species movement under climate change means that neighbouring regions need to be considered also.

CLIMEX was used as the method for distribution modelling. Background to this method and explanation for the choice of model are given in the National AdaptNRM Module 2: Weeds and climate change (Scott et al. 2014). The website and associated document and data repository can be consulted for species distribution models of relevance to the Rangelands Cluster region.

8.3 Results

8.3.1 Buffel grass distribution

Buffel grass is very widespread and has the capacity to disperse further, potentially to all of Australia. Buffel grass is currently found in the Northern Territory and all Australian states except Victoria (and probably not Tasmania) (Figure 8.2).

The record in Figure 8.2 for the plant's presence in Tasmania does not correspond to the plant being permanently present in Tasmania and illustrates the plant's ability to disperse some distance from source populations. However, in South Australia there are

Figure 8.1. Buffel grass (Cenchrus ciliaris).
Photo: Mark Marathon,
http://en.wikipedia.org/wiki/File:Cenchrus_ciliaris.jpg.

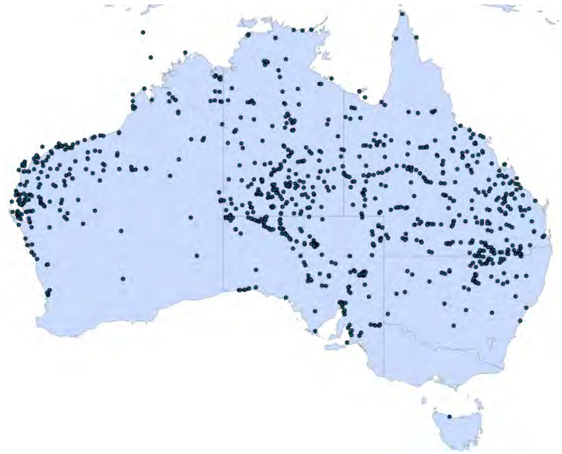

Figure 8.2 Distribution of buffel grass (**Cenchrus ciliaris*****) (black dots) in Australia based on records in http://www.ala.org.au/.***

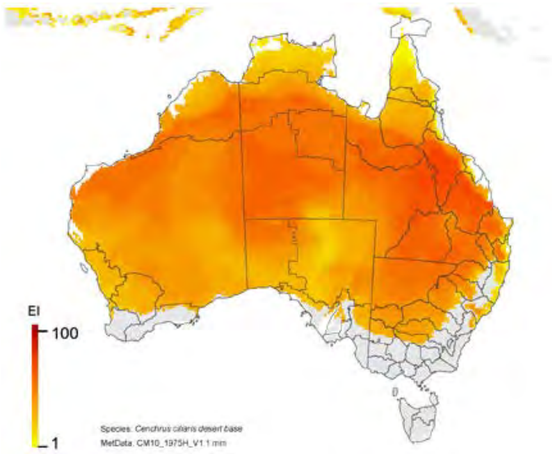

Figure 8.3 NRM regions and species distribution model for buffel grass (**Cenchrus ciliaris*****) using CLIMEX. The higher the value for Ecoclimatic Index (EI), the more suitable is the climate for buffel grass. Values of EI = 0 (grey areas) indicate regions where populations will not persist. CLIMEX parameters for this model were modified from Lawson et al. (2004) and can be found at http://data.csiro.au.***

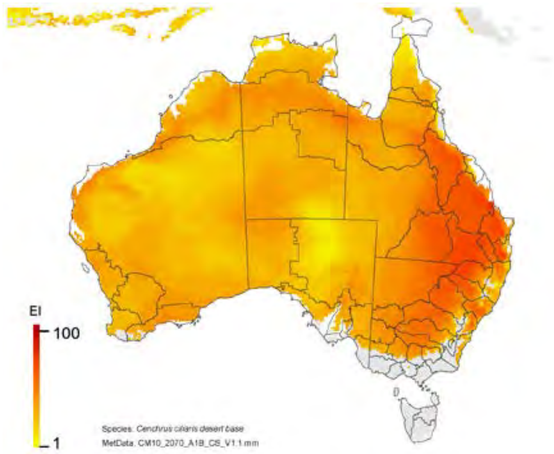

Figure 8.4 NRM regions and projected distribution of buffel grass in Australia as indicated by the CLIMEX Ecoclimatic Index (EI) using CSIRO Mk3 projections for 2070 based on the A1B SRES emissions scenario. The CLIMEX parameters are those used in Figure 8.3.

already established populations and records of the plant's presence in southern regions well south of the main buffel grass population (Biosecurity South Australia 2012).

The wide spread of records (Figure 8.2) indicates that buffel grass is able to disperse readily in addition to being deliberately planted for agricultural purposes. Its fluffy burrs are accidentally transported by humans, especially on vehicles, and by animals, both livestock and native species. This means that the plant has the ability to invade new areas, often initially establishing along roadsides before invading pasture or the natural environment.

The species distribution model (Figure 8.3) shows that most of Australia has a climate suitable for growth and survival of buffel grass, except for the most southerly regions (and even here there may be favourable microhabitats).

The model used here (CLIMEX) has been extensively used to model weed distributions (see https://data.csiro.au/dap/) and is based on information on the plant's temperature and moisture requirements, plus response to stress factors. Note that the climate data used in the model (Figure 8.3) are based on climate averages and do not cover the situation of favourable microhabitats and the effect of climate extremes. The distribution of buffel grass and its response to climate change has also been modelled for Australia by the following methods: BIOCLIM within ANUCLIM (Steel et al. 2008), BIOCLIM (Biosecurity South Australia 2012) and MaxEnt (Wilson et al. 2011, http://www.weedfutures.net/).

8.3.2 Growth response of buffel grass to climate change

Buffel grass is one of the few species of weed in Australia to be extensively assessed for growth response to climate change. Buffel grass has a typical plant response to increased CO_2 with increased biomass (Bhatt et al. 2007) and decreased nitrogen concentration. Leaf transpiration rates were halved at elevated CO_2 (Rudmann et al. 2001). Buffel grass has C_4 photosynthesis like many other warm climate grasses. It is generally considered that C_4 plants have an advantage in a warmer climate due to their higher CO_2 assimilation rates at higher temperatures and higher photosynthetic optima than their C_3 counterparts (Dwyer et al. 2007). Indeed, plants of buffel grass were able to acclimate to warmer temperatures (growth at 35°C versus 25°C) by adjusting the physiology of photosynthesis (Dwyer et al. 2007). Higher day/night temperatures (45/35°C) were lethal, although it is evident the plant can survive in areas such as the Sonoran Desert with air temperatures approaching 50°C (De La Barrera and Castellanos 2007).

In addition, buffel grass, along with other exotic grasses, had higher biomass when resprouting after fire than native grasses when grown under elevated CO_2 (Tooth and Leishman 2014). This indicates a mechanism – better response to fire under elevated CO_2 – which implies that buffel grass will remain, if not increase, in its ability to transform ecosystems under climate change.

8.3.3 Change in potential distribution

The projection for climate change up to 2070 (Figure 8.4) shows a declining Ecoclimatic Index (EI) in central and northern Australia, but none of these areas became completely unsuitable for growth of buffel grass. This model is based on the current plant physiology and distribution records. The evidence from the plant physiology of buffel grass in response to climate change is that it will adapt to the changed environment, and thus it may prove likely that there will not be a reduction in the invasion capacity of buffel grass in central Australia.

In common with many invasive species (see the National AdaptNRM Module 2: Weeds and climate change), buffel grass is projected to spread southwards as the climate becomes warmer (Figure 8.4). This is because cold temperature (temperatures at or less than 5°C, Cox et al. 1988) is the factor likely to be limiting the southern edge of the distribution in Australia. The second factor favouring buffel grass is climate with predominantly summer rainfall (Cox et al. 1988, Marshall et al. 2012). This factor may mitigate against a southward spread, although buffel grass is found across a range of rainfall patterns (Marshall et al. 2012). Another factor that could limit the southwards spread are frosts, which have already increased in frequency due to the clear skies that come with the current drying environment.

The warming of the environment can have two effects. Firstly, it will facilitate the establishment of new populations, and, secondly, it will facilitate the spread from existing populations from suitable microhabitats. Two conservation regions, the Great Western Woodlands and the arid lands of South Australia (Alinytjara Wilurara Natural Resources Management Region and the Great Victoria Desert bioregion), show why it is important to monitor and manage this southward spread or to contain infestations that are persisting in more southern regions.

Great Western Woodlands

The Great Western Woodlands (GWW) in the rangelands of the south-west of Australia are the world's largest remaining Mediterranean-climate woodland. There are few (5%) exotic plant species that occur in the GWW. Perhaps the most important invasive plant threat to the GWW is the southward spread of buffel grass due to increasing winter temperatures and increased summer rain. While buffel grass impacts negatively on native flora and fauna, the most threatening aspect is the potential to provide connectivity of fire fuels, combined with increased risk of fire ignition and spread. At present, the GWW has areas bare of vegetation that limit the ability of fire to spread. Buffel grass could provide the fuel for fires to link across the vegetation. This could potentially transform both the ecosystem structure and overall landscape (Prober et al. 2012). This risk is recognised in the invasive management plans for the GWW, where at present buffel grass is mainly restricted to some roadsides (Department of Environment and Conservation Western Australia 2013).

South Australia

Buffel grass is now widely distributed across northern regions of South Australia as scattered populations, with extensive infestations in the far north-west of the state (Biosecurity South Australia 2012) (Figure 8.2). South Australia has developed a Strategic Plan with the overall aim to contain buffel grass and reduce its impact. This includes preventing the southward spread and infilling. Areas identified for the containment of buffel grass include the Alinytjara Wilurara Natural Resources Management Region and the Great Victoria Desert bioregion (Biosecurity South Australia 2012).

8.3.4 Response to extreme events

Examining a plant's response to extreme climatic events gives an indication to how the plant might respond under climate change. Understanding the role of extreme events also helps direct management that will be useful under current climate conditions as well as under climate change.

Buffel grass can proliferate in response to extreme events such as hot temperatures, exceptional rainfall, drought and fire, events that are also likely to increase under future climate change. Whereas buffel grass does not tolerate extended flooding, it is able to grow roots to a soil depth of 3 m, which would give it resilience in the face of extended drought.

In the USA, buffel grass is causing the transformation of fire-resistant desert dominated by cacti to flammable grassland. Buffel grass fires are more intense and frequent than fires in surrounding USA ecosystems (McDonald and McPherson 2011). In contrast, Australian ecosystems are already fire-adapted, but buffel grass will still increase the fuel loading (Miller et al. 2010) leading to increased frequency and intensity of fires.

8.3.5 Management

Beneficial aspects

Buffel grass is a valuable pasture species for rangelands areas and may become more important under a climate change scenario because of its ability to acclimate to higher temperatures, to persist and provide productive grazing. In dry areas it may become an important soil stabiliser, especially if climate change causes a reduction in other plant species. It has already been used to prevent erosion (Marshall et al. 2012).

A detailed study of the genetic variability in buffel grass, both here and overseas, is needed to enable identification of strains that will be useful to future agriculture. There is already concern that genotypes of buffel grass will be lost from its native habitat (e.g. Tunisia: Kharrat-Souissi et al. 2014) were the plant is subject to overgrazing and increased aridity.

Potential ecological impacts

In the rangelands area buffel grass has been implicated in decreases in native plant diversity and abundance, lessening tree recruitment and increasing fire intensity that changes woodland structure. As a consequence, the diversity is reduced of native fauna, including invertebrates, reptiles and native mammals (references in Bradshaw et al. 2013 and Marshall et al. 2012). Increased densities and infilling by buffel grass are likely to exacerbate these problems under conditions of climate change. Long-term studies (28 years) show that the decline in native biodiversity has stronger associations with competition by buffel grass than with fire and variable rainfall (Clarke et al. 2005).

A management approach could be to avoid introduction of new genetic material, to increase control efforts where the plant is sparse, perhaps including containment, and establishing quarantine barriers to prevent incursions into nature reserves (Grice et al. 2012). Better identification (Kharrat-Souissi et al. 2014) is needed of the buffel strains in Australia, which will help with understanding origins and invasion potential.

Novel ecosystems

Management of buffel grass as a 'novel ecosystem' (Belnap et al. 2012) may form the basis for survival of other species. It is clear that buffel grass is difficult to remove, and ecosystem restoration is impossible without exceptional resources. In addition, buffel grass provides valuable ecosystem services in the form of grazing for cattle and provision of erosion control. Together these drivers point to the desirability of retention of this novel ecosystem (Belnap et al. 2012). Such a conclusion should not be accepted uncritically. There is a need to explore the options for management of buffel grass to favour species diversity and pasture production at the same time. However, the results of an ecological impact and fire study by Schlesinger et al. (2013) indicate that the novel ecosystem approach will be a challenge to achieve given the competiveness of buffel grass.

A novel ecosystem due to an increase in a weed distribution or abundance may lead to unintended consequences. A study of King Brown snakes (*Pseudechis australis*) found that the snake is associated with increased buffel grass density (McDonald and Luck 2013). The distribution of King Brown snakes in Australia is very similar to that of the current distribution of buffel grass, so a spread southward with the weed might be possible under climate change. The management option mentioned by McDonald and Luck (2013) is to remove buffel grass from near human habitation as a way of reducing the risk of snake presence. As humans are likely to be the main vector of buffel grass seeds, removing the weed near human habitation will also reduce the risk of weed spread.

Management plans

A selection of management and strategy guides for buffel grass are listed here:

- CRC for Australian Weed Management (2008) *Weed management guide: managing weeds for biodiversity*. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/347153/awmg_buffel-grass.pdf.
- Biosecurity South Australia (2012) *South Australia buffel grass strategic plan: a plan to reduce the weed threat of buffel grass in South Australia*. Government of South Australia. http://www.pir.sa.gov.au/__data/assets/pdf_file/0005/177656/91806_SA_Buffel_Grass_Strat_Plan_FIN_WEB.pdf.
- Northern Territory Government (no date) *Buffel grass management guide for central Australia*. http://www.lrm.nt.gov.au/__data/assets/pdf_file/0014/19211/buffel_guide_web_version.pdf.
- Moore et al. (2006) *Perennial pastures for Western Australia*. Department of Agriculture and Food Western Australia, Bulletin 4690, Perth.
- Queensland Department of Agriculture, Fisheries and Forestry (2013). *Buffel grass in south Queensland*. http://www.daff.qld.gov.au/plants/field-crops-and-pastures/pastures/buffel-grass.

8.4 Conclusions

Buffel grass is a contentious plant species, both beneficial and detrimental, depending on the situation (Friedel et al. 2011). Landholders generally have similar perceptions of the positive and negative impacts of buffel grass. However, the main contentious area is that of high conservation value pastures (Friedel et al. 2011), and such areas newly suitable for buffel grass after climate change should be the target of adaptation responses and planning well beforehand. Part of this planning would include understanding pastoralist perceptions towards the costs and benefits of buffel grass (Marshall et al. 2011).

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Australian rangelands and climate change – dust

Gary Bastin

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Figures

9. Australian rangelands and climate change – dust

Key points

- Rangelands dust is related to ground cover and fluctuates with seasonal conditions (i.e. dust is more likely to emanate from erodible soils during drought). Atmospheric dust provides a local- to regional-scale indicator of the effectiveness of grazing management in pastoral country and the recent fire regime in spinifex deserts. Land managers should endeavour to maintain critical levels of ground cover so as to minimise soil and nutrient loss via dust resulting from wind erosion in dry times.
- There have been some dramatic year-to-year changes in dust activity in the recent past, particularly between 2009 (when there was substantial dust in the atmosphere) and 2010 (minimal atmospheric dust). These changes were mainly associated with rainfall, that is, improved seasonal quality in 2010.
- It is probable that the domains and magnitudes of recent dust activity in drought periods will recur with continuing climate variability, particularly rainfall. Increased frequency and intensity of heatwaves and lower humidity may also contribute to increased dust.
- Visibility as affected by atmospheric dust can indicate wind erosion rate, although actual weather conditions, soil type, vegetation type and amount of ground cover are also important.
- Griffith University uses a Dust Storm Index (DSI) to report wind erosion activity across Australia. The index is based on historic visibility data recorded by Bureau of Meteorology observers. DSI maps indicate the likely sources of dust and their levels over time.
- In the recent past (1992–2010) within the Rangelands Cluster region, most dust appeared to emanate from within the more arid parts of the Lake Eyre Basin (particularly the Simpson–Strzelecki Dunefields and Channel Country bioregions) extending west into central Australia (the MacDonnell Ranges), north into the Mitchell Grass Downs and Mount Isa Inlier bioregions, east and south-east into the Mulga Lands and Riverina, and south into the Gawler bioregion (SA Arid Lands). The WA Rangelands were less active as a dust source.

9.1 Introduction

The level of dust in the air is related to ground cover and provides a useful indicator of wind erosion rate, although the amount of dust observed is influenced by several factors (e.g. actual weather conditions, soil type, vegetation type and amount of ground cover). Prof. Grant McTainsh and his team at Griffith University calculate a Dust Storm Index (DSI) based on visibility records made by Bureau of Meteorology (BoM) observers. The DSI provides a measure of the frequency and intensity of wind erosion activity at continental scale. It is a composite measure of the contributions of local dust events, moderate dust storms and severe dust storms using weightings for each event type, based upon dust concentrations inferred from reduced visibility during each of these event types.

The Australian Collaborative Rangelands Information System (ACRIS) reports annual and averaged multi-year values of the DSI as one of its indicators of environmental change in the rangelands.[8] The most recent reporting period for dust was 1992–2010, a period that covered considerable climate variability and, as such, provided a useful guide to likely locations and severity of future dust-storm events under continuing rainfall variability. Important points from ACRIS reporting are included here.

9.2 Data source and method

DSI values are calculated from visibility data recorded by BoM observers. A number of different wind erosion event types are evaluated by BoM, ranging from severe dust storms to local blowing dust. The intensity of these event types can be approximated by the extent to which they reduce visibility. DSI is a composite measure of the weighted contributions of local dust events, moderate dust storms and severe dust storms. Values calculated by Griffith University are spatially interpolated between stations and integrated over time to provide annual and multi-year DSI maps.

The reliability of dust storm patterns in the DSI maps depends on the observation frequency at each recording station, for example, those BoM stations recording up to eight visibility readings a day provide more reliable records of dust storm events than those with lower observation frequencies. In addition, the number of recording stations where manual observations of visibility are made has, unfortunately, declined over the years.

Manual observation frequency (MOF) is standardised such that there must be a continuous record between the start and end reporting period for the data from a recording station to be included. This reduces the risk of generating erroneously high or low mean DSI values for particular areas where a station has a discontinuous recording history. When interpreting spatial and temporal patterns in DSI (following maps), it is important also to consider the associated maps of observation frequency.

[8] See http://www.environment.gov.au/resource/acris-dust-product-update-2006-2010 and http://www.environment.gov.au/resource/update-dust-storm-index-dsi-maps-2005-2010 for the most recent ACRIS reporting.

9.3 Caveats

1. Interpolated DSI values indicate the relative amount and location of observed atmospheric dust, not necessarily the source of that dust.
2. Refer to the associated MOF maps as an indicator of the reliability of spatially interpolated dust levels. A higher spatial density of BoM recording stations with a higher recording frequency provides the most reliable data for spatially interpolating DSI values.

9.4 Findings

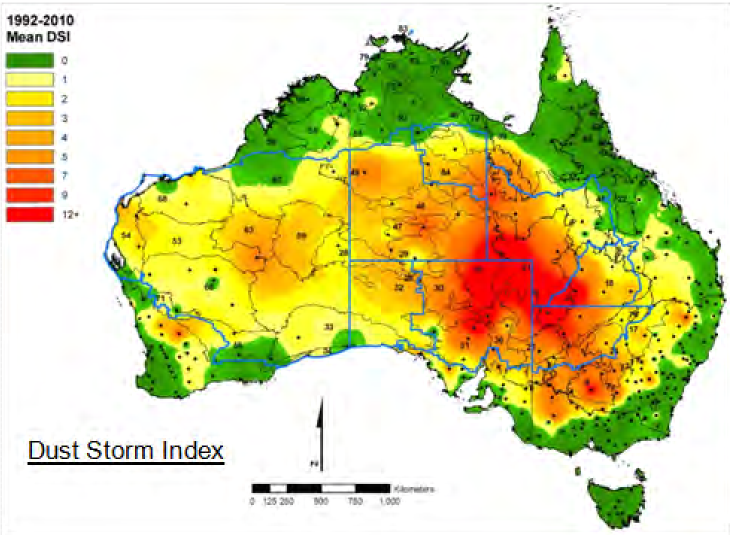
9.4.1 Dust Storm Index: 1992–2010

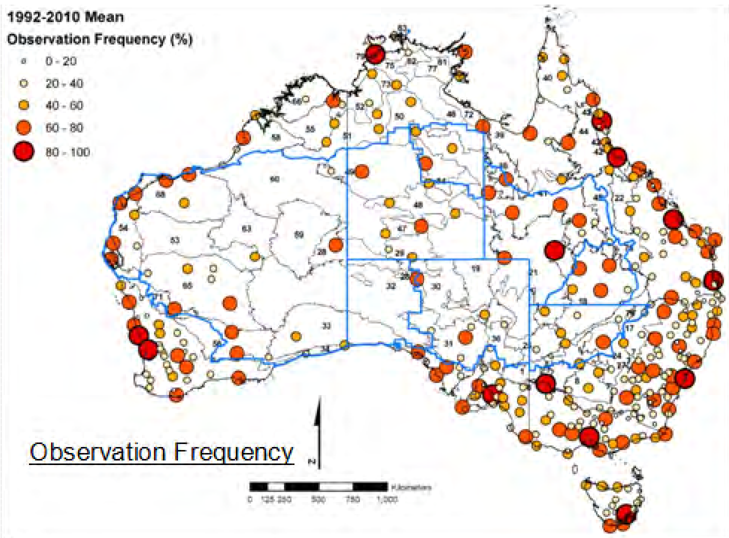
Recent change in dust activity for rangeland bioregions is presented in two ways:

1. Time-averaged DSI values for 1992 to 2010: this map shows where most of the dust is observed and partly indicates where it came from.
2. By contrasting change for two recent years in the DSI record: this map illustrates the dramatic change that occurs when good rains ended an extended drought.

The maps (Figure 9.1 and Figure 9.2) show that:

- The Simpson–Strzelecki Dunefields and Channel Country bioregions (mainly Desert Channels Queensland and SA Arid Lands but also Western Catchment, NSW) had the highest time-averaged mean DSI values between 1992 and 2010 (Figure 9.1, numbered bioregions 19 and 21). Although DSI shows observed dust, it is probable that these regions were also the most active wind erosion regions. This probable high wind-erosion zone was centred on the Lake Eyre Basin and extended west into the MacDonnell Ranges (47), north into the Mitchell Grass Downs (41) and Mount Isa Inlier (38), east and south-east into the Mulga Lands (18) and Riverina (8), and south into the Gawler bioregion (31). The WA Rangelands were less active as a dust source.
- This assessment is tempered by a reduction in the number of stations with a high observation frequency (MOF of 80–100%) in the latter period. In 2010, high MOF was primarily restricted to coastal stations and capital cities. The rationalisation of BoM stations is unfortunate from a wind erosion monitoring perspective, as it is degrading the DSI record.
- Comparing among recent years, the most dramatic changes in regional DSI occurred between 2009 and 2010 (Figure 9.2; see Figure 9.3 for corresponding maps of observation frequency).
  - DSI values between 2002 and 2008 were broadly similar to those shown in Figure 9.1.
  - Dust activity in 2009 was at its highest level since 1992 (Figure 9.2, top image). The pre-existing high erosion zone centred on the Lake Eyre Basin and extended east into the western Murray–Darling Basin, increasing to an area of approximately 1 million km^2. North–south, it extended from the Channel Country (21) to the Flinders Lofty Block (36) and Broken Hill Complex (25). The Stony Plains (30) bounded the western extent with the Mulga Lands (18) forming the eastern boundary. There were secondary regions of high wind erosion in the Cobar Peneplain (24) and further east beyond the Rangelands Cluster boundary.
  - There were moderate DSI values in the western desert region (Gibson Desert [59], Little Sandy Desert [63], Great Victoria Desert [32]) in 2009. These DSI values largely resulted from spatial data interpolation, as there are very few observations from this area (Figure 9.3). Moderate DSI values in the Gulf Fall and Uplands (46) and Gulf Coastal (72) (Monsoonal North Cluster region) also resulted from observations external to each region.



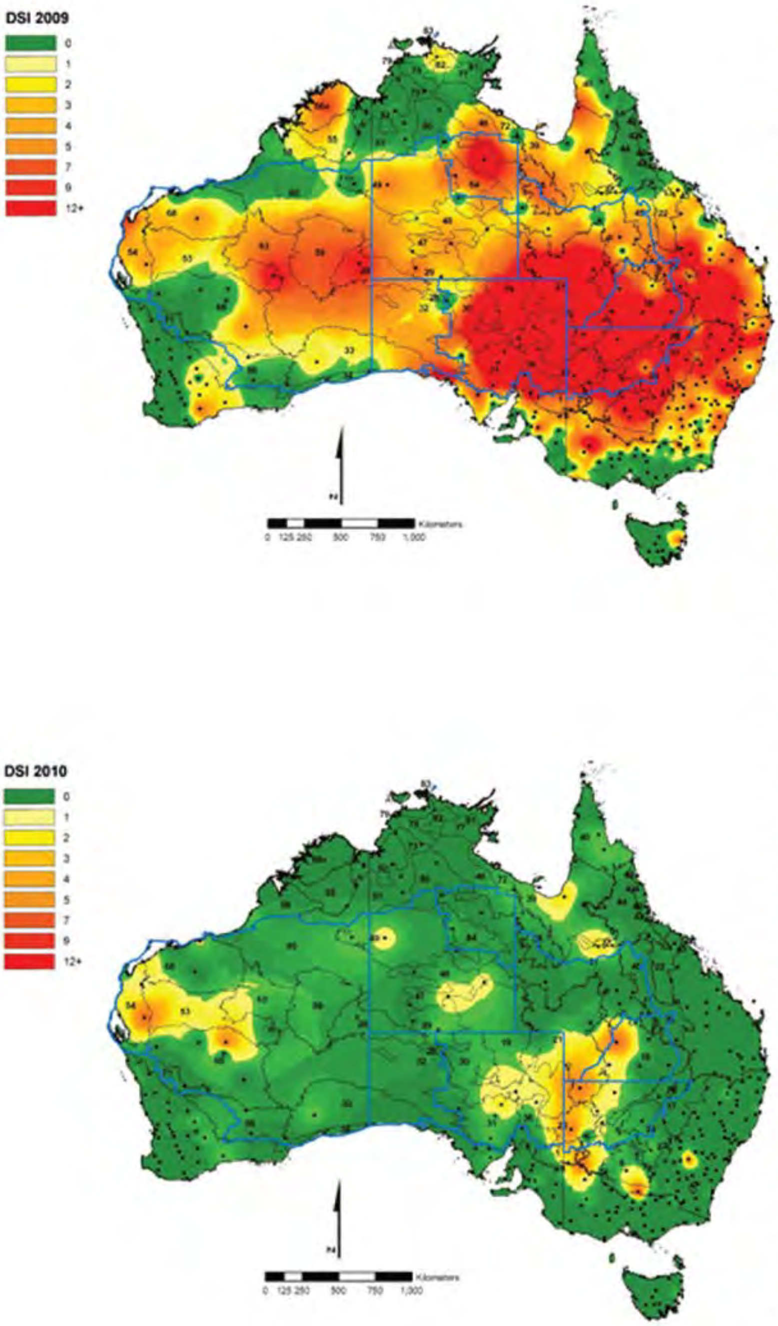


Region	IBRA name
1	Murray Darling Depression
8	Riverina
17	Darling Riverine Plains
18	Mulga Lands
19	Simpson Strzelecki Dunefields
21	Channel Country
22	Brigalow Belt North
24	Cobar Peneplain
25	Broken Hill Complex
28	Central Ranges
29	Finke
30	Stony Plains
31	Gawler
32	Great Victoria Desert
33	Nullarbor
34	Hampton
36	Flinders Lofty Block
38	Mount Isa Inlier
39	Gulf Plains
40	Cape York Peninsula
41	Mitchell Grass Downs
44	Einasleigh Uplands
45	Desert Uplands
46	Gulf Fall and Uplands
47	MacDonnell Ranges
48	Burt Plain
50	Sturt Plateau
51	Ord Victoria Plains
52	Victoria Bonaparte
53	Gascoyne
54	Carnarvon
55	Central Kimberley
56	Coolgardie
58	Dampierland
59	Gibson Desert
60	Great Sandy Desert
63	Little Sandy Desert
65	Murchison
66	Northern Kimberley
68	Pilbara
71	Yalgoo
72	Gulf Coastal
73	Daly Basin
75	Pine Creek
76	Brigalow Belt South
77	Central Arnhem
79	Darwin Coastal
81	Arnhem Coast
82	Arnhem Plateau
84	Davenport Murchison Ranges

Figure 9.1 Top: mean DSI values for the 1992–2010 period; bottom: observation frequency.

Blue lines show NRM regions in the Rangelands Cluster, and black dots (top image) show BoM recording stations. Bioregions are mapped and numbered for the extent of the rangelands as defined by ACRIS (numbers refer to bioregion names listed to the right of the maps).

Source: Data and maps from Prof. Grant McTainsh, Griffith University (adapted from ACRIS reporting).



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32	Great Victoria Desert
33	Nullarbor
34	Hampton
36	Flinders Lofty Block
38	Mount Isa Inlier
39	Gulf Plains
40	Cape York Peninsula
41	Mitchell Grass Downs
44	Einasleigh Uplands
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47	MacDonnell Ranges
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50	Sturt Plateau
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53	Gascoyne
54	Carnarvon
55	Central Kimberley
56	Coolgardie
58	Dampierland
59	Gibson Desert
60	Great Sandy Desert
63	Little Sandy Desert
65	Murchison
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71	Yalgoo
72	Gulf Coastal
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75	Pine Creek
76	Brigalow Belt South
77	Central Arnhem
79	Darwin Coastal
81	Arnhem Coast
82	Arnhem Plateau
84	Davenport Murchison Ranges

Figure 9.2 DSI values in 2009 (top) and 2010 (bottom).

The dots and blue lines show BoM recording stations and Rangelands Cluster NRM regions respectively.

Source: Data and maps from Prof. Grant McTainsh, Griffith University (maps adapted from ACRIS reporting).

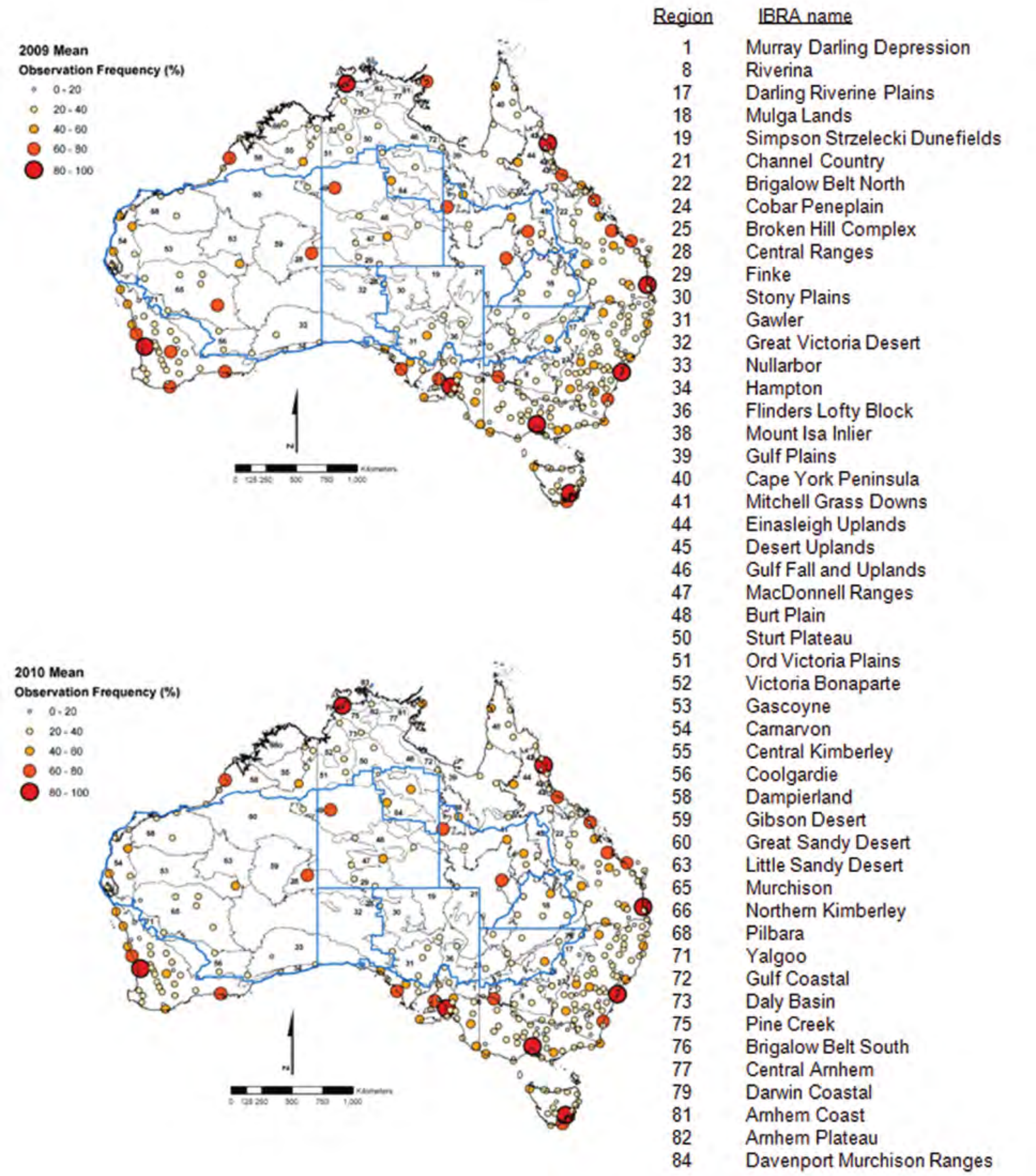

Figure 9.3 Manual observation frequency at BoM recording stations for visibility: 2009 (top) and 2010 (bottom).

Circles show BoM recording stations, with the size and colour of the circle representing observation frequency. Blue lines show NRM regions in the Rangelands Cluster.

Source: Data and maps from Prof. Grant McTainsh, Griffith University (maps adapted from ACRIS reporting).

- In stark contrast, 2010 had the lowest wind erosion in the 1992–2010 period (Figure 9.2, bottom), and at least as far back as 1974. The only stations to record wind erosion activity were Quilpie in the Mulga Lands (18) region of Queensland, as well as Tibooburra and Broken Hill in NSW. Remarkably, the Birdsville meteorological station, which had seen dust activity every year since it started operating, did not record a single dust code (not even haze) for the entire 2010 calendar year. In WA, the only wind erosion was recorded in the northern Murchison (65) and eastern Carnarvon (54) region.

- Vastly improved seasonal quality in eastern and central Australia in 2010 (and continuing in many areas to 2012) likely contributed to reduced dust observations and associated wind erosion activity in 2010. It is expected that observed dust levels have again increased in the Lake Eyre Basin, neighbouring Simpson Desert, parts of central Australia, much of south-west Queensland and western NSW with the return of drier seasonal conditions (2013) and extensive wildfire in 2011 and 2012.

9.4.2 DustWatch

DustWatch[9] is a community program that monitors and reports on the extent and severity of wind erosion across Australia. Additionally, it raises awareness of the effects of wind erosion on the landscape and the impacts of dust on the community. DustWatch is led by scientists but relies very much on community participation. Within (or on the edge of) the Rangelands Cluster region, Dr John Leys (NSW Office of Environment and Heritage) has collaborated with an active group of landholders and other participants in the former Lower Murray Darling NRM region of NSW.

DustWatch observations can potentially contribute to the national DSI, particularly where BoM observations are sparse and/or infrequent and, increasingly, becoming more so. However, community observations have to be sufficiently consistent in quality and maintained through space and time to meaningfully contribute.

Perhaps more importantly, the DustWatch community provides ground truth and valuable local context to interpolated DSI data. That is, participants on the ground can provide powerful local interpretation of significant dust events, with this evidence often supported by contributed photos and other anecdotal information. By raising awareness of the environmental and economic damage caused by wind erosion (often combined with community hardship), these advocates are seeking to improve land management and thereby reduce the risk and impact of further events. Active community participation such as this has to be a powerful ally in planning and adapting for further climate variability and projected change.

[9] http://www.environment.nsw.gov.au/dustwatch/index.htm

9.5 Adaptation strategies

On pastoral country, the most direct strategy to minimise soil and nutrient loss through wind erosion and associated dust relates to maintaining minimum acceptable levels of ground cover for the major erodible soil types. This, in turn, relates to grazing management, particularly adjusting stocking rate as seasonal conditions become increasingly drier. Further information is provided about remotely sensed ground cover in Bastin (2014) and about pastoral production in Bastin et al. (2014).

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Acknowledgements

DSI data and maps presented here have been adapted from material supplied to ACRIS by Prof. Grant McTainsh and colleagues at Griffith University.

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Australian rangelands and climate change – aquatic refugia

Jenny Davis

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10. Australian rangelands and climate change – aquatic refugia

Key points

- The NRM Rangelands Cluster region is highly water-limited, and all water (surface and groundwater) in the region is environmentally, culturally and economically important. Given that water scarcity is likely to continue under all climate change scenarios, the identification, management and restoration of aquatic refugia is a critical adaptation strategy for rangelands ecosystems and the biota they support.
- Refugia are defined as habitats that biota retreat to, persist in and potentially expand from under changing environmental conditions. Different types of refugia are important for different species over differing spatial and temporal scales. Two major types of refugial habitats are recognised: evolutionary refugia and ecological refuges.
- Evolutionary refugia are defined as those waterbodies that contain short-range endemics (species that occur only within a very small area) or vicariant relicts (species with ancestral characteristics that have become geographically isolated over time). Although these species often have very small geographical ranges, their populations are relatively stable and high levels of genetic diversity are present. All aquatic evolutionary refugia in the NRM Rangelands Cluster regions are groundwater-dependent ecosystems. Evolutionary refugia are most likely to persist into the future and should be accorded the highest priority in NRM adaptation planning.
- Ecological refugia are defined according to the water requirements of the species they protect. Obligate aquatic organisms (fishes and some aquatic invertebrates that can only disperse via water) need perennial (permanent) aquatic habitats, or closely located near-perennial habitats, to ensure persistence. In contrast, important ecological refugia for waterbirds are the large temporary or ephemeral freshwater lakes and salt lakes that hold water after infrequent but large episodic rainfall events. The conservation significance of ecological refugia, and the priority assigned to their conservation, depends on the level of knowledge available for the species they support. Information regarding species characteristics, such as dispersal traits, is particularly important for the determination of the importance of ecological refugia. Highly mobile species are less likely to be dependent on perennial systems.
- The vulnerability of aquatic refugia to climate change is influenced by their source of water (groundwater or surface water). Those waterholes that depend primarily on rainfall (surface water) for their water supply are highly sensitive, and those that depend primarily on discharge from groundwater (either regional or local) systems are the least sensitive, because of the great buffering capacity of groundwater, both hydrologically and thermally. The climate adaption capacity of aquatic species in the rangelands is influenced by their habitat requirements and their dispersal ability. Short-range endemics and relictual species have limited capacity to recolonise waterbodies that dry out and so these species are at the greatest risk of extinction, particularly from the indirect impacts of climate change.
- The indirect effects of climate change, particularly an increase in human demands for water (for direct consumption and production of food, fibre and energy) are likely to have greater impacts than direct climatic effects. Excessive groundwater drawdown will destroy spring-based evolutionary refugia, and the construction of surface water impoundments will destroy the aquatic connectivity essential for the persistence of riverine waterholes as ecological refugia. The existing adverse impacts of livestock, feral herbivores, invasive fishes, exotic plants, recreation and tourism must also be managed.

Tools for NRM adaptation planning provided in this report include a list of priority aquatic refugia (sites likely to act as future refugia) and a decision support tree. The latter will aid the identification of major types of waterbodies and the refugia they provide, vulnerability assessments and development of management responses to address direct and indirect climate impacts and other stressors. A site register of important rangelands aquatic refugia is provided at Appendix A. This is regarded as a 'living' register that should be updated as more information becomes available.

10.1 Introduction

Water scarcity, highly variable annual precipitation and high rates of potential evapotranspiration are defining characteristics of the Australian rangelands. Climate projections for the Rangelands Cluster region indicate that high natural rainfall variability will continue and may mask trends in average rainfall for some decades to come, particularly for summer rainfall. The intensity of extreme rainfall events will increase; average summer rainfall may change in some regions, but the median change is likely to be small relative to natural variability. Winter rainfall is likely to decline in both the north and south. Potential evapotranspiration is projected to increase in all seasons, most strongly in summer.

In water-limited environments such as the rangelands, all natural waterbodies are environmentally, culturally and economically valuable. Accordingly, one of the most important climate adaptation strategies for the NRM Rangelands Cluster is the identification, management and restoration of aquatic refugia.

10.1.1 What are refugia?

Refugia are habitats that biota retreat to, persist in and potentially expand from under changing environmental conditions (Keppel et al. 2012). Two major types of arid zone refugial habitats, evolutionary refugia and ecological refuges, were defined by Davis et al. (2013). However, Reside et al. (2014) suggested that the term 'refuge' should only be applied to habitats that shelter individuals from short-term disturbances, while 'refugia' describes habitats that provide protection to populations or species over ecological or evolutionary timescales. To avoid confusion, this report uses only the term 'refugia'. However, the distinction that Davis et al. (2013) made between evolutionary and ecological refugial habitats remains important for prioritising conservation measures as part of climate adaptation planning. For this reason, guidance for the identification of both evolutionary refugia and ecological refugia forms a major part of this report.

10.1.2 Direct vs. indirect climate change impacts on aquatic refugia

All freshwater ecosystems are vulnerable to climate change because of their relative isolation and physical fragmentation within terrestrial landscapes (Woodward et al. 2010). These factors mean that many aquatic species will have limited ability to disperse as temperatures increase and previously perennial waterbodies become temporary or ephemeral. However, it is the potentially large, indirect effects of increasing human demands for water that are likely to have even greater impacts on freshwater ecosystems (Palmer et al. 2008). A rising global population means that there will be an ever-increasing demand for water for domestic consumption and the production of food. This demand, occurring in concert with a warming and drying climate, suggests that there will be intense competition for water between human and environmental needs. This competition will be exacerbated in arid and semi-arid landscapes of the rangelands. Indirect effects include the depletion of aquifers and lowering of water tables caused by increasing extraction of groundwater. Mine dewatering will have a similar impact. Connectivity along river networks will be disrupted through the construction of dams and an increase in river offtakes for irrigation. The likely severity of impacts means that assessing the vulnerability of refugia to both direct and indirect effects is an important part of climate adaptation planning.

10.2 Methods

This project was undertaken primarily as a desktop study. It builds on previous work on arid and semi-arid zone refugia described by Davis et al. (2013) and information relating to rangelands sub-regions as listed in Table 10.1.

Table 10.1 Aquatic refugia data sources listed by Rangelands Cluster sub-region

REGION	DATA SOURCES
Alinytjara Wilurara	Nathanael Wiseman ([Researcher, Geography, Environment and Population, The University of Adelaide] 2014, pers. comm., 23 April)
Desert Channels NRM	Silcock (2009)
Rangelands WA	Pinder et al. (2010) Adrian Pinder ([Principal Research Scientist, Department of Parks and Wildlife, WA], 2014, pers. comm., 9 September)
SA Arid Lands	Costelloe & Russell (2014) McNeil et al. (2011) Jackie Watts ([Monitoring, Evaluation and Reporting Officer, Natural Resources, SA Arid Lands, Adelaide] 2014, pers. comm., 15 April) Nick Murphy ([Lecturer, Genetics Department, La Trobe University, Melbourne] 2014, pers. comm., 3 June)
South West NRM	Silcock (2009)
Territory NRM	Duguid et al. (2005)
Western CMA	
National	Morton et al. (1995) Directory of Important Wetlands (Environment Australia 2001)

10.3 Findings

10.3.1 Identifying aquatic refugia

Evolutionary refugia

These are perennial freshwater ecosystems that have supported aquatic species over millions of years. Identification of evolutionary refugia requires knowledge of the species (plants, aquatic invertebrates and fishes) that they support. Most importantly, waterbodies are considered to be evolutionary refugia if they contain short-range endemics (species that occur only within a very small area) or vicariant relicts (species with ancestral characteristics that have become geographically isolated over time). Although these species often have very small geographical ranges, their populations are relatively stable and high levels of genetic diversity are present. All aquatic evolutionary refugia in the NRM Rangelands Cluster region are groundwater-dependent ecosystems. This is not surprising, given that groundwater is the only source of water within arid Australia that has persisted over millennial timescales.

Ecological refugia

The most important ecological refugia in the NRM Rangelands Cluster region are perennial and near-perennial waterbodies supported by groundwater, surface water or a combination of both. These systems are governed by the boom and bust dynamics described by Kingsford et al. (1999), Bunn et al. (2006) and others. The identification of an ecological refuge varies depending on the characteristics, particularly the dispersal abilities, of the species of concern. Obligate aquatic organisms (fishes and some aquatic invertebrates) need perennial habitats, or closely located near-perennial habitats, to ensure persistence. Perennial systems are also important for the persistence of terrestrial species such as bats and some snakes and amphibians. Waterbirds, which can disperse aerially over long distances, can use a mosaic of temporary wetlands over broad spatial scales (Roshier et al. 2001).

Table 10.2 Major types of rangeland aquatic ecosystems and their water sources.

NAME	WATER SOURCE	DESCRIPTION
Subterranean aquifers	GW*	Shallow, underground carbonate habitats in the central region of WA and in WA palaeo-river channels. Sites within fractured rock aquifers in the Pilbara region. Sites within alluvial aquifers in north-east Australia. Characterised by permanent water, no light and therefore no primary production.
Discharge (mound) springs	GW	Surface expressions of the Great Artesian Basin (GAB). Characterised mainly by permanent and consistent flows and alkaline waters with high concentrations of dissolved solids. Clustered at a range of scales, from individual vents to spring complexes to 13 major 'super-groups.' Discharge springs are also present outside the GAB, e.g. Mandora Marsh in north-west Australia.
Outcrop springs	GW	Mainly arise from local fractured rock (sandstone, limestone or quartzite) aquifers and are usually located near the base of ranges. Slightly acidic and very fresh. Usually permanent, although some can contract and sometimes dry completely.
Relict streams	GW	Small, permanently flowing sections of streams in the headwaters of the rivers of the Central Ranges, supported by outcrop springs. Cool, mesic-type habitats, mostly within deeply shaded, south-facing gorges. Called 'relict streams' because they support stream-dwelling insects with Gondwanan affinities.
Riverine waterholes	SW*/ GW	Permanent, temporary or ephemeral waterbodies present in dryland river networks. Connected when large but infrequent rain events result in high flows or flooding; disconnected and reduced in area and depth when flows cease, except for hyporheic (below surface) flows. Waterholes in the eastern Lake Eyre Basin (LEB) are often turbid; those in the western LEB and the Pilbara are often clear. Often surface water–fed, but some permanent waterholes may receive groundwater/hyporheic flows. The latter includes the large waterholes on the Finke River (Running Waters and Boggy Hole) and nearly all permanent river pools in the Pilbara region.
Stream pools/ rockholes	SW	Pools or rockholes in small, rocky headwater creeks within arid zone ranges. Fed by local rainfall events, they are usually temporary or ephemeral.
Isolated rockholes/ gnammas	SW	Water stored in natural hollows formed by fracturing and weathering of rocky landscapes. Fed by local runoff from infrequent rainfall events. Small and isolated habitats that are widespread, but not abundant, throughout the arid zone. Also called gnammas. Mainly temporary or ephemeral systems.
Temporary lakes, swamps and marshes	SW	Isolated, shallow basins, not in watercourses, fed by local runoff after infrequent rain events. These include interdunal systems within desert dune regions and extensive floodplains (e.g. in LEB). Hydroperiods are highly variable and unpredictable. The distinction between lakes, swamps and marshes can be arbitrary, but the latter two usually refer to vegetated systems.
Clay pans	SW	Temporary, shallow basins with an impervious base fed by local runoff and dominated by evaporative processes. They contain fresh and characteristically turbid water when fed by local run-off after infrequent rain events or left behind as flood waters recede. Hydroperiods are short, highly variable and unpredictable.
Salt lakes/ saline playas	SW/GW	Temporary, shallow basins fed by SW and/or GW (depending on site). They are characterised by highly episodic hydroperiods, high salinities and clear water. Highly productive systems when water is present.
Soaks	GW	Sub-surface systems that support groundwater-dependent plant communities but do not have free surface water.

Source: Davis et al. 2013

* GW = groundwater, SW = surface water

10.3.2 Refugia provided by different types of waterbodies

A typology of rangeland waterbodies has been developed to support the assignation of refugial status (Table 10.2). The typology used here (from Davis et al. 2013) extended the work of Fensham et al. (2011) who recognised four types of permanent waterbodies: riverine waterholes, rockholes, discharge springs and outcrop springs, in the eastern Lake Eyre Basin (LEB). Their typology was based on the major geomorphic attributes of these systems, which, being fixed or structural attributes of geology and landform, are much less variable than water quantity or quality. The typology developed for the eastern LEB was extended to include all types of waterbodies across the NRM Rangelands Cluster region.

Three types of perennial waterbodies, all groundwater-dependent ecosystems, have been identified as evolutionary refugia, based on the presence of endemic and relictual species, by Davis et al. (2013). These are subterranean aquifers, discharge (Great Artesian Basin mound) springs and relict streams. Some perennial riverine waterholes may also act as evolutionary refugia, but more phylogenetic information is needed to confirm their value as evolutionary refugia (Table 10.3).

Table 10.3 Timescales of evolutionary refugia inferred from phylogenetic studies

WATERBODY	TIME
Subterranean aquifers	Mid-Miocene, 3–11 mya
Mound springs, GAB	2.5–0.4 mya
Relict streams/ local springs	LGM*, 18,000 yrs
Riverine waterholes	Pleistocene, LGM to present (depending on taxon)

Source: Davis et al. 2013
*LGM = Last Glacial Maximum

Most perennial and near-perennial waterbodies, either groundwater or surface water–fed, are likely to act as ecological refuges. These systems provide 'reservoirs' to which species contract during dry periods and droughts and disperse from during wetter phases.

Refugia provided by different types of waterbodies are listed in Table 10.4.

Table 10.4 Summary of refugia provided by different types of waterbodies and suggested priority for protection of specific biota based on current information

NAME	TYPE OF REFUGIA	PRIORITY FOR PROTECTION BASED ON CURRENT INFORMATION
Subterranean aquifers	Evolutionary	**Very High** for protection of endemic species (stygofauna)
Discharge (mound) springs	Evolutionary and Ecological	**Very high** for protection of endemic species of plants, fishes and invertebrates
Outcrop springs	Ecological	**Medium**
Relict streams	Evolutionary and Ecological	**Very high** for protection of relict species of invertebrates
Riverine waterholes	Evolutionary and Ecological	**Very high** at perennial waterholes for protection of regionally endemic species (fishes and invertebrates)
Stream pools/ rockholes	Ecological	**Medium**
Isolated rockholes/ gnammas	Ecological	**Medium**; dry sediments act as refugia for egg and seed banks. Note: these waterbodies may have very high cultural significance
Temporary lakes, swamps and marshes	Ecological	**Very high** when wet for protection of waterbirds; dry sediments act as refugia for egg and seed banks

NAME	TYPE OF REFUGIA	PRIORITY FOR PROTECTION BASED ON CURRENT INFORMATION
Clay pans	Ecological	**Medium**; sediments act as refugia for egg and seed banks
Salt lakes/ saline playas	Ecological	**Very high** when wet for protection of waterbirds; dry sediments act as refugia for egg and seed banks
Soaks	Ecological	**Very high** to **Medium**, based on conservation significance of groundwater-dependent vegetation supported by sub-surface water

10.3.3 Stepping stones

Temporary and ephemeral aquatic habitats potentially play important roles as 'stepping stones' between perennial sites. They can also provide extra resources that enable populations to increase, reproduce and replenish egg and seed banks during wet phases (booms). However, with the exception of the research on the role of temporary wetlands as waterbird habitats by Roshier et al. (2001), the exact role of non-perennial systems as stepping stones or intermediate spatial refugia is not well understood. How extensive and how closely located systems must be to act as stepping stones are two questions that need to be answered to inform conservation planning. This is an important research gap that needs to be addressed in the near future. Despite this lack of knowledge, it is clear that protecting a dynamic (spatial and temporal) mosaic of perennial, temporary and ephemeral waterbodies across the rangelands is needed to support the persistence of aquatic and water-dependent species with varying life history traits and dispersal abilities.

10.3.4 Sediments as refugia

The importance of the sediments of non-perennial freshwater lakes, clay pans, salt lakes and rockholes as temporal refugia is well established (Brendonck & De Meester 2003). The seed and egg banks present in the sediments of these systems act as biotic reservoirs. Protecting the integrity of the sediments of non-perennial systems is clearly important. However, the spatial scales at which protection will be most useful still need to be determined.

10.3.5 Prioritising aquatic refugia for climate adaptation planning

Different types of waterbodies provide refugia for different components of the rangelands aquatic and, in some cases, terrestrial biota. Rather than prioritising refugia based only on their evolutionary and ecological value, which can be difficult to ascertain given the lack of information for many ecosystems in the NRM Rangelands Cluster region, a prioritisation has been developed that combines both biological knowledge and the level of confidence (high, medium and low) of this knowledge for one or more biotic groups (Table 10.5). Note that refugia currently listed as Conservation Priority 2 could move to Conservation Priority 1 as more information becomes available.

10.3.6 Distribution of aquatic refugia by NRM Rangelands Cluster sub-regions

The distribution of aquatic refugia varies considerably across the rangelands. A register listing the locations of aquatic refugia within the NRM Rangelands Cluster Sub-Regions is provided at Appendix A. The sites included in this register are based on current information and should be updated as more information becomes available over time.

Table 10.5 Conservation priority assigned to aquatic refugia based on the level of confidence of knowledge of the importance of the waterbody to specific biota

CONSERVATION PRIORITY 1 – HIGH CONFIDENCE
Evolutionary refugia (fishes, aquatic invertebrates and plants) (a) Subterranean aquifers *All calcrete aquifers in the mid-west of WA* *Palm Valley aquifer, NT* (b) Discharge (mound) springs *Mound springs in the GAB: SA, NT, NSW, Qld* (c) Relict streams *Groundwater-fed headwaters of rivers in the Central Ranges, NT* (d) Spring-fed streams *Spring-fed streams of the Pilbara-Hamersley Ranges WA (as identified by Pinder et al. 2010) – see Appendix A*
Ecological refugia (fishes and waterbirds) (d) Perennial waterholes *Riverine waterholes of the LEB with cease-to-flow depths > 4 m (as mapped by Silcock 2009)* *Riverine waterholes of the Pilbara-Hamersley Ranges WA (as identified by Pinder et al. 2010)*
Ecological refugia (waterbirds) (e) Large temporary lakes (freshwater and salt) in the LEB, including *Lake Eyre* and *Lake Torrens*, SA *Lake Gregory, Mandora Marshes, WA*
CONSERVATION PRIORITY 2 – MEDIUM TO LOW CONFIDENCE
Ecological refugia (waterbirds) (f) Non-perennial riverine waterholes in river networks in: *the LEB: NT, SA, Qld, NSW* *Pilbara-Hamersley Ranges, WA* *Flinders Ranges, SA*
Ecological refugia (aquatic invertebrates) (g) Sediments of freshwater lakes, salt lakes, claypans, rockholes and gnammas: continental distribution

10.3.7 Vulnerability assessments

The vulnerability of aquatic refugia to climate change falls between two extremes: those dependent primarily on rainfall for their water supply are highly vulnerable, and those dependent primarily on discharge from groundwater (either regional or local) systems are the least vulnerable, because of the great buffering capacity of groundwater systems to thermal and hydrological change. However, the situation is not as simple as this statement suggests. Climate change impacts, although important, are not the only impacts affecting rangelands aquatic refugia. Other stressors, including indirect climate impacts on water availability (groundwater drawdown and surface water impoundments) and the impacts of livestock, feral herbivores, invasive fishes, exotic plants, recreation and tourism must also be considered.

Although groundwater-fed evolutionary refugia are well buffered from a local decrease in rainfall, the endemic and relictual species they support are highly sensitive to changes in local conditions. The absence of water and habitat degradation will result in population declines, and, ultimately, extinction because populations cannot be 'rescued' by dispersal of individuals from other sites. In contrast, the species present in ecological refugia are well adapted to 'boom and bust' cycles. These species will persist where suitable habitats are available and dispersal pathways are maintained. They have dispersal mechanisms that facilitate metapopulation dynamics and gene flow over larger spatial scales. Maintaining connectivity by mitigating barriers to dispersal and alterations to the natural flow regime are important management strategies for obligate aquatic species such as fish.

A vulnerability assessment can help identify whether refugia are likely to be affected by direct and indirect climate impacts and other stressors and provides a framework for understanding why systems are likely to be vulnerable (Glick et al. 2011). Vulnerability is a function of exposure to climate change: the magnitude, intensity and duration of the changes experienced; the sensitivity of the species or community to these changes; and the capacity of the system to adapt (IPCC 2007, Williams et al. 2008). Vulnerability assessments can be an important part of the process supporting identification and prioritisation of climate adaptation strategies.

A recent Ramsar report (Gitay et al. 2011) provided a framework for assessing the vulnerability of wetlands to climate change. This framework can be used to assess the vulnerability of aquatic refugia in the rangelands. The processes that need to be followed are listed in Figure 10.1. These include a) establishing present status and recent trends; b) determining sensitivity and adaptive capacity to multiple pressures; c) developing responses; and d) the need for monitoring and adaptive management to ensure that desired outcomes are achieved. This type of approach emphasises the need for developing and implementing responses that will help reduce the vulnerability of refugia. One major qualifier, however, is that climate change is not the only driver of change that aquatic refugia are likely to experience or already experience.

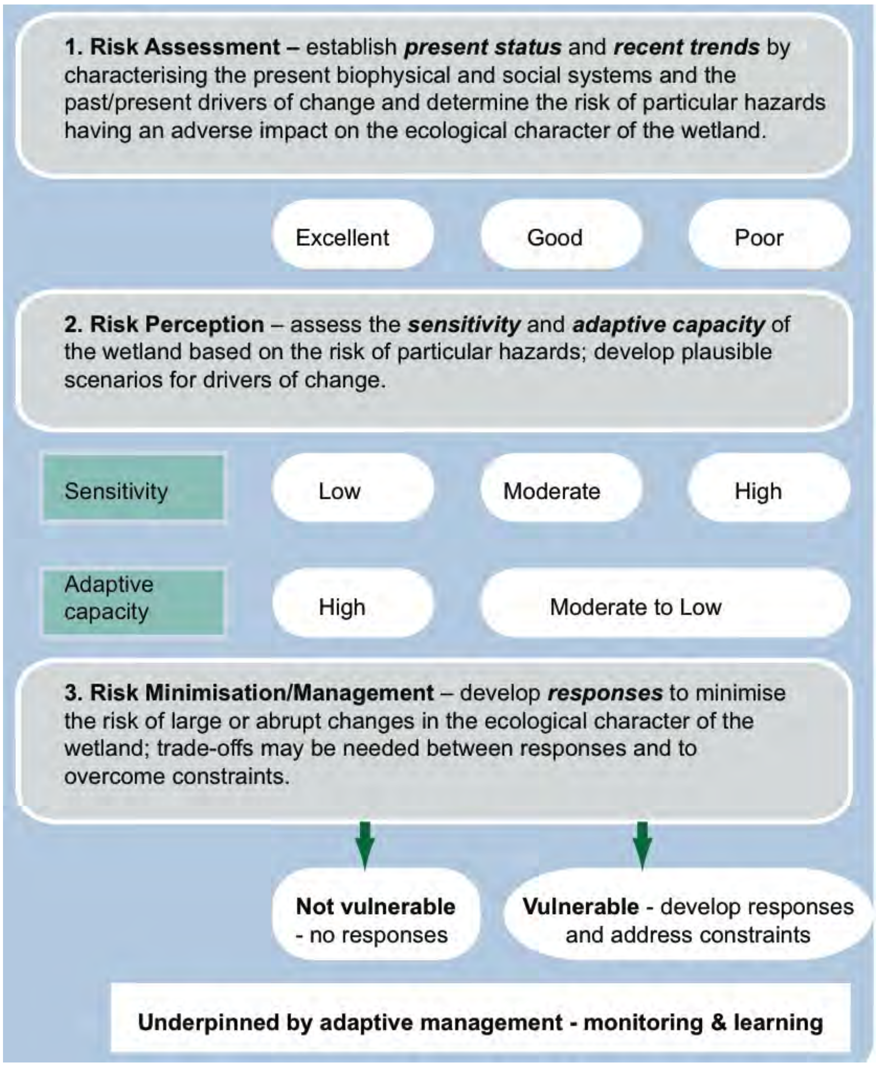

Figure 10.1 A vulnerability assessment framework for Ramsar wetlands that has application for aquatic refugia

Source: Gitay et al. (2011)

The application of this framework to aquatic refugia is demonstrated by the case study provided in the following box.

Vulnerability assessment: Dalhousie Springs

Description: Supergroup of ~80 active GAB springs, Witjira National Park, SA

1. Risk assessment

Present status

Springs are classified as evolutionary refugia because they contain short-range endemics. Biodiversity conservation value is very high. Springs are protected within a declared conservation area (Witjira National Park).

2. Risk perception

Sensitivity

Low to direct climate impacts because springs are groundwater-fed (GAB). **Very High** to indirect climate impacts (groundwater extraction) and other stressors (degradation of habitat and poor water quality due to impacts of livestock and feral herbivores, predation pressure from exotic fish, invasion by exotic plants).

Adaptive capacity

HIGH for habitat, LOW for endemic biota because although springs are buffered from direct climate impacts by groundwater, endemic spring biota have little capacity to recolonise if springs run dry.

3. Risk minimisation/management

Vulnerability

Direct climate impacts: **LOW**

Indirect climate impacts and other stressors: **VERY HIGH**

Risk minimisation / Adaptation strategy

Protect aquifer and monitor water levels in key springs. Fence or add alternative watering points to reduce impacts of livestock and feral herbivores. Restore degraded habitats. Assess new developments for potential impacts on springs and the aquifer supporting them.

10.3.8 Decision tree to support climate adaptation planning to protect aquatic refugia in the NRM Rangelands Cluster region

The following decision tree has been developed to provide guidance for adaptation planning for NRM Rangelands Cluster aquatic refugia.

1. Classify type of waterbody (use Table 10.2)

   ↓

2. Identify type of refugium provided by the waterbody and the suggested protection priority. This can be done by using Table 10.4 and Table 10.5 or from first principles based on information on the water source (groundwater or surface water), water regime (perennial or temporary) and the attributes of species (particularly dispersal traits) recorded at the waterbody.

   ↓

3. Undertake a vulnerability analysis (use Figure 10.1) to determine both direct and indirect impacts of climate change and other stressors (see case study for example).

   ↓

4. Develop an adaptation action plan based on risks and impacts identified by vulnerability analysis and conservation priority list.

   ↓

5. Assess new proposals (e.g. mining and energy extraction approvals, groundwater extraction, surface water impoundments and offtakes) to ensure that future vulnerability is minimised.

   ↓

6. Apply climate adaptation plan within an adaptive management program. Actions include monitoring water availability (continuous depth logging, where possible), monitoring habitat condition and persistence of key species, at regular intervals (annual) and with regular review (5 years). Implement restoration activities at degraded refugial sites.

10.4 Knowledge gaps

New waterbodies produced by rangelands industries – for example, dewatering by mines and watering points on pastoral stations – may potentially have some refugial values. However, they may also have negative effects on flora and fauna (James et al. 1999, Fensham & Fairfax 2008). The role that such waterbodies may play in off-setting the loss of ecological refugia through climatic drying needs to be determined. Further research is needed to ascertain the refugial value of artificial waterbodies in the context of a warming and drying climate.

10.5 Synthesis

Water scarcity, created by low and highly variable annual rainfall and high rates of evaporation and evapotranspiration, is a defining feature of the NRM Rangelands Cluster region. Given that water scarcity is predicted to continue under all climate change scenarios, the identification, management and restoration of aquatic refugia is a critical adaptation strategy for rangelands waterbodies and the biota they support.

Refugia are defined as habitats that biota retreat to, persist in and potentially expand from under changing environmental conditions. Two major types of refugial habitats are recognised: evolutionary refugia and ecological refugia. All aquatic evolutionary refugia in the NRM Rangelands Cluster regions are groundwater-dependent ecosystems. They are defined as waterbodies that contain short-range endemics (species that occur only within a very small area) or vicariant relicts (species with ancestral characteristics that have become geographically isolated over time). Evolutionary refugia are most likely to persist into the future because their source of water is independent of local rainfall. They should be given the highest priority in NRM adaptation planning.

Ecological refugia are defined according to the aquatic requirements of the species they protect. Obligate aquatic organisms (fishes and some aquatic invertebrates which can only disperse via water) need perennial habitats, or closely located near-perennial habitats, to ensure persistence. Important ecological refugia for waterbirds are the large temporary or ephemeral freshwater lakes and salt lakes that hold water after infrequent but large episodic rainfall events. The conservation significance of ecological refugia, and the priority assigned to their conservation, depends on the level of knowledge available for the species they support. Highly mobile species are less likely to be dependent on perennial systems than obligate aquatics.

The vulnerability of aquatic refugia to climate change is influenced by their source of water (groundwater or surface water). Those waterholes that depend primarily on rainfall (surface water) for their water supply are highly sensitive, and those that depend primarily on discharge from groundwater (either regional or local) systems are the least sensitive, because of the great buffering capacity of groundwater, both hydrologically and thermally. The climate adaption capacity of aquatic species in the Rangelands is influenced by their habitat requirements and their dispersal ability. Short-range endemics and relictual species have limited capacity to recolonise waterbodies that dry out and so these species are at the greatest risk of extinction, particularly from the indirect impacts of climate change.

It is important to recognise that the indirect effects of climate change, particularly an increase in the demand for water for direct consumption and production of food, fibre and energy, may have a greater negative impact on aquatic ecosystems than direct climatic effects. Excessive groundwater drawdown will destroy spring-based evolutionary refugia and the construction of surface water impoundments will destroy the aquatic connectivity essential for the persistence of riverine waterholes as ecological refugia. The existing impacts of livestock, feral herbivores, invasive fishes, exotic plants, recreation and tourism also need to be managed in the context of a changing climate.

This report provides some tools for NRM adaptation planning. These include a list of priority aquatic refugia (sites likely to act as future refugia) and a decision support tree to guide decision-making. Suggested actions include the identification of major types of waterbodies and the refugia they provide, vulnerability assessments and development of management responses to address both direct and indirect climate impacts. A site register of important rangelands aquatic refugia is provided at Appendix A. This is a 'living' register that needs to be updated as more information becomes available.

Appendix A List of permanent aquatic refugia (evolutionary and ecological) in the NRM Rangelands Cluster Region

In the accompanying zip file at http://www.nintione.com.au/resource/AustralianRangelandsAndClimateChange_AquaticRefugia_RegisterAquaticRefugia.zip, there are 15 lists of permanent aquatic refugia (evolutionary and ecological) in the NRM Rangelands, which have been compiled from the information on permanent waterbodies provided by Silcock (2009) for the eastern Lake Eyre Basin and Fensham et al. (2007) for the Great Artesian Basin mound springs. In addition, expert knowledge has been used to identify refugia in the WA Rangelands by Adrian Pinder (Department of Parks and Wildlife), for the SA Arid Lands (Lake Eyre South mound springs) by Dr Nick Murphy (Latrobe University) and for the NT Arid Lands sub-region by Professor Jenny Davis. These lists are not complete, and further refugia should be added as more information becomes available. No permanent waterbodies have yet been identified for the Alinytjara Wilurara region. Nor have sites been entered for the Tablelands sub-region of the NT.

The files included in the zip file are as follows:

- Desert Channels _Outcrop Springs Ecological Refugia.xlsx
- Desert Channels Coopers Ck Ecological Refugia.xlsx
- Desert Channels Diamantina Ecological Refugia.xlsx
- Desert Channels GAB Springs_Fensham et al.(2007).xlsx
- Desert Channels Georgina Ecological Refugia.xlsx
- Desert Channels LEB GABsprings_ Evolutionary Refugia (Silcock, 2009).xlsx
- Desert Channels Permanent_Rockholes_Ecological Refugia.xlsx
- NT Arid Lands Ecological Refugia.xlsx
- NT Arid Lands Evolutionary Refugia.xlsx
- SAAL GAB Mound Springs Evolutionary Refugia_Nick Murphy.xlsx
- SAAL GAB Mound Springs_Evolutionary Refugia_Fensham et al (2007).xlsx
- SW QLD GAB Springs Evolutionary Refugia.xlsx
- WA Rangelands Aquatic Refugia Coordinates.xlsx
- Western NRM.docx
- Western NRM.xlsx

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Australian rangelands and climate change – native species

Chris Pavey

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11. Australian rangelands and climate change – native species

Key points

- Macro-ecological modelling indicates that the impacts of climate change will vary across biological groups and, for a number of these groups, will be greater in some regions of the Rangelands Cluster.
- The three groups that will be most impacted by climate change are plants, snails and reptiles; impacts on mammals will be moderate, whereas impacts on birds and frogs will be low.
- Future climate refugia are modelled to occur in the MacDonnell and Central Ranges (NT Arid Lands sub-region, WA Rangelands and Alinytjara Wilurara regions), the Channel Country (Desert Channels and SA Arid Lands regions), Mount Isa Inlier (Desert Channels region), the Gibson Desert, the Pilbara (both WA Rangelands), the Nullarbor (WA Rangelands and Alinytjara Wilurara regions) and parts of inland Queensland and NSW (Western LLS and South West Queensland regions).

11.1 Introduction

Australia supports a unique and globally significant diversity of plants and animals. An important component of this diversity occurs within the Rangelands Cluster region. The interim results from the latest global climate modelling suggest likely changes in a range of climate variables within the region by 2090 (Watterson et al. 2015). These changes in climate are likely to have significant impacts on the native flora and fauna.

In response to these projected changes, this report is tasked to cover the three topics described below.

7. To provide ecological interpretation and synthesis of existing macro-ecological models projecting broadscale changes in distribution of major biological groups (plants, vertebrates).
8. To provide ecological interpretation of existing macro-ecological models projecting the locations of climate change refuges of major biological groups (plants, vertebrates).
9. To provide a planning synthesis focusing on adaptation options in the face of climate change.

11.2 Approach and methods

11.2.1 Summary of methods

The approach used in this report has involved the following steps. First, published reports summarising macro-ecological modelling projects were obtained and interpreted with respect to the Rangelands Cluster region. These reports have been interpreted within the framework of the latest global climate modelling, which predicts changes in a range of climate variables within the region by 2090 (Watterson et al. 2015). A summary of the key changes predicted for the region is given in Table 11.1.

The next step was to examine existing macro-ecological models projecting the locations of climate change refuges of major biological groups (plants, vertebrates). This modelling is currently available at a national scale. The opportunity to 'downscale' the national-scale assessments to spatial scales appropriate for NRM regions and sub-regions was investigated. This task involved discussions with the team undertaking Project 5 (Scaling Biodiversity Data) of the Monsoon Cluster (J. VanDerWal, D. Burrows, A. Reside, all James Cook University).

All land tenures are considered in these assessments.

Table 11.1 Summary of the predicted changes in a range of climate variables within the Rangelands Cluster region by 2090

CLIMATE VARIABLE	PROJECTED CHANGE
Temperature	**Increase in all seasons**
Extreme temperatures	**Increase in hot days**, decrease in cold days
Rainfall variability	**Remain high**
Extreme rainfall events	**Increase in intensity and frequency**
Winter and spring rainfall	A decrease more likely than an increase
Summer and autumn rainfall	Trend is unclear
Potential evapotranspiration	**Increase in all seasons**, most strongly in summer

Source: Watterson et al. (2015).
Bold indicates the changes of most importance when considering impacts on native species

11.2.2 Explanation of the two main modelling approaches

The available macro-ecological modelling examined as part of this work used two discrete analysis methods. These methods are described briefly below in the context of assessing species responses to a changing climate.

1. **Species Distribution Modelling**. The most widely used method is Species Distribution Modelling (SDM). This is a species-specific approach whereby observational records are used to model the current potential distribution of a species. Under this method, current climate is defined as the average for a period centred on a particular year (e.g. the 30-year average centred on 1990, thus covering 1976 to 2005). The data are then used to project into the future to reveal the distribution expected using future climate data. The projection focuses on a particular year (such as 2030, 2070 or 2085), and the projections of future climate are based on a combination of global circulation models (GCMs) and representative concentration pathways (RCPs). The models produce a simultaneous measure of climate suitability for the species that ranges from 0 to 1 (1 being the most suitable).
2. **Generalised Dissimilarity Modelling**. A second, less commonly used method is Generalised Dissimilarity Modelling (GDM). This method is based on compositional turnover of a group of species at a location. It is performed reasonably differently from SDM and considers whole biological groups rather than individual species. It has been argued that this approach is more useful where the whole ecosystem is the target of planning and management rather than individual species.

11.3 Data sources and availability of data

The major sources of data for this report have been key reports that have been completed since 2012. Additional modelling has also been provided directly by James Cook University.

The key reports are as follows:

- A recent study looking at the location of refugia for terrestrial biodiversity in the event of climate change at a national scale (Reside et al. 2013).
- An analysis of the impacts of climate change for conservation of biodiversity within Australia's National Reserve System (Dunlop et al. 2012).
- Within the Dunlop et al. (2012) project, an analysis that specifically looked at the hummock grasslands biome of arid and semi-arid Australia and assessed the impacts of a changing climate on plants, vertebrates and snails (Smyth et al. 2012).
- A recent analysis that examined the sensitivity and exposure of each taxon of Australian birds to climate change, modelled future climate space and developed adaptation options (Garnett et al. 2013; Garnett & Franklin 2014).

11.4 Broadscale changes in distribution of major biological groups

The impacts of climate change on major biological groups across the Rangelands Cluster region have been assessed in a number of national-scale macro-ecological modelling projects. These projects are summarised in the section above, and full citations (including web-links) to the reports from the projects are provided in the references.

The macro-ecological modelling study that is most relevant to the Rangelands Cluster region is one published in 2012 (Smyth et al. 2012), which assessed the impacts of climate change on fauna and flora within the hummock grasslands biome. The distribution of this biome overlaps broadly with that of the Rangelands Cluster region (Smyth et al. 2012). Other reports in the same series that were assessed covered a) the tropical savanna woodlands and grasslands biome (Liedloff et al. 2012), which is relevant to the NT tablelands sub-region and the eastern edges of the Desert Channels and South West Queensland regions, and b) the temperate grasslands and grassy woodlands biome (Prober et al. 2012), which is relevant to the south-eastern edge of the Western LLS region (see Figure 11.1).

Each of these studies used the GDM approach to assess impacts of climate change for four time-emissions scenarios: 2030 Medium, 2030 High, 2070 Medium and 2070 High. The analyses examined six groups of native species: plants, snails, frogs, reptiles, birds and mammals.

The modelling shows clearly that the impacts of climate change will a) vary across biological groups, and b) for a number of these groups, will be greater in some regions (Table 11.2). The three groups that will be most impacted by climate change are plants, snails and reptiles. The changes in composition will be moderate by 2030 (under both medium and high emissions scenarios) and then high for reptiles and very high for plants and snails by 2070 (Figure 11.2). These impacts will occur broadly across the Rangelands Cluster region.

Another group that will be impacted by climate change within the region is the mammals. The modelled compositional change in mammals will not be as dramatic as for plants, snails and reptiles. However, moderate compositional change will be experienced under the 2070 high emissions scenario in the NT arid lands and NT tablelands sub-regions and in the Desert Channels and South West Queensland regions.

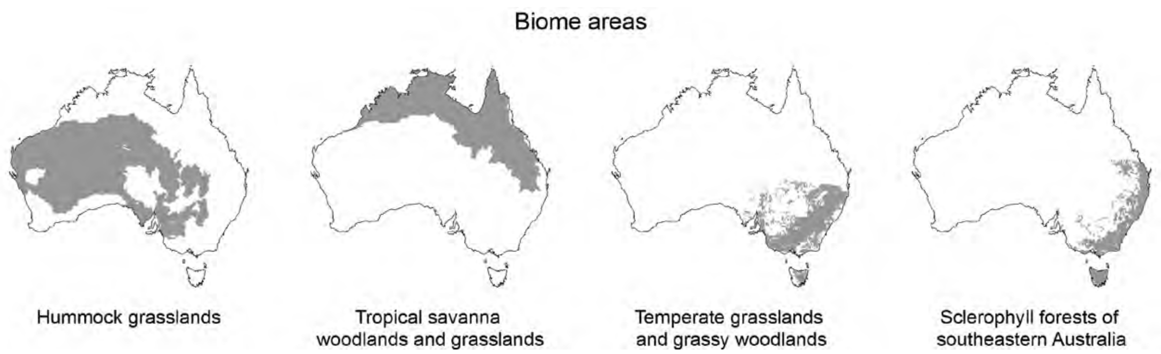

Figure 11.1 The four biomes covered in the macro-ecological modelling project of Dunlop et al. (2012). The first three are relevant to the Rangelands Cluster region.

The projected low impact of climate change on birds within the Rangelands Cluster region (Table 11.2) is corroborated by another study that used Species Distribution Modelling (SDM). This study produced a climate change adaptation plan for Australian birds (Garnett et al. 2013; Garnett and Franklin 2014). The project assessed all 1,232 taxa (i.e. species and sub-species) of Australian birds and concluded that 59 taxa were both highly sensitive and highly exposed to climate change. Of these 59 species only eight species occurred within the Rangelands Cluster region. Of the eight species, climate suitability by 2085 was expected to decline for five taxa (red-tailed black-cockatoo, *Calyptorhynchus banksii*; Western bowerbird, *Ptilonorhynchus guttatus*; short-tailed grasswren, *Amytornis merrotsyi*; slender-billed thornbill, *Acanthiza iredalei*; and Western whipbird, *Psophodes nigrogularis*), to increase for two taxa, and remain stable for the remaining taxon.

The similar prediction of Australian birds' response to climate change produced by the two studies gives confidence in the results. This is especially the case because one study used the GDM modelling approach (Smyth et al. 2012) and the other the SDM modelling approach (Garnett and Franklin 2014).

Table 11.2 A summary of projected compositional change using GDM modelling of six major biological groups within the Rangelands Cluster region at two time periods (2030 and 2070) and two emissions scenarios (medium and high).

BIOLOGICAL GROUP	2030 MEDIUM	2030 HIGH	2070 MEDIUM	2070 HIGH	REGIONS MOST IMPACTED
Plants	moderate	moderate	high	very high	All regions and sub-regions
Snails	moderate	moderate	high	very high	All regions and sub-regions
Frogs	low	low	low	low to moderate	NT arid lands and NT tablelands sub-regions, WA rangelands
Reptiles	moderate	moderate	high	high	All regions and sub-regions
Birds	low	low	low	low	None
Mammals	low	low	low	moderate	NT arid lands and NT tablelands sub-regions, Desert Channels, South West Queensland

'Low' indicates a GDM dissimilarity score of 0 to 0.3 across the majority of the Rangelands Cluster region. 'Moderate' indicates a GDM dissimilarity score of 0.4 to 0.6. 'High' indicates a GDM dissimilarity score of 0.7 and 0.8 whereas 'very high' represents scores of 0.9 and 1.0. The closer the GDM dissimilarity score is to 1.0 the greater the change in composition of that group in response to climate change.

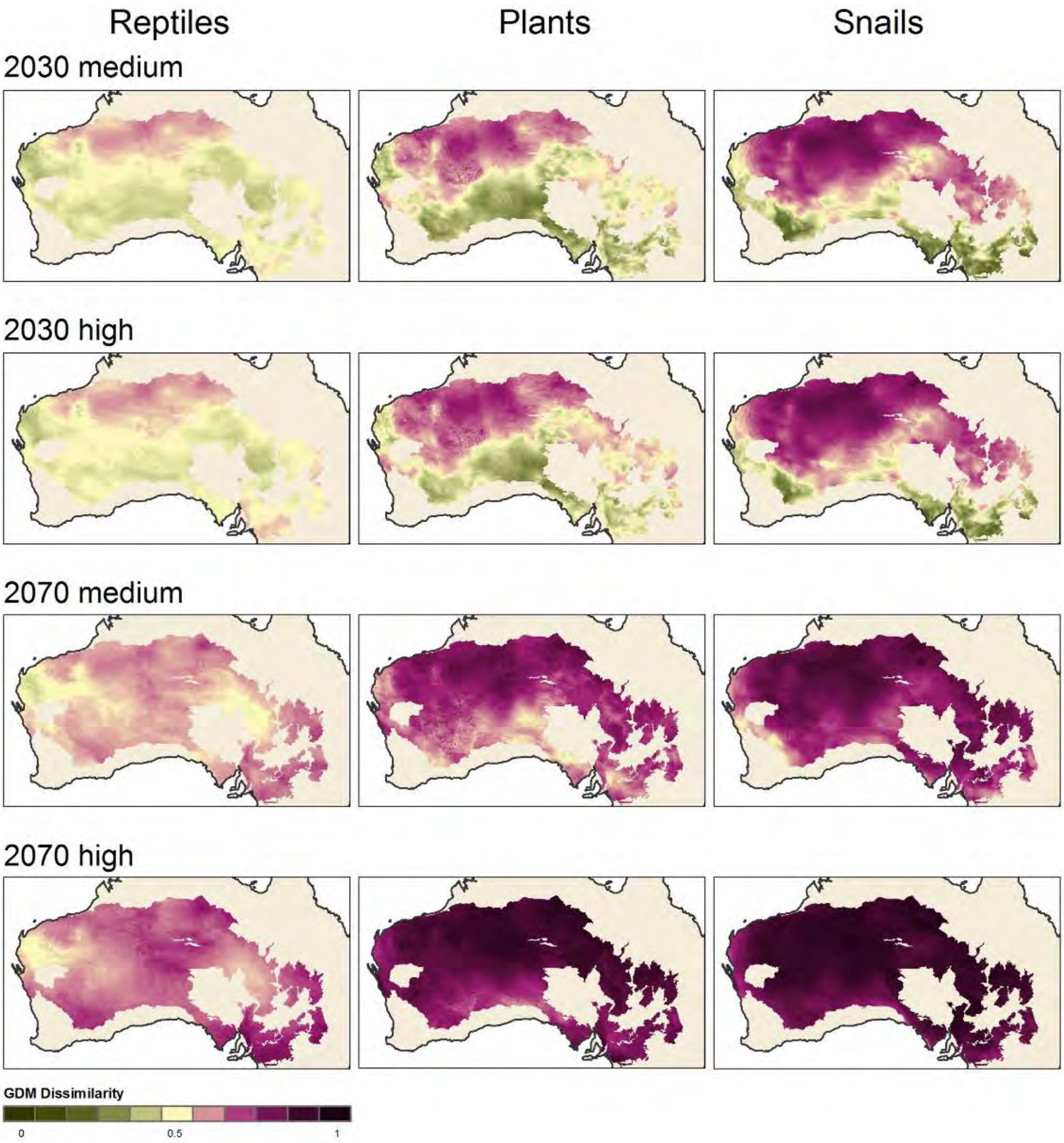

Figure 11.2 Projected compositional changes from GDM modelling under four time-emissions scenarios for plants, snails and reptiles within the hummock grassland biome.

Green represents low levels of compositional change; dark purple represents very high levels.

11.5 Location of climate change refuges

11.5.1 Summary of national scale modelling projects

The impetus for identifying climate change refugia is that these are the parts of the landscape where species can retreat to and persist in the future. Thus by focusing management on these key sites it should be feasible to minimise species loss.

A recently completed study examined the location of refugia for terrestrial biodiversity in the event of climate change at a national scale (Reside et al. 2013). This type of analysis is new and the study should be seen as the start of attempts to identify refugia at a broad scale. This study used both GDM and SDM modelling approaches to identify climate change refugia.

Few locations within the Rangelands Cluster region were identified as refugia using both approaches (Figure 11.3). Rather, concentrations of refugia were found in coastal areas around Australia and were particularly prevalent along the east coast. Both approaches identified most of Tasmania to contain refugia (Reside et al. 2013).

The GDM approach identified more refugia locations within the Rangelands Cluster area (Figure 11.3). Concentrations were apparent in the Channel Country (Desert Channels and SA Arid Lands regions), Mount Isa Inlier (Desert Channels region), the Gibson Desert and the Pilbara (both WA Rangelands). In contrast, the SDM approach found concentrations along the Nullarbor (WA Rangelands and Alinytjara Wilurara regions), and parts of inland Queensland and NSW (Western LLS and South West Queensland regions). Both approaches indicated the importance of the MacDonnell and Central Ranges (NT Arid Lands sub-region, WA Rangelands and Alinytjara Wilurara regions) as sites of future climate refugia.

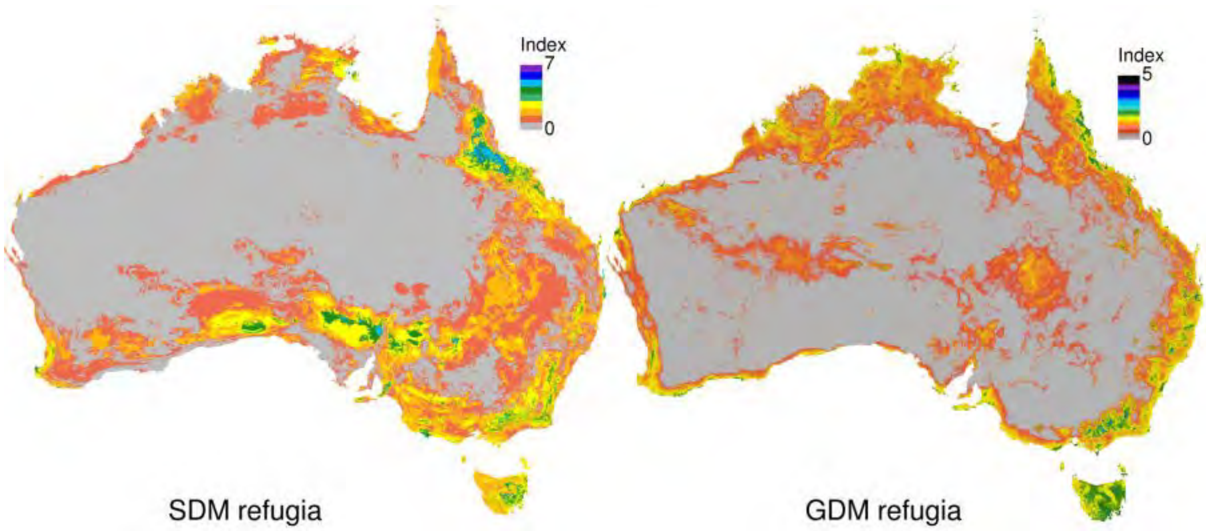

Figure 11.3 Suitability of sites as climate change refugia based on SDM and GDM modelling approaches.

Higher index values represent higher suitability. Note that the scales between the two maps differ.

Source: This figure is a reproduction of Figure 66 of Reside et al. (2013).

11.6 Adaptation principles and strategies

11.6.1 Planning under uncertainty

Climate change adaptation strategies are management actions that are developed to deal with the consequences of climate change (Smithers and Smit 1997). Planning under climate change is a difficult and challenging task. Among the challenges is the lack of precise information on the future directions for climate change and the subsequent high levels of uncertainty. For example, projections for changes in rainfall in arid Australia variously suggest an increase or possibly a decrease. To some extent this uncertainty has been reduced through the detailed analysis undertaken and presented in Watterson et al. (2015). However, uncertainty remains.

There are a number of important design considerations for adaptation under uncertainty (Hallegatte 2009; Addison 2013). These are framed around reducing vulnerability to current and future threats, as well as to future exposure to climatic change. These strategies are covered in detail below.

1. 'No-regret' strategies are an important group of strategies for dealing with uncertainty because they yield benefits even if there is not a change in climate. An example of a no-regret strategy to be used in the conservation of native species is to include a large area of natural habitat within the national reserve system that currently both supports a high diversity of species and in the future has been identified as a climate refuge. Such an approach will have benefits for fauna and flora conservation regardless of whether or not the climate changes.
2. Reversible strategies are flexible and can be changed if predictions about climate change are incorrect. Such strategies minimise the cost of being wrong about future climate change. Reversible strategies should be favoured over irreversible choices, all other factors being equal. An example of this strategy is to manage a large area of natural habitat for a threatened species and to provide a buffer around this within which disturbance is not allowed. There may be a cost of setting aside the buffer area but if in the future the buffer is shown to be not needed then the decision to ban disturbance can be instantly reversed.
3. Safety margin strategies are those that reduce vulnerability at little or no cost. For example, the area of impact of climate change can be estimated to be 50% greater than available models indicate. Conserving this additional area will account for any unexpected negative change in the estimated impacted area.
4. Soft strategies are those that involve the use of institutional, educational or financial tools to reduce species vulnerability to climatic change. An example in wildlife conservation is to educate homeowners about the biodiversity impacts associated with keeping cats within a peri-urban area or to introduce new lease conditions to prevent new water points from being established on pastoral leases that may be within identified climate refugia.
5. Strategies that reduce time horizons are an option for dealing with the uncertainty in predicting future climate conditions. This approach reduces the lifetime of particular investments. For example, win-win and no-regrets strategies may be appropriate when uncertainty levels about future climate change scenarios are high, but high cost, high risk strategies such as assisted colonisation may only be appropriate if they are attempted as a last resort once future climatic conditions are more certain.

11.6.2 Adaptation options

Providing advice in terms of adaptation options in a generic sense is difficult to do and potentially misleading. There is a wide range of adaptation options available (Table 11.3). One type of management is to maintain and enhance habitat of native species. This approach can be achieved by expanding the protected area network and/or incentivising conservation management outside of the protected area network, maintaining and improving habitat quality, identifying and protecting refugia, maintaining and extending landscape connectivity and creating new habitats.

A second type of management is more intensive and involves facilitating the responses of wild populations. Available options to achieve this type of management include assisted colonisation to new areas using translocation, enhancing the genetics of populations and enhancing the population growth rate while managing threatening processes (e.g. by predator control).

The most intensive and expensive type of management involves ex-situ conservation, where the focus in on preserving populations. Options here include captive breeding and storage of germplasm.

A final group of management approaches are those that focus on understanding on what is happening to animal and plant populations and using this information to predict what may happen. Perhaps the most widely used approach here is to monitor populations and their threats. Other options include investigating the ecology of species and assemblages of interest, modelling of habitat and climate suitability and modelling management options.

Table 11.3 Potential adaptation strategies for native plants and animals in response to climate change.

APPROACH	SPECIFIC ACTIONS
In-situ management	Expand the protected area network
	Maintain and improve habitat quality
	Identify, protect and expand refugia
	Maintain and extend ecological connectivity
	Create new habitats
Facilitate responses of wild populations	Assisted colonisation
	Enhance genetics
	Enhance population growth rate
Ex-situ management	Captive breeding
	Store germplasm
Monitoring and research	Monitor populations
	Monitor habitats and threatening processes
	Study ecology of species and assemblages
	Model habitat and climate envelopes
	Model management options

Source: The structure and content are based on Garnett et al. (2013)

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Australian rangelands and climate change – invasive animals

Chris Pavey
Gary Bastin

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12. Australian rangelands and climate change – invasive animals

Key points

- Ten species of significant vertebrate pest in the Rangelands Cluster region are considered in this report.
- Predicted changes in abundance and distribution with climate change indicate a decrease in the abundance and/or distribution of five species within the region (cat, goat, pig, rabbit and cane toad) with a further three species predicted to have stable abundance and distribution (camel, horse, donkey).
- Only two species, red fox and dingo, may show increased abundance and/or distribution in response to climate change.
- Management recommendations are made for each species taking into account changes in distribution and abundance with climate change.

12.1 Introduction

High levels of uncertainty make it difficult to predict how climate change and biological invasions will affect ecosystems, as these changes are likely to have interacting effects that compound the uncertainty associated with each driver of change (Hellman et al. 2008; Tylianakis et al. 2008). Indeed, the very definition of invasiveness may change as previously defined invasive animals may become less invasive, previously non-invasive species may become more invasive and native species will become invasive-like as they shift their geographic distribution (Hellman et al. 2008). Species invasiveness can refer, variously, to a species that causes environmental or socioeconomic impacts, is non-native to an ecosystem or rapidly colonises and spreads (see Ricciardi and Cohen 2007). Here, we use the term to refer to non-native species (that is, those introduced to Australia post-1788) that have caused significant environmental or agricultural changes to the ecosystem or that are believed to present such a risk.

The aim of this report is to provide the highest quality climate change adaptation information on feral animal distribution and control.

12.2 Approach and methods

12.2.1 Approach

A wide range and significant number of non-native animal species have been introduced and become established in the rangelands of Australia. Some groups of species either have limited impacts or, if impacts are high, occur within a small part of the Rangelands Cluster region. Among this group is the European honeybee (*Apis mellifera*), which has been present in Australia for about 190 years. The species is used for honey production and is of major economic value in Australia. However, it also has negative impacts on the environment although the full extent of impacts is poorly known (Paton 1996; Carr 2011). Foremost among the negative impacts is the ability to displace endemic wildlife from tree hollows along river channels in arid and semi-arid Australia. For instance, an estimate of 77.1 colonies/km^2 was made in riparian woodland in Wyperfeld National Park, north-west Victoria (Oldroyd et al. 1994). The common carp (*Cyprinus carpio*) is a significant freshwater pest in the Murray–Darling Basin and other rivers of NSW (West 2008); however, it occupies only a small area along the eastern edge of the cluster region. Other species in this group include the common starling (*Sturnus vulgaris*).

Another group of non-native species are those that have either no documented evidence of impact or those which are such recent migrants to Australia that the impact(s), if any, on the environment are unclear. A range of bird species, including the spotted turtledove (*Streptopelia chinensis*), are in the first category. The Asian honeybee (*Apis cerana*) is an example of a new species. It was detected in Australia for the first time in 1998 and has the potential to move in to the north-east edge of the Desert Channels region (Carr 2011).

The most invasive animals are large herbivores, mammalian carnivores and the cane toad. These species, with the possible exception of the cane toad, are having the most impact and are of greatest management concern within the Rangelands Cluster region. Each species occupies a significant area of inland Australia. We therefore selected ten of these species to be the focus of this report. Here, we briefly describe the known recent history for the ten selected invasive animals in the Rangelands Cluster. We then comment on their likely future distribution and abundance with predicted climate change.

12.2.2 Summary of methods

Despite our choice of the most significant invasive species for consideration in this report, much is unknown about their current impacts and ecology. Even less is known about the future impacts that climate change may have on their distribution, density and ecology. To inform the report, current information on distribution, abundance and, where available, density was sourced from the references listed below.

- Annual aerial surveys of feral goats (*Capra hircus*) as part of the regular count of macropod numbers in Western Australia, South Australia, New South Wales and Queensland. These data were collated and analysed for ACRIS by Biosecurity Queensland in 2011 (Pople and Froese 2012).
- The recently completed Australian Feral Camel Management Project (AFCMP) (Ninti One Limited 2013) and the preceding foundational work on feral camel populations and their impact by the Desert Knowledge CRC (Edwards et al. 2008).
- A 2008 report on indicators of the extent and impact of ten invasive animal species for Australia compiled by the National Land & Water Resources Audit and the Invasive Animals CRC (West 2008).
- Information in the scientific literature (e.g. Caley et al. 2011).
- Unpublished modelling carried out by the Spatial Ecology group of Dr Jeremy Vanderwal within the Centre for Tropical Biodiversity and Climate Change at James Cook University. This work involves species distribution modelling (SDM) carried out using the program MAXENT. Further details are at http://www.jjvanderwal.com/home. In some cases using this modelling approach, the predicted and actual distributions of a species differ. Examples of this situation in the current report are the red fox (Figure 12.4 and Figure 12.5) and cane toad (Figure 12.9 and Figure 12.10).

In line with the conceptual model for assessing risk posed by invasive species under climate change proposed by Sutherst (2000), gaps in the published and grey literature were bridged through using our knowledge of species physiology, habitat requirements and trophic interactions. While we make every effort to justify our extrapolations, we acknowledge that there are extremely high levels of uncertainty associated with some of these assessments.

12.2.3 Distribution and abundance

In the absence of quantitative density data (number per km^2) for many species, the West (2008) report used distribution to describe the spatial pattern of an invasive species throughout an area (i.e. localised or widespread) and abundance to report relative density within a defined area (i.e. occasional, common or abundant). Data were collated from Rangelands Cluster state and territory government agencies and relevant non-government organisations. Where feasible, state and territory information was either updated or collected to facilitate accurate reporting.

12.3 Problem invasive animals in the Rangelands Cluster

12.3.1 Feral goat

Introduction

Key points, for NRM regions in the Rangelands Cluster, from the Biosecurity Queensland analysis of feral goat data are:

1. Aerial surveys for kangaroo management in the rangelands have also provided estimates of the density of feral goats.
2. Feral goats are present throughout most of the Western (NSW) and South West NRM (Queensland) regions (Figure 12.1). They also occur in the eastern part of the Desert Channels (Queensland), predominantly sheep-grazed SA Arid Lands and the Gascoyne-Murchison pastoral region of Rangelands WA (also extending into the Goldfields region). Mean goat density since the 1980s has been highest in the Western region of NSW.
3. The estimated feral goat population in Australia grew from 1.4 million in 1997 to 4.1 million in 2008. In 2010, there were an estimated 3.3 million feral goats in the Australian rangelands.
4. Over time, an increasing proportion of the feral goat population occurs in NSW, comprising 70% in 2010 (Figure 12.2). In 2011, there were an estimated 2.95 million feral goats in NSW.
5. A caveat to this summarised reporting is that observers cannot readily distinguish truly feral goats from domestic or managed goats during aerial

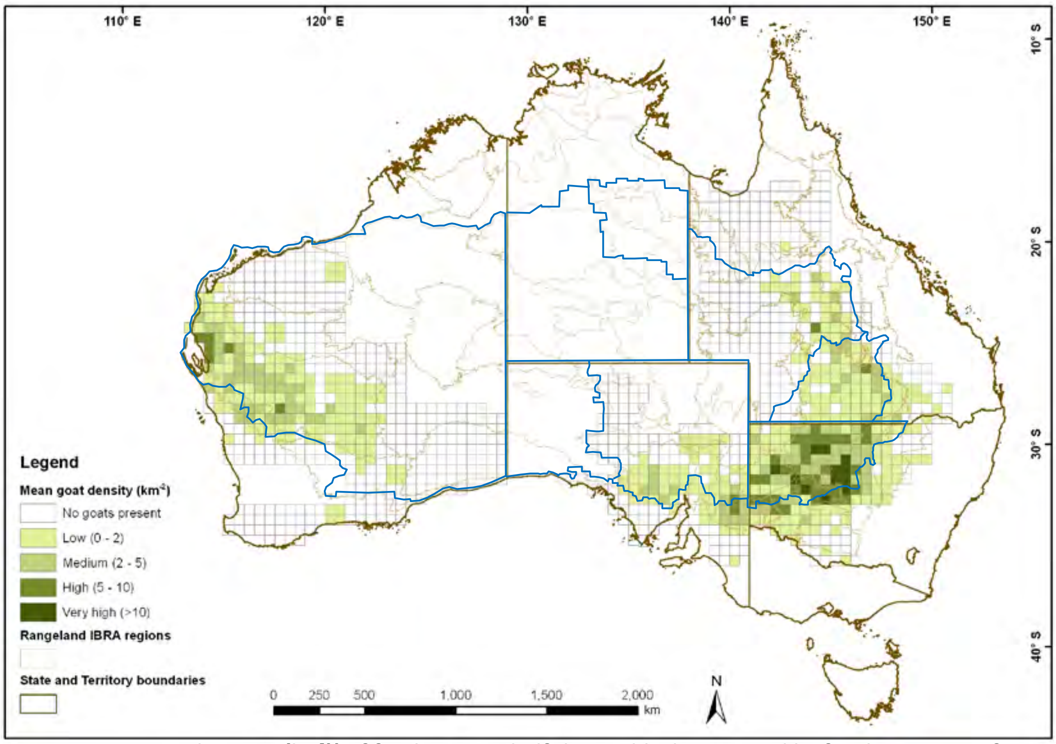

Figure 12.1 Average densities (km^{-2}) of feral goats in half-degree blocks surveyed by fixed-wing aircraft across Queensland (1984–92, 2001), NSW (1993–2011), SA (1989–2011) and WA (1987–2011).

Rangeland bioregions (brown lines) and Rangelands Cluster NRM regions (blue lines) are also shown.

Source: Figure adapted from Figure 7 in Pople and Froese (2012).

surveys. This problem is growing as numbers of domestic goats and the practice of mustering feral goats into fenced paddocks increases (goats were not counted in Queensland in 2011 because of the perceived difficulty by observers in identifying feral goats).

6. Data obtained by Biosecurity Queensland from the Australian Bureau of Statistics (ABS) surveys indicate that the proportion of domestic relative to feral goats is low, suggesting the problem of misidentification is small. However, the ABS data need validation. Surveys of abattoir operators suggest much larger numbers of domestic goats than that recorded by the ABS.

Feral goats and climate change

Predicting the response of feral goats to climate change is difficult because their populations will be influenced by other factors occurring as the climate changes. These changes will include the level of control efforts for unmanaged goats. Feral goats have been controlled at various scales within the rangelands through dedicated commitment and varying levels of support funding. Examples of this include Operation Bounceback in South Australia and total grazing pressure (TGP) fencing. Further, there is evidence that restructuring of pastoral activities in the rangelands, and particularly an increase in wild dogs / dingoes, may suppress goat populations in the future. With these factors in mind, a decrease in the distribution and density of feral goats in the rangelands of NSW by 2050 is predicted by Caley et al. (2011).

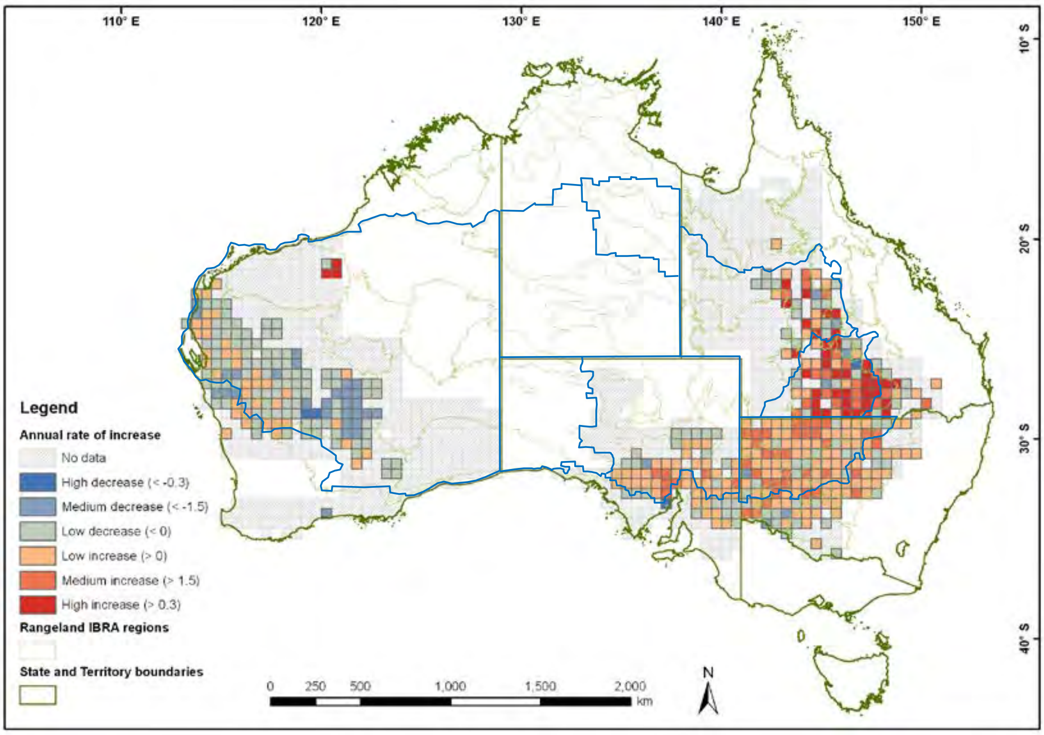

Figure 12.2 Annual exponential rate of increase of feral goats in half-degree blocks surveyed by fixed-wing aircraft across Queensland (1984–92, 2001), NSW (1993–2011), SA (1989–2011) and WA (1987–2011).

Rangeland bioregions (green lines) and Rangelands Cluster NRM regions (blue lines) are also shown.

Source: Figure adapted from Figure 10 in Pople and Froese (2012).

12.3.2 Feral one-humped camel

Introduction

The population of the feral one-humped camel (*Camelus dromedarius*) in Australia was estimated at 1 million in 2008, distributed over an area of 3.3 million km^2 (Figure 12.3, top panel) (Edwards et al. 2008) (Table 12.1). Based on available data for the NT, it was estimated that the population could double every nine years. A number of caveats applied to the population estimate. In particular, the population size

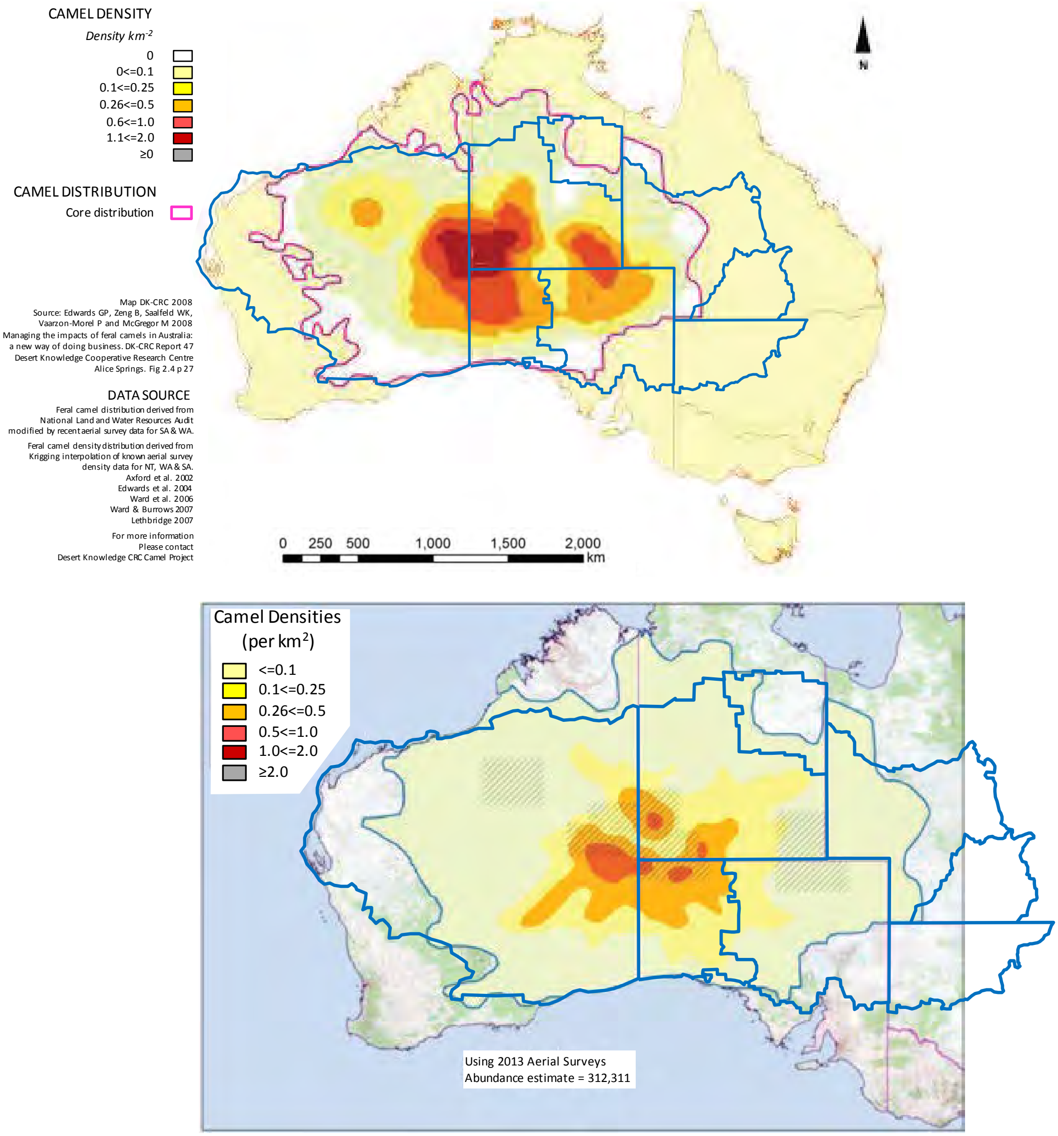

Figure 12.3 Estimated feral camel densities before (top) and at the end (bottom) of the Australian Feral Camel Management Project.

Blue lines show NRM regions in the Rangelands Cluster.

Source: Maps adapted from (top) Edwards et al. (2008, Figure 2.4, p. 27) and (bottom) Ninti One Limited (2013, Figure 28, p. 60).

estimate was based on a limited survey area and surveys were conducted in different areas in different years.

Edwards et al. (2008) reported that remodelling of the data used in the 2008 report provided 'a better estimate of the feral camel density outside of survey areas and ... a revised total population figure of around 600,000 in 2008'. The Australian Feral Camel Management Project (AFCMP) removed approximately 160,000 feral camels to reduce the population to an estimated 312,000 feral camels in 2013 (Figure 12.3, bottom map).

For the immediate future, Ninti One Limited (2013) advises that:

- The AFCMP density targets have been met completely in 13 of the 17 buffer zones around environmental assets (see Figure 29, p. 60, in Ninti One Limited 2013) and have largely been met in the other four buffer zones, with some sections of these four zones having densities above the targets.
- In particular, there is now a real opportunity to maintain very low densities of feral camels in the Pilbara and Simpson regions.
- Although densities in the Surveyor Generals Corner region have been reduced, they are still generally above the broad long-term target of 0.1/km^2. Within this region, there are two large areas (Anangu Pitjantjatjara Yankunytjatjara and Ngaanyatjarra lands) where the landholders have expressed a strong preference for commercial use. It is hoped that strengthened capacity for commercial use will allow a level of removal that drives the density down rather than just being a sustainable offtake.
- Aerial culling in the non-commercial use zones of Surveyor Generals Corner has undoubtedly helped reduce the overall density of feral camels in this region over the life of the project, given the mobility of feral camels between commercial and non-commercial zones.

Feral camels and climate change

- Without continued systematic control of their numbers, feral camel numbers will again increase in the deserts and marginal/remote pastoral lands of the Rangelands Cluster.
- The AFCMP has demonstrated that planned, coordinated, collaborative control can reduce camel densities over relatively large areas. Aerial culling (shooting to waste) has to be an integral part of the control program. It is highly desirable that human capacity and skill levels required to efficiently mount and run removal operations in remote locations are maintained/enhanced.
- Further control (whether through a downscaled AFCMP or some alternative program) must transcend tenure and jurisdictional boundaries.
- Camels are adapted to the desert (thus heat tolerant) and highly mobile. Their general distribution and relative abundance is unlikely to be adversely affected by higher temperatures, continuing (or enhanced) rainfall variability and possibly more frequent and intense droughts.

Table 12.1 Estimated 2008 feral camel population abundance and density by land-tenure type

TENURE CLASSIFICATION	AREA (KM^2)	POPULATION (%)	DENSITY (ANIMALS/KM^2)
Aboriginal	783,000	415,000 (43%)	0.53
Pastoral	1,399,000	210,000 (22%)	0.15
Vacant Crown Land	813,000	236,000 (25%)	0.29
Conservation / Other	335,000	94,000 (10%)	0.28
Total	3,330,000	955,000 (100%)	0.29

Source: reproduced from Table 2.5 (p. 28) in Edwards et al. 2008)

12.3.3 Feral horse/brumby

Introduction

The horse (*Equus caballus*) arrived in Australia in 1788 as part of the First Fleet. Because much of the country was grazed without fences, escapes were common and invasive populations formed rapidly. Currently, feral populations are estimated to contain about 400,000 individuals (Australian Government 2011a). Densities can be high in some areas. For example, the Victoria River District of Northern Territory (Monsoon Cluster region) was estimated to have a density of 0.33 km^{-1} in 2006 (Saalfeld et al. 2006). A significant proportion of Australia's feral horse population is within the Rangelands Cluster region.

Feral horses can be a serious environmental issue. This impact results from erosion and damage to vegetation and, potentially, movement of weeds. The only significant natural threats are likely to be drought and severe bushfire. The Brucellosis and Tuberculosis Eradication Campaign (BTEC) led to successful control over relatively large areas in some pastoral districts (e.g. southern NT and northern SA). This process involved the shooting of wild horses as a by-catch to removal of feral/unmusterable cattle. The Northern Territory Government's declaration of a 'Pest Control Area' over the Victoria River District (Monsoon Cluster region) in 2006 with the issue of control notices to properties with required off-take targets for horses is another model for broadscale control (Saalfeld 2005; Saalfeld et al. 2006).

Feral horses/brumbies and climate change

Feral horses are likely to be minimally affected by climate change and are likely to be an ongoing or recurring problem in remote and difficult-to-manage country within the Rangelands Cluster.

12.3.4 Feral donkey

Introduction

The donkey (*Equus asinus*) was brought to Australia as early as 1866 for use as a form of transport. Anecdotal information suggests that invasive populations were present by the 1920s (Choquenot 2008). Currently, the national population is estimated to be in the millions (Australian Government 2011a). Densities can be high in some areas. For example, the Victoria River District of the Northern Territory (Monsoon Cluster region) was estimated to have a density of 0.41 km^{-1} in 2006 (Saalfeld et al. 2006). A significant proportion of the Australian donkey population is within the Rangelands Cluster region.

Feral donkeys are similar to horses in potentially being a serious environmental issue. This impact results from erosion and damage to vegetation and, potentially, movement of weeds. The only significant natural threats are likely to be drought and severe bushfire. Donkeys appear to be more tolerant to drought than horses.

Feral donkey and climate change

Donkeys are likely to be minimally affected by climate change and, similar with horses, will be an ongoing or recurring problem in difficult-to-manage country.

12.3.5 Feral pig

Introduction

Domestic pigs (*Sus scrofa*) have been present in Australia since European settlement and the invasive populations currently present are the result of escapes from domestic populations as well as deliberate introductions to the wild for recreational hunting. Feral pigs do not currently occupy all suitable available habitat in Australia. The species occupies about 38% of mainland Australia, with their distribution largely a product of the location of releases/domestic source populations. The current non-domesticated pig population in Australia is estimated at between 3.5 million and 23.5 million (Australian Government 2005).

The feral pig can seriously impact the environment through predation, habitat degradation, competition with native species and disease transmission. Habitat changes resulting from feral pig activity include destruction of plants, changes in floristic composition, decreased plant regeneration, alteration of soil structure and increased spread of weeds. Pigs prey on a range of native species including frogs, reptiles, bird chicks, eggs of birds and reptiles, invertebrates, seeds, fruit, roots, tubers, bulbs and plant foliage. Feral pigs also provide reservoirs for endemic diseases and can be vectors of exotic diseases.

Feral pigs and climate change

The increased temperatures projected to occur within the Rangelands Cluster region are predicted to reduce the distribution of feral pigs (Caley et al. 2011). Effective management of surface water through the capping of free flowing bores and the management of water troughs will further reduce the abundance of pigs through much of the region.

12.3.6 Red fox

Introduction

The red fox (*Vulpes vulpes*) occurs in all states and territories, including Tasmania, and inhabits an estimated 76% (i.e. 5.79 million square kilometres) of Australia (Figure 12.4). However, foxes do not appear to be capable of maintaining permanent populations in northern Australia, most likely because of physiological constraints. Therefore, they are considered to be at their northern geographic limit under current climatic conditions. Foxes occupy almost the entire Rangelands Cluster region.

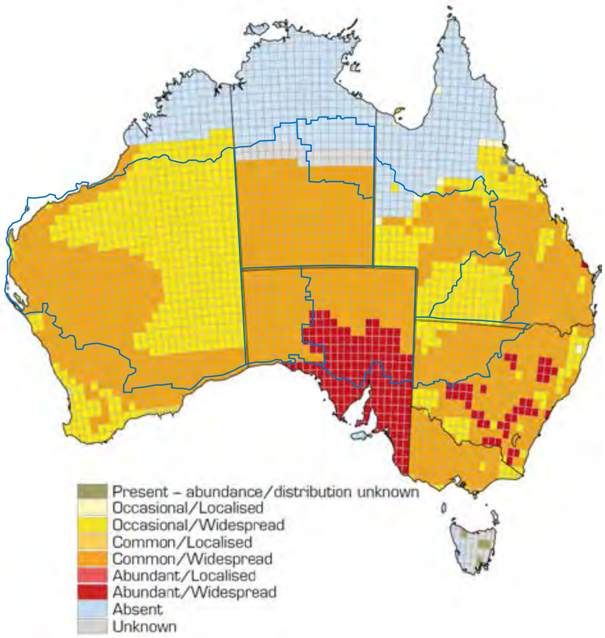

Figure 12.4 Occurrence, distribution and abundance of foxes

Source: West 2008, p. 35

Foxes are predominantly ‘occasional’ to ‘common’ throughout their range, but they are often found in low numbers where dingoes are prevalent (Saunders et al. 1995). Population densities can reach 7.2/km^2 (Saunders et al. 1995). In the Rangelands Cluster region fox abundance varies with environmental conditions. After large rainfall events, pulses in primary productivity occur which result in massive increases in some vertebrate populations such as native rodents and granivorous birds. Fox abundance remains high until vertebrate numbers crash and then populations drop although the species persists in arid areas such as the Simpson Desert during drought periods.

Foxes are opportunistic predators and scavengers and are a significant threat to native fauna, especially mammals (Saunders and McLeod 2007). They possess a number of attributes that allow them to occupy a wide range of habitats (Saunders et al. 1995). Foxes are effective predators of native wildlife and vulnerable livestock. Their impacts are significant, and the total cost is the highest of any pest species — an estimated $227.5 million per year (McLeod 2004). For this reason, 'Predation by the red fox' is listed as a 'key threatening process' under the *Environment Protection and Biodiversity Conservation Act (1999)* and under NSW legislation.

Information on the trend in abundance is limited to SA and the NT. In these areas, their abundance is largely stable.

Red fox and climate change

The distribution of foxes is unlikely to change dramatically in the Rangelands Cluster region under current climate change scenarios (Figure 12.5). In Figure 3.5, the current climate space is actually less than the current distribution of the species (Figure 12.4). This indicates that the species may occupy a larger area than predicted in 2085. This information may change with more refined modelling. The density may increase moderately in some areas, including in western NSW (e.g. Caley et al. 2011).

Trophic cascades resulting from climate change may impact negatively on foxes and lead to decreases in abundance. Specifically, across broad areas of the Rangelands Cluster region dingo/wild dog abundance is predicted to increase in response to climate change and changes in management (that will lead to a decrease in dingo control). One such area is north-west NSW (Caley et al. 2011). If dingoes do keep foxes in check through direct predation and competition as predicted by much of the scientific literature (e.g. Ripple et al. 2014) then an increase in dingo/wild dog abundance will likely result in a decrease in fox abundance.

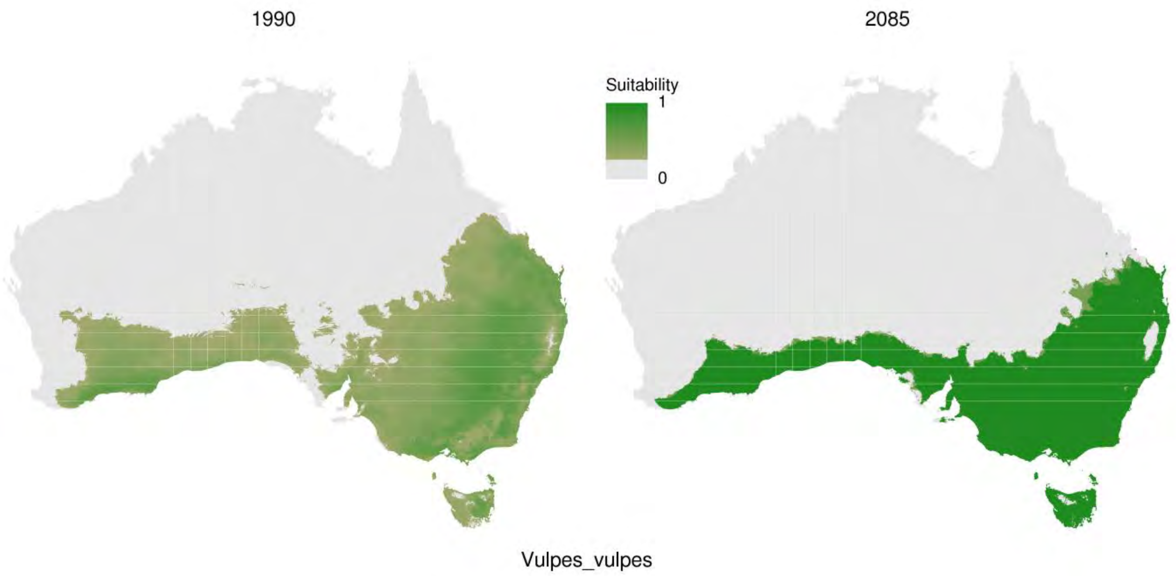

Figure 12.5 Projected change in suitable climate space of the red fox between 1990 and 2085.

Source: J. Vanderwal et al. unpublished data.

12.3.7 Feral domestic cat

Introduction

Domestic cats (*Felis catus*) were introduced to Australia either before or during European settlement. It is likely that this species had colonised most of the continent by 1890 (Denny 2008). Feral cats presently inhabit an estimated 99% (i.e. 7.54 million km^2) of Australia (Figure 12.6). Feral cat populations have now established in almost every significant habitat type throughout the continent; they also inhabit numerous islands.

The feral cat population in Australia is estimated at approximately 18 million animals (McLeod 2004). Populations can reach as high as 57/km^2 (Dickman 1996). Over a recent two-year period, a total of 2900 feral cats were killed in Astrebla Downs National Park, western Queensland. They are highly effective predators and are responsible for predation of a wide range of native species (Dickman 1996). 'Predation by feral cats' has been listed as a 'key threatening process' in NSW and Commonwealth legislation.

Information on the trend in abundance reveals that feral cats are largely stable in SA and the NT (West 2008). In the Rangelands Cluster region, cat abundance varies with environmental conditions. After large rainfall events, pulses in primary productivity occur which result in massive increases in some vertebrate populations such as native rodents and granivorous birds. After a lag of up to six months, cat numbers increase dramatically in response to increases in prey availability. Abundance remains high until vertebrate numbers crash and then cat abundance drops, although the species persists in arid areas during drought periods.

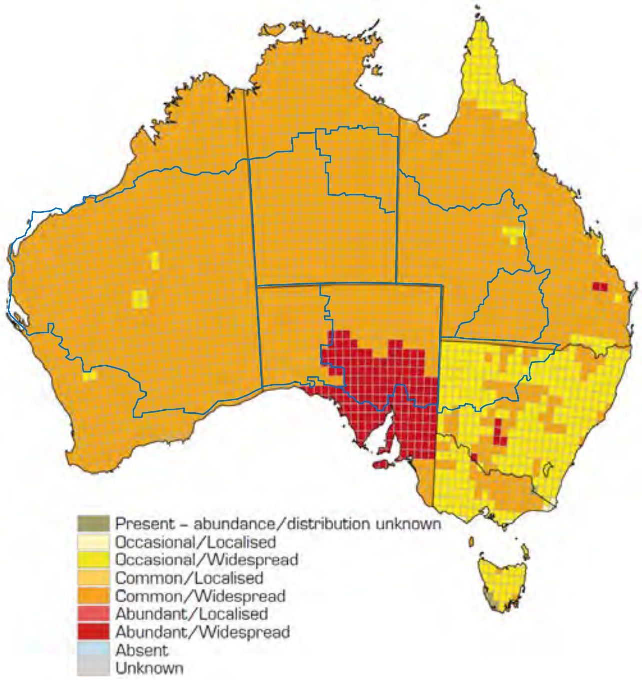

Figure 12.6 Occurrence, distribution and abundance of feral cats

Source: West 2008, p. 35

Feral cat and climate change

The distribution of cats is predicted to decline across the rangelands under climate change. In some areas abundance may decrease also, such as in the rangelands of NSW (Caley et al. 2011).

12.3.8 Dingo

Introduction

The term is used here to include the dingo (*Canis dingo*) and hybrids between the dingo and feral domestic dogs (*Canis lupus familiaris*). The term 'wild dog' is sometimes used rather than dingo (e.g. Wicks et al. 2014). Dingoes are considered to be major pests of agriculture because they kill livestock (Wicks et al. 2014). Specifically, dingo predation can reduce the profitability of sheep properties in particular and can have important negative social impacts (Allen and West 2013; Wicks et al. 2014; Forsyth et al. in press).

The dingo is classified as a native species and is Australia's largest land predator. It occupies most of mainland Australia, including all of the Rangelands Cluster region (Figure 12.7). It has been present on the Australian continent for at least 3000–5000 years (Crowther et al. 2014). There is a growing body of recent research showing that the dingo has a positive role in biodiversity conservation through the control it exerts on native herbivores (especially kangaroos), introduced herbivores and the red fox (Ripple et al. 2014). This control results in a cascading effect through food webs, which results in increased survival of native small mammals, birds and reptiles. Dingo–dog hybridisation is a threat to 'pure' dingoes, and it is a further issue because of policies in some Australian jurisdictions that aim to exterminate dingo–dog hybrids. Separation of 'pure' dingoes from dingo–dog hybrids is vital if this control process is to be successful (Crowther et al. 2014).

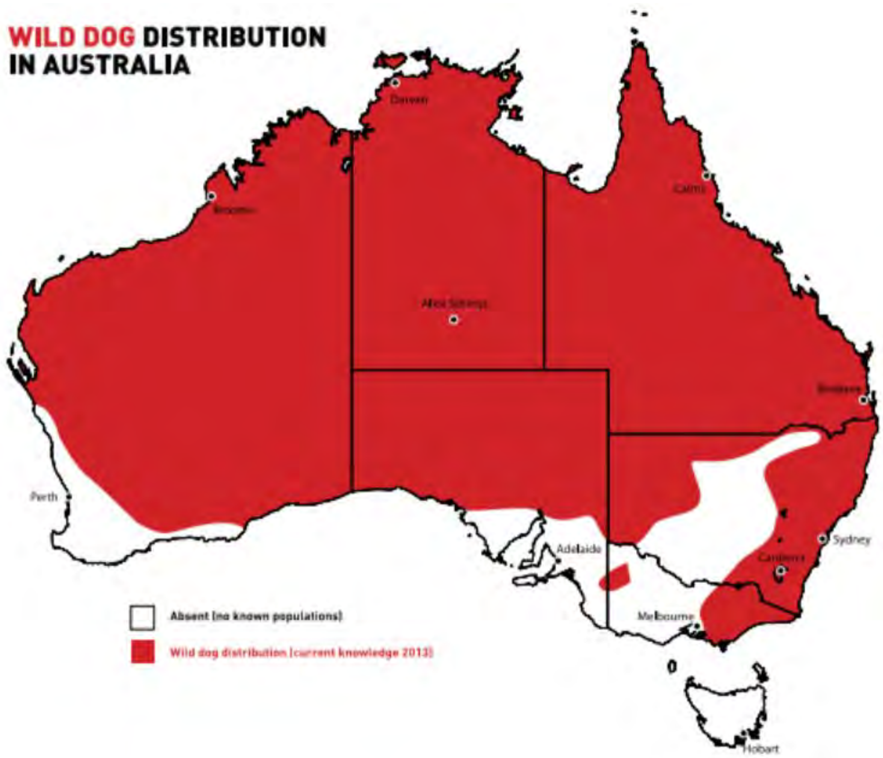

Figure 12.7 Current wild dog distribution in Australia.

Source: WoolProducers Australia (2014), with material provided by Peter West (Invasive Animals Cooperative Research Centre), prepared from data collated 2006–2013.

Dingo and climate change

The distribution and abundance of dingoes within the Rangelands Cluster region is predicted to increase in response to both climate change (Figure 12.8) and changes in rangeland management. The expectation is that climate change will cause increases in distribution and abundance of dingoes indirectly as a consequence of changes in their prey base (Caley et al. 2011). The management changes are twofold. First, there is a growing appreciation of the positive impacts of dingoes on ecosystems and of the need to manage them appropriately as a keystone species (e.g. Ripple et al. 2014). Second, dingoes are persecuted most heavily in sheep-grazing regions. The extent of sheep grazing in the rangelands of Australia is declining steadily, as it is in other parts of the world (Forsyth et al. in press) and as this happens the need to control dingoes will decline (e.g. Caley et al. 2011).

12.3.9 European rabbit

Introduction

The European rabbit (*Oryctolagus cuninculus*) has been present in Australia since 1858, when it was introduced into the south-east of the country for sport shooting. It rapidly became established and spread and has been one of the most prominent environmental issues in Australia. The species is now widespread across the southern and central sections of the continent, including Tasmania. However, it is absent from the northern third of Australia (Williams and Myers 2008). The rabbit occurs throughout most of the Rangelands Cluster region but is absent from the extreme north.

The rabbit remains a serious environmental and agricultural pest in Australia despite the relative success of biological control agents (myxoma virus and rabbit haemorrhagic disease virus). The impact of rabbits on agricultural and horticultural production in Australia is estimated at $206 million per year (Gong et al. 2009). Rabbits also cause significant environmental damage. Their impacts include damage to native plants and pastures, which increases the susceptibility of soils to wind and water erosion. In addition, rabbits are a major food of introduced carnivores that prey on native wildlife.

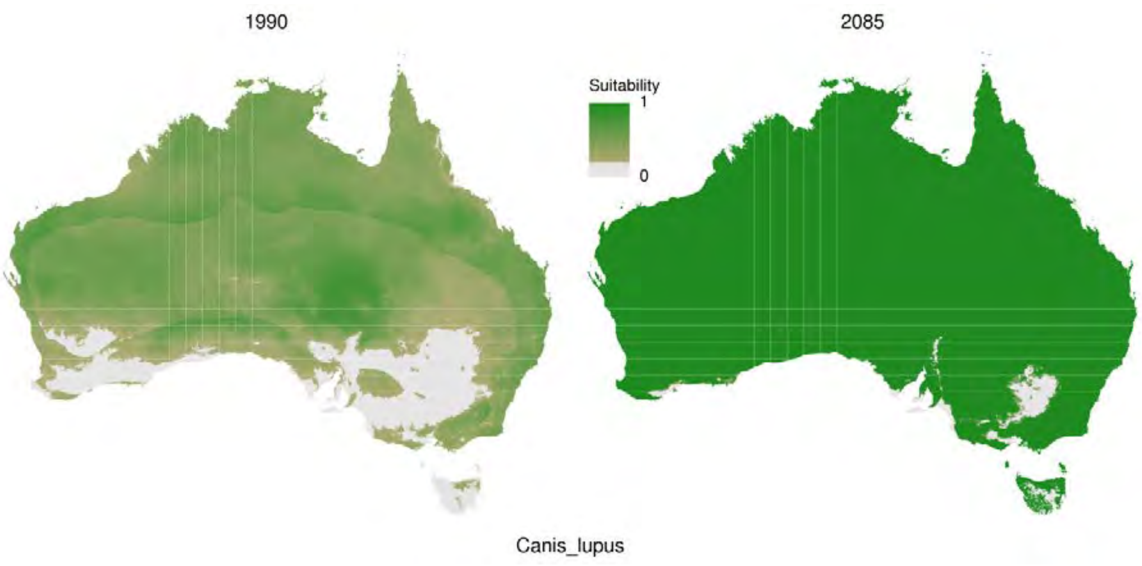

Figure 12.8 Projected change in suitable climate space of the dingo between 1990 and 2085.
Source: J. Vanderwal (unpublished data).

European rabbit and climate change

All predictions for climate change for the Rangelands Cluster region predict an increase in temperature. Available modelling predicts that this will have a negative impact on rabbits, with the species becoming absent from sizeable areas of the Rangelands Cluster region. This decrease is predicted to occur irrespective of whether the climate becomes hotter and wetter or hotter and drier (Caley et al. 2011). In the rangelands of NSW, the rabbit is predicted to become absent from large areas of the centre and west by 2050.

12.3.10 Cane toad

Introduction

Cane toads (*Bufo marinus*) were introduced to Queensland in 1935 to control pest beetles in sugar cane crops. Their success as a pest control agent has never been determined; however, they have become an environmentally significant and much publicised invasive species in their own right. Cane toads are presumed to cause a range of adverse impacts, primarily to native animals. A wide range of native species have been known to die following ingestion or part-ingestion of cane toads. Cane toads may also be a threat to domestic pets, because they can release toxins from their skin. However, it is clear that in some cases their impacts have been overstated (e.g. Brown et al. 2011), and the long-term impacts of cane toads are poorly understood. Cane toads are tolerant of a wide range of conditions and can produce spawn containing up to 35,000 eggs.

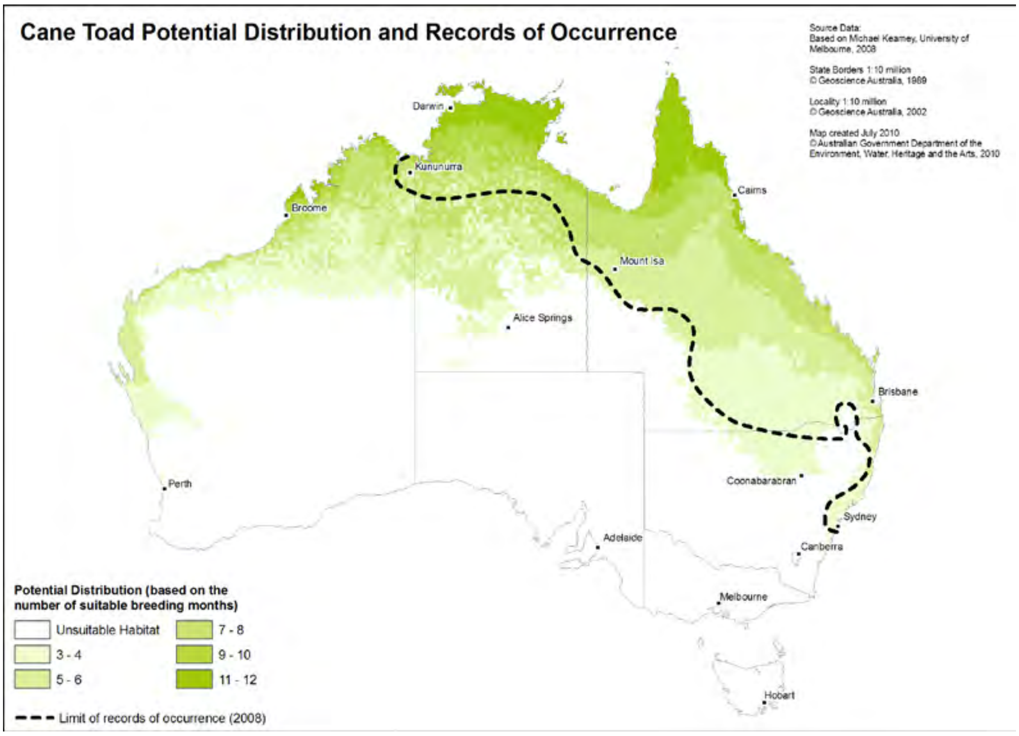

Figure 12.9 Known occurrence and potential distribution of the cane toad based on 2008 data.
Source: Australian Government (2011b).

Cane toads continue to expand their range in Australia. Since the original release at Gordonvale in north Queensland, the species has dispersed over 2000 km west and now occurs through much of Queensland, northern NSW, the Northern Territory and into the East Kimberley in WA. In recent years, they have rapidly spread across the NT and crossed the WA–NT border in 2009. The rate of spread is estimated to be 55 km per year. They have successfully colonised several large coastal islands in Queensland and the NT and have been found in densities up to 2000 per hectare in newly colonised areas (Molloy and Henderson 2006). Flooding events hasten the rate of spread of cane toads.

Cane toads presently inhabit an estimated 20% (i.e. 1.52 million km^2) of Australia. It appears likely that they now occupy a large proportion of their estimate range in Figure 12.9.

Cane toad and climate change

The climate space of cane toads is projected to decline significantly by 2085 under current climate scenarios. Almost all of the current range in the Kimberley area of Western Australia and the Northern Territory and most of the climate space on Cape York Peninsula will disappear, and the species will contract to the east coast. The decline in available climate space is such that it is predicted that no cane toads will likely be present within the Rangelands Cluster region (Figure 12.10).

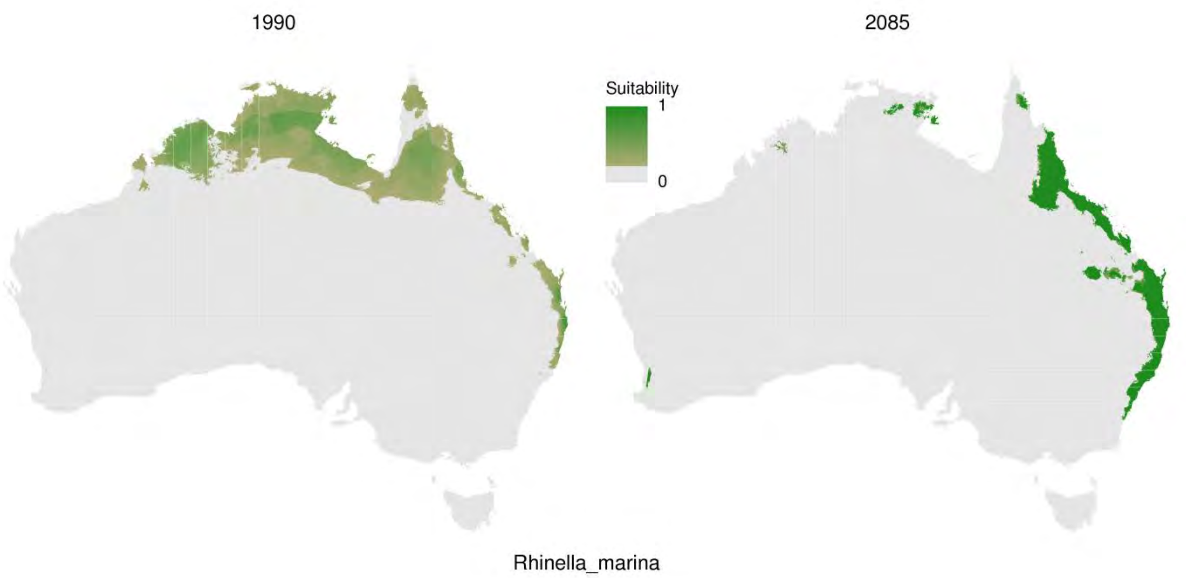

Figure 12.10 Projected change in suitable climate space of the cane toad between 1990 and 2085.
Source: J. Vanderwal (unpublished data).

12.3.11 Summary

Table 12.2 Summary of predicted changes in abundance and distribution of invasive animals covered in this report within the Rangelands Cluster region, in decreasing order of abundance change.

SPECIES	ABUNDANCE	DISTRIBUTION	COMMENTS
Red fox	Moderate increase	Stable	Negative impact of increased dingo abundance
Feral domestic cat	Moderate decrease	Decrease	
Dingo	Increase	Increase	May be favoured by changed management involving less control activities
One-humped camel	Stable	Stable	
Feral horse	Stable	Stable	
Feral donkey	Stable	Stable	
Feral goat	Moderate decrease	Moderate decrease	Negative impact of increased dingo abundance
Feral pig	Decrease	Decrease	Predicted to increase outside rangelands
European rabbit	Decrease	Decrease	Influenced by predator abundance and continuing effective forms of biological control
Cane toad	Decrease	Decrease	Will be impacted by water management practices

12.4 Management responses

Table 12.2 (above) predicts a decrease in the abundance and/or distribution within the Rangelands Cluster region in response to climate change of five of the major pest vertebrates covered in this report. These species are the cat, goat, pig, rabbit and cane toad. A further three species are predicted to have stable abundance and distribution (camel, horse, donkey). Only two species, red fox and wild dog, may show increased abundance and/or distribution in response to climate change (Table 12.2).

As a consequence of the limited positive impacts of climate change on pest vertebrates, the management recommendations in Table 12.3 (below) are essentially in the category of 'do more of the same'.

Table 12.3 Recommended future management actions for the ten species of vertebrate pests covered in this report. These actions factor in the potential impacts of climate change on the abundance and distribution of these species.

SPECIES	GOAL	ACTION	TARGET REGION/SUB-REGION(S)
Goat	Exclude species from areas of high agricultural/conservation value. Implement a suite of rigorous control measures elsewhere to maintain the feral goat population at regionally low densities. This goal assumes goats are a pest rather than a resource.	Continue existing actions	Western LLS, South West Queensland, Desert Channels, SA Arid Lands, WA Rangelands
Camel	Maintain regional density target of < 0.1 camels per km^2 (Ninti One Limited 2013)	Continue existing actions	Desert Channels, SA Arid Lands, Alinytjara Wilurara, NT Arid Lands sub-region, WA Rangelands
Horse	Landscape-scale eradication	Continue and intensify existing actions	NT Arid Lands and NT Tablelands sub-regions, SA Arid Lands, Alinytjara Wilurara, WA Rangelands, South West Queensland, Desert Channels
Donkey	Landscape-scale eradication	Continue and intensify existing actions	NT Arid Lands and NT Tablelands sub-regions, SA Arid Lands, WA Rangelands
Pig	Prevent colonisation of new locations	Local-scale management, including preventing access to water and eradication	NT Tablelands sub-region, South West Queensland, Desert Channels, Western LLS
Fox	Landscape-scale eradication	1080 baiting Positive dingo management	All
Cat	Landscape-scale control and eradication (once methods available)	Local-scale lethal control Positive dingo management	All
Dingo	Reduce impacts on livestock production	Local-scale control of dog–dingo hybrids and feral domestic dogs, including lethal methods and exclusion fencing	All
Rabbit	Landscape-scale suppression	Continue integrated management (including poisoning, warren ripping, shooting, biocontrol)	All regions except NT Tablelands sub-region
Cane toad	Prevent colonisation of new locations	Local-scale management, including preventing access to water, and collection	NT Arid Lands and NT Tablelands sub-regions, South West Queensland, Desert Channels, Pilbara sub-region of WA Rangelands

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Australian rangelands and climate change – guidance to support adaptation

Addressing climate adaptive capacity, resilience and vulnerability of people in remote and marginalised regions

Tom Measham

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13. Australian rangelands and climate change – guidance to support adaptation

Most mainstream adaptation has focused on standard vulnerability reduction in areas with relatively high populations, often in urban areas. This approach was not designed for the rangelands.

This report brings together information and methods that will be of practical use in addressing adaptive capacity, resilience and vulnerability of people in the rangelands.

To date, most adaptation responses to climate impacts have tended to develop in urban areas where relatively dense populations are concerned about specific and localised threats, such as coastal inundation. In practical terms, a main focus of climate adaptation has been concerned with prioritising assets and estimating impacts on those assets. Priority is given to defending those assets against impacts such as related tidal surge and storm events.

Although this report draws on those approaches, they have limited value in rangelands due to the dispersed nature of climate impacts, the already highly variable climate in rangelands regions and the distinct character of rangelands populations. The people of the rangelands are not only more sparsely distributed compared to people in higher rainfall areas, they have different social networks. Moreover, they are accustomed to bouncing back from adversity, are highly resourceful and rely more on their local knowledge.

For this reason, rangelands researchers have developed a unique framework tailored to remote areas, and this framework is summarised in this report. Importantly, it brings together two different sides to adaptation, vulnerability reduction and enhancing resilience, in a single coordinated framework. Rangelands populations tend to think long term – and this is exactly the approach put forward in the remote area framework – using some types of management strategies to 'buy time' while other types of strategies are coming into effect.

This framework is illustrated with case studies drawing on past research, including research about human responses to heatwaves, to show how different strategies for reducing vulnerability and building resilience can be combined over time (Maru et al. 2014). The framework is also considered in relation to buffel grass management, drawing on one of the other cluster research projects (Scott 2014).

The report was developed in collaboration with rangelands NRM planners, biophysical scientists and social scientists to provide an appropriate level of detail in an accessible format.

Key points

- Rangelands have distinct ecologies and social systems such that conventional approaches to climate adaptation may not always work in these remote areas.
- This report draws on those approaches but presents a rangeland-specific approach to information and guidance to support climate change adaptation.
- The approach balances resilience and vulnerability reduction and draws on the existing capacity of rangelands residents.

13.1 Introduction

The purpose of this report is to bring together information and methods that will be of practical use in addressing adaptive capacity, resilience and vulnerability of people in remote and marginalised regions. Before focusing on the specific case of remote regions, it is important to consider the general experience of climate adaptation, which has mostly focused on reducing vulnerability to specific hazards in densely populated areas.

13.1.1 Background to adaptation and vulnerability

Adaptation to climate impacts has mostly evolved in urban (Bulkely 2013; Gill et al. 2007), and coastal areas (Adger 1999). The concept of vulnerability has evolved as the fundamental issue for climate change (Adger 2006), and the predominant response has been to reduce vulnerability. In practical terms, a main focus of climate adaptation has been concerned with prioritising assets and estimating impacts on those assets. Priority is given to defending those assets against impacts such as sea level rise and related tidal surge and storm events. At the local scale, this has seen a prevalence of climate adaptation expressed as infrastructure to reduce vulnerability. This can include careful positioning of wind turbines to protect urban beaches (Jacobson et al. 2014) and raising roads to reduce vulnerability (HCCREMS 2010).

Capacity building is also an important way of adapting to climate change (Adger et al. 2005), focusing on communicating climate information and building awareness of impacts.

While there has been progress towards climate adaptation (Webb et al. 2013), it is important to note that the way that most climate adaptation has been developed is not well suited to rangelands areas. Conventional approaches to adaptation will work in some contexts. For example, the construction of levee banks in Charleville has contributed to flood protection. However, studies have shown that rather than rely on engineering solutions, residents are already accustomed to dealing with flood and prefer to rely on their own methods of personal resilience, such as shifting valuable items to higher ground (Keogh et al. 2011) and drawing on their social networks for support. Building levee banks and raising roads in all areas vulnerable to inundation is simply not viable. The case of Charleville is therefore a useful analogy for much of the rangelands: conventional vulnerability reduction represents a relatively small part of climate adaptation in rangelands compared with denser, coastal settlements.

13.1.2 Steps in vulnerability assessment and reduction

There are a range of approaches to climate adaptation, but they tend to have significant overlap in terms of the actual steps involved. The following steps have been simplified and adapted from Li and Dovers (2011), which is one approach that has been implemented successfully in different parts of Australia, including rural areas.

Recognise climate change and climate variability as whole-of-system problems

To establish the context for vulnerability assessment, it is important to understand climate impacts and climate variability as 'whole of system' challenges and responses. On this basis, bring together existing knowledge to inform the vulnerability assessment process (Li and Dovers 2011).

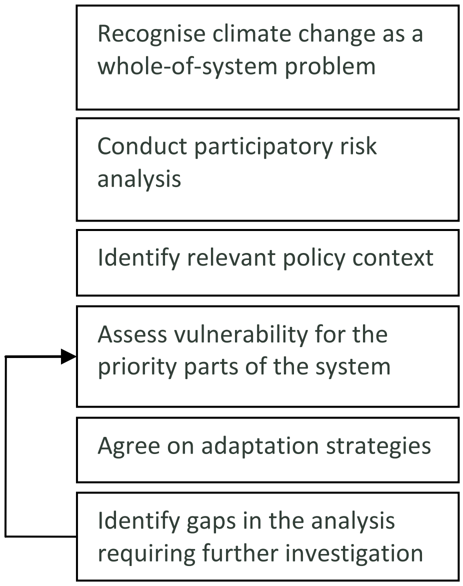

Figure 13.1 Generic integrated vulnerability assessment framework

Source: adapted from Li and Dovers (2011)

Conduct participatory risk analysis

The next step is to identify what is at risk and establish priorities to focus on within the overall system. Conducting this as an inclusive process involving non-government actors has multiple benefits. These include seeing risk from different perspectives and negotiating over what's at stake (Renn and Schweizer 2009).

Identify relevant policy context

It is important to identify current and historical policies and initiatives that may be relevant to the vulnerability assessment process.

Assess vulnerability for priority parts of the system

Assess the vulnerability for the priority issues drawing on available data to establish exposure, sensitivity and adaptive capacity. Indicators of *Exposure* encompass such factors as days above a certain temperature, days without rainfall and population density. Indicators of *Sensitivity* refer to how sensitive the system is to hazards; examples of these indicators are the type of dwellings people live in, and the percentage of the population with certain health characteristics. The combination of exposure and sensitivity define the potential impacts or the gross vulnerability of the system. It may be helpful to express exposure and sensitivity in spatial formats. *Adaptive capacity* refers to the ability to change and therefore reduce gross vulnerability. Indicators of adaptive capacity may include issues such as mobility, financial resources and education (Measham and Preston 2012).

Assessing vulnerability can draw on quantitative and/or qualitative descriptions of sensitivity. This phase involves exploring potential adaptation strategies and actions to reduce overall vulnerability and ways to draw on adaptive capacity (Li and Dovers 2011).

Agree on adaptation strategies

Following the best available information about exposure and sensitivity, and after considering options to reduce gross vulnerability, this phase is focused on defining and agreeing on adaptation strategies (see Table 13.1 for an example looking at buffel grass). It is recommended that this phase is conducted with stakeholders as a dialogue, to ensure that diverse views are represented and actions are realistic (Renn and Schweizer 2009). It helps to address multiple spatial and temporal scales together. Given the importance of stakeholder engagement at this phase, it is important to recognise principles of successful engagement in rangelands regions. These include working strategically to understand the rules and priorities of different parties. It involves making use of social networks and involving local champions. Finally, it means acknowledging the unique timeframes and distances of dryland regions, and setting times that are realistic within these (Measham et al. 2011).

Table 13.1 Example of buffel grass in vulnerability assessment

Exposure/ sensitivity	Possible adaptation strategies
Future southerly expansion of buffel grass into high conservation value pastures	**Establish quarantine barriers for conservation reserves before buffel grass reaches those areas** **Raise awareness of likely new distribution**
Expansion of buffel grass in areas where it is currently sparsely distributed	**Adjust burning practices to favour species diversity before buffel grass takes hold** **Increase existing control efforts e.g. spraying to slow expansion**

Identify gaps in the analysis requiring further investigation

The vulnerability assessment process may bring to light knowledge gaps that require further investigation. This may require researching primary or secondary data to fill these knowledge gaps.

After addressing knowledge gaps it is time to communicate the vulnerability assessment and adaptation strategies to all stakeholders with a view to implementation. Depending on how complete and detailed the vulnerability assessment outcomes are, it may be necessary to take an iterative approach and go through some of the above steps again as required (Li and Dovers 2011).

13.1.3 How do you actually do it?

The steps above set out the agenda for conducting a vulnerability assessment, but how does it work in practice? Many NRM planners and managers who are already familiar with resource planning will likely have many of the skills for developing climate adaptation strategies, because there is some overlap with other types of planning processes. These involve choosing an appropriate working group to manage the overall process, including representation from partner organisations (Beer et al. 2014). Another important aspect is having access to resources and information about appropriate climate impacts, through cluster partners who can help translate climate information into relevant regional impacts.

Some stakeholders may be sceptical about climate change occurring. In these situations it may help to focus on strengthening responses to existing climate variability and thinking about 'no regrets' actions, that is, those that are valuable even if the climate does not change.

A recent National Climate Change Adaptation Research Facility (NCCARF) review identified the following principles of 'good adaptation' (Webb and Beh 2013):

- Sustained and effective leadership
- Effective stakeholder engagement
- Maintaining a balance of social, economic, environmental and institutional objectives
- Learning from experience of other adaptation initiatives
- Following adaptive management approaches, including evaluation and social learning
- Explicit framing of adaptation issues agreed up front
- Addressing multiple spatial and temporal scales together
- Taking a systems approach to climate risks
- Evaluating adaptation options most relevant to support decision-making
- Articulating a clear statement of adaptation vision
- Carefully choosing appropriate methods for relevant issues.

The higher costs of conducting stakeholder engagement in remote regions compared with more densely settled areas cannot be ignored. Furthermore, seasonal variability and a changing policy environment complicate the practice of climate adaptation and vulnerability assessment for rangeland regions. For these reasons, a flexible approach is recommended, working closely with stakeholders in a way that is compatible with their many NRM commitments (Measham et al. 2011).

Further information on practical implications

In addition to the material in this report, practical guidelines to support adaptation have been prepared by a range of organisations. For example, generic guidelines for local scale adaptation have been prepared by the International Council for Local Environmental Initiatives (ICLEI), which has actively supported adaptation in North America and Oceania. As with many adaptation resources, they tend to focus on urban areas, but not exclusively (Snover et al. 2007; ICELI Oceania 2008; ICLEI Canada 2010).

While it is not focused on remote areas, a practical guide aimed at rural towns prepared by NCCARF may also be useful. The guide uses a slightly different procedure to Li and Dovers (2011), presenting adaptation planning in five steps: 'Review, plan, decide, implement and promote' (Beer et al. 2014). The guide includes an appendix summarising potential impacts relevant to rural regions, including issues such as increased costs of maintaining infrastructure, migration of rural residents and health impacts from natural hazards, as well as issues that will be more familiar to NRM organisations, such as changes to species distribution and fire regimes.

13.2 Approach

While it is useful to understand general approaches to climate adaptation and vulnerability assessment, it is crucial to recognise that rangelands regions are different in terms of both their physical environment and their human population. It is widely recognised that people in rangelands have become accustomed to higher levels of climate variability compared to other parts of the country (Stafford Smith 2008) and are therefore innovative and prepared for climatic challenges (Stafford Smith and Cribb 2009).

13.2.1 Social characteristics

Rangelands residents live across 70% of the land area of Australia, yet make up less than 3% of the national population. Moreover, rangeland residents have different characteristics from those of more densely settled areas. In particular, they are more spread out, with different types of social networks. Notably, in rangelands regions social networks have an increased number of 'weak ties' – 'a friend of a friend' connection – that can span great distances. Sometimes these links are called 'wiry' ties, as they can endure long timeframes and be drawn on efficiently to access resources. These types of links are an important characteristic of the resilience of rangeland populations and are very important for managing risk across time and space (McAllister et al. 2011).

Rangeland populations are highly mobile. Arid and semi-arid regions of Australia have a high degree of intra-regional mobility, such that there is a relatively high degree of people moving around within the rangelands, particularly among Aboriginal populations (Brown et al. 2008). In addition to internal mobility, there is a high migratory population as well, of people who visit the region for a period. These include 'Fly in, fly out' (FIFO) labour forces, which visit the rangelands regularly. Although the FIFO model was originally developed for remote mining projects, FIFO labour forces are prevalent across many sectors (Carson and Carson 2014).

13.2.2 Stronger resilience

Given the sparsely distributed exposure to risk in rangelands, and the small, widely distributed population, approaches to vulnerability in the rangelands will need to be different from that in more densely settled areas close to particular impacts such as coastal flooding. While there will always be some role for containing impacts through physical infrastructure, the combined physical environment and social characteristics of the rangelands dictate that there will always be some areas that cannot be elevated or barricaded in some way. Therefore, rangeland-specific vulnerability frameworks need to draw more on the existing resilience of rangeland populations and find ways to maintain and extend that resilience. Furthermore, it will be necessary to be very strategic about combining resilience and vulnerability reduction to work together as best as possible. For this reason, vulnerability researchers have developed a vulnerability framework that is specifically designed for remote areas (Figure 13.2).

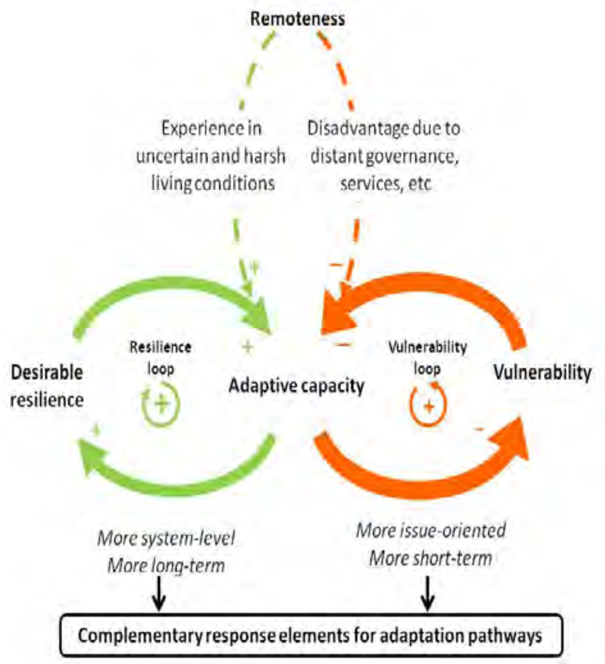

Figure 13.2 Remote regions vulnerability framework

Source: Maru et al. (2014)

13.3 Application of framework

To apply the remote regions vulnerability framework it is important to keep in mind the two dimensions (vulnerability reduction/resilience) and to align the different types of responses across time, so that near-term actions can ‘buy time’ to deal with longer-term actions. An example of the framework from Maru et al. (2014) is presented below in relation to heatwaves.

In Figure 13.3, which was tested through case study research, the frequency of heatwaves is presented as increasing from currently one or two per year though to five or six per year.

Considering that rangeland residents already have a high level of resilience and are accustomed to climate variability, doing nothing will suffice for a little while, but eventually residents will be overwhelmed as frequency increases. One option to reduce vulnerability would be to install air-conditioning, which might help for a little while longer. Improving the quality of the housing stock will help further. However, eventually the ‘vulnerability reduction’ side of the model will become exhausted. Considering the resilience side of the framework, investments in better health will be important, given that heatwaves express themselves through health impacts. However, improving health takes time to achieve, so relying only on resilience options will not work in the short term. Only by combining vulnerability-reduction and resilience-enhancing options can a complete response be developed.

The framework can be used in conjunction with any of the findings developed during the Rangelands NRM Cluster research process. In Figure 13.4, this framework is used to structure the lessons from the report on buffel grass, showing how different strategies from vulnerability reduction and resilience can be brought together.

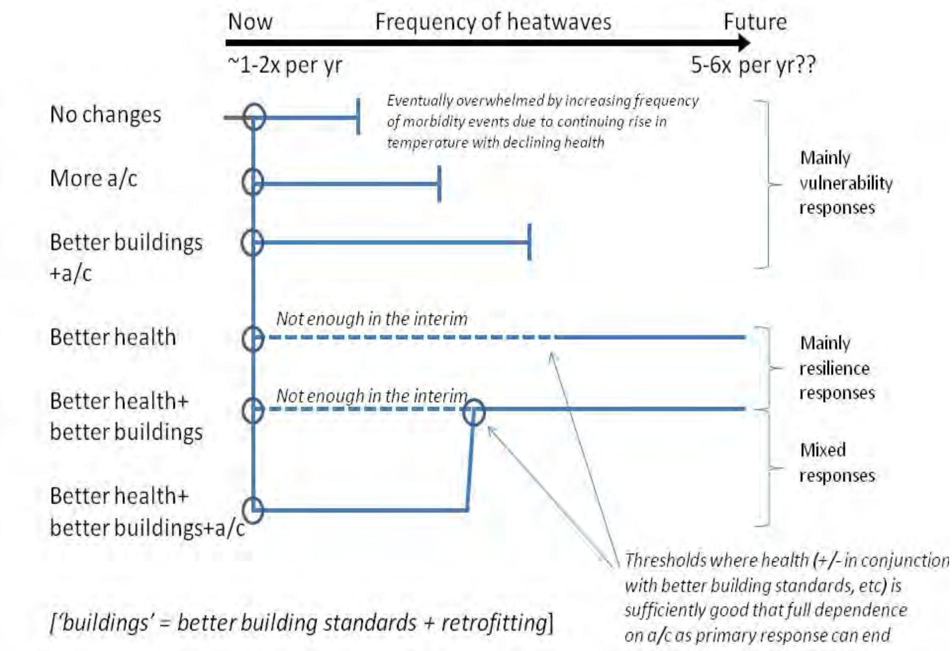

Figure 13.3 Application of the remote regions vulnerability framework to heatwaves

Source: Maru et al. (2014)

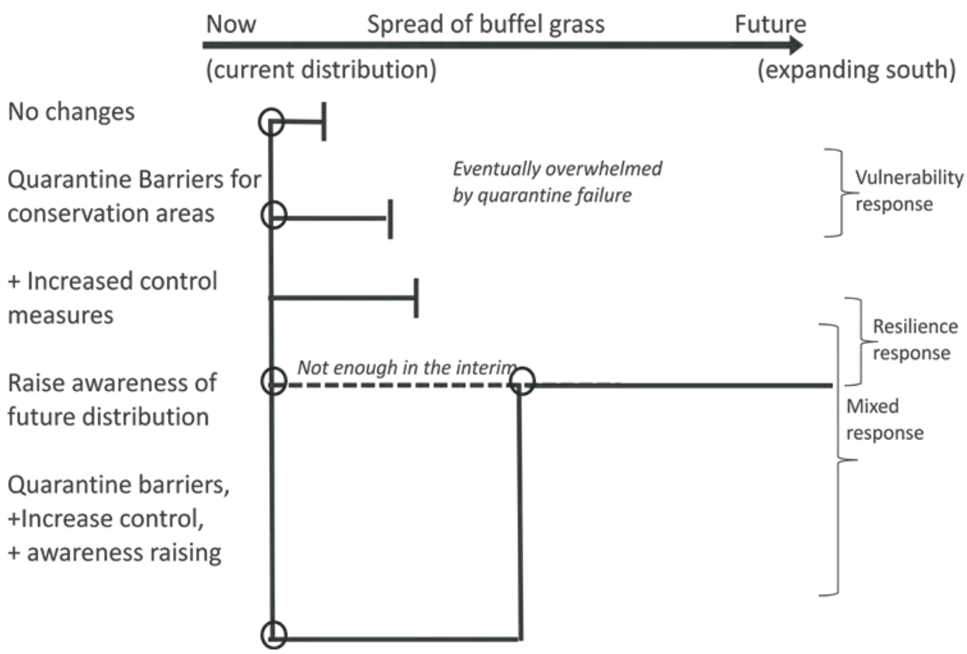

Figure 13.4 Example of using the framework to structure the recommendations of the buffel grass report prepared as part of the Rangelands NRM Cluster research process

13.4 Conclusions

Rangelands communities are already accustomed to dealing with climate variability and extreme events, but these are likely to increase in the future. The purpose of this document has been to provide information and guidance to support climate change adaptation with a particular focus on addressing climate adaptive capacity, resilience and vulnerability of people in remote and marginalised regions.

There are a range of well-developed vulnerability assessment and reduction frameworks, which all have some value. These frameworks draw on general principles but will not always work in rangeland regions due to the distinct biophysical and social characteristics of these areas.

For this reason, a remote area–specific framework has been developed that brings together the vulnerability reduction and resilience sides of adaptation. Moreover, it emphasises addressing adaptation by thinking of different types of actions that 'buy time' while other actions are developed and implemented.

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Australian rangelands and climate change – pastoral production and adaptation

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14. Australian rangelands and climate change – pastoral production and adaptation

Key points

- We anticipate that both gradual and transformational adaptation responses are required to suitably respond to likely climate change impacts on pastoral land use in the Rangelands Cluster region. Appropriate transformational change will probably require a fundamental shift in the current thinking (paradigm) about how rangelands are managed towards a more conservative risk-based approach to the use of natural resources. This will be a gradual process that requires facilitation, structural change and perhaps supporting legislation to achieve the best long-term outcomes for the pastoral industry and the natural resources on which grazing is based. It is unlikely that current best-management practices will remain so under projected climate change.
- We use a linked vulnerability and resilience framework (Maru et al. 2014) to illustrate how the range of available pastoral adaptations might best be implemented across the different NRM regions in the Rangelands Cluster.
- Among the climate change projections, hotter maximum temperatures and associated heatwaves, continuing highly variable rainfall and the probable occurrence of both more frequent drought and intense rainfall are considered the most adverse factors affecting future pastoralism.
- Good practical examples and appropriate technical advice are available to guide required short to medium timeframe adaptation responses to continuing rainfall variability and recurrent drought (e.g. out to about 2030). Examples of such packaged information include the Grazing Land Management program and Ecosystem Management Understanding™. Longer term adaptation may require a fundamentally more conservative approach to stocking rates, adjusting stocking rates as local pasture productivity changes (whether increases or decreases) and increasing the robustness of pastures by encouraging regeneration of palatable perennial forage (where possible). Repairing formerly productive, but now degraded, country may also have increased prominence as maximising rain use efficiency becomes more important through increased evaporation and reduced soil water availability.
- Hotter maximum temperatures and increased frequency and duration of heatwaves will place greater emphasis on human safety and wellbeing and animal welfare (particularly when stock is being handled). Both aspects may need to be more formally recognised and planned as part of routine station management.
- Longer periods of hotter weather will also require increased robustness in stock water supply. There will be a reduced safety margin around existing supplies as livestock consume more water in such periods. Repairs following failure will become more time critical before stock risk perishing or being exposed to conditions that threaten their welfare and production. Human occupational health and safety will also be paramount when attempting repairs to failed water infrastructure during heatwaves.
- Increased rainfall intensity has the potential to damage station infrastructure and increase erosion. The latter can be partly mitigated by maintaining minimum critical levels of ground cover on the most vulnerable soil types. Reducing the actual and financial risk of infrastructure damage may require its relocation to less vulnerable areas, a degree of over-engineering (by present-day standards) and increased use of insurance.
- Higher temperatures negatively affect pasture growth by reducing the efficiency with which plants use water, but this will be partly offset by the beneficial effects of rising atmospheric CO_2 on pasture. Tropical and subtropical grasses with the C_4 photosynthetic pathway are likely to expand ranges southward at the expense of existing C_3 grasses. The digestibility and nutritive value of pastures are likely to decline from the combined effects of rising

temperatures, increasing CO_2 and increases in C_4 grasses, so overall animal production may decrease. This can be alleviated for cattle by introducing/increasing *Bos indicus* genetics and increased use of nutritional supplements. C_4 grasses are more flammable, and more extensive and frequent fires that burn hotter may result.

- Finally, we include in Appendix A a broad range of management options that may provide appropriate adaptation responses to anticipated climate change impacts. This list is meant to be illustrative rather than exhaustive.

14.1 Introduction

Grazing of livestock is the most extensive land use in the Rangelands Cluster region. Projected changes in climate will impact the future way in which pastoralism occurs and adaptations will be required, both at enterprise scale and regionally. Climate change projections relevant to continuing pastoral land use include:

- continued substantial warming for mean, maximum and minimum temperatures, meaning increased evaporation and evapotranspiration, that is, reduced soil moisture availability.
- more frequent and intense heatwaves.
- continuing high variability in annual rainfall with the prospect of less rainfall in winter and spring. This will particularly influence seasonal pasture growth and forage availability in the southern part of the cluster region. In the central and northern parts of the cluster region, grasses with the C_4 photosynthetic pathway are likely to increase at the expense of C_3 vegetation.
- increased intensity of heavy rainfall, which will particularly threaten infrastructure (water points, fences, roads, etc.) on flood-prone and more erodible parts of pastoral leases.
- a probable increase in the frequency and severity of drought.
- increased periods of high fire-danger weather that will likely translate to variable levels of fire activity following wetter years.

Put simply, changes in pastoral management to cope with this more severe climate may take two different forms:

1. Gradual and progressive changes to the way things are done. Examples include:
   - changing heat-sensitive operations to the relatively cooler months of the year: e.g. join merino rams and ewes in the cooler months to reduce the risk of heat-induced sterility; similarly, shift shearing from summer if that is the current practice
   - relocating fences and tracks away from more erodible country.
2. Transformational change:
   - moving to a radically different form of livestock production, e.g. from merino wool production to tropically adapted beef cattle
   - drought-proofing: conservative stocking, perennial-based pastures, repairing formerly productive but now degraded land, total control of various sources of grazing pressure
   - diversifying sources of income within and beyond the pastoral enterprise.

   Longer term transformations in the face of climate change may also require changed institutional structures, particularly with regard to pastoral tenure and the way that pastoral leases are currently administered, including monitoring of land condition.

This brief report uses a linked vulnerability and resilience framework (Maru et al. 2014) as outlined in the socioeconomic sub-project (Measham 2014) to indicate how the range of available pastoral adaptations might best be implemented across the different NRM regions in the Rangelands Cluster.

14.2 Method

This section draws on known literature relevant to pastoral adaptation with regard to climate change, well established examples of good pastoral management in highly variable environments (e.g. Lange et al. 1984; Purvis 1986; Landsberg et al. 1998; Bastin 2014a, 2014b, 2014c, 2014d, 2014e, 2014f) and the observations and experience in different rangelands regions of two of us over recent decades (Daryl Green and Gary Bastin).

14.3 Data sources

The primary data sources for this sub-project are not presented here but are provided in Purvis (1986), Landsberg et al. (1998), James and Bubb (2008), McKeon et al. (2009) and Stokes et al. (2012). The commentary is based on that literature.

14.4 Caveats

The major caveat or underpinning assumption to this pastoral management report is that there is no simple or single recipe to successful pastoral management in the highly variable rangelands environment (where variability occurs in both time and space). Rather, a systems approach is required where appropriate (and successful) management strategies are founded on a comprehensive understanding, at both enterprise and regional scales, of the capability (and limitations) of the available natural resource (i.e. soil and vegetation) to grazing and a fundamental recognition of the requirement for conservative use of these available resources through time. Thus, various and mixed management tactics may be applied but these are underpinned by such sentiments as 'managing for every year as though it were dry', 'living within one's means', 'recognising and driving down the cost of production' while building the business on the principle that 'sensible investment should be based on those parts of the station that have the long-term potential to repay this investment' (including, for example, repair of formerly productive grazing land).

Thus possible adaptive actions described in the following content should not be selected singularly based on perceived attractiveness or ease of implementation. Rather, they should be considered as parts of a palette of possible action which, when combined and used within a philosophy of conservative resource use, may result in a regional grazing system that is more resilient to projected climate change.

14.5 Findings

The probable impacts of climate change on the natural resource base (particularly vegetation) and related livestock production in the northern part of the Rangelands Cluster region are listed in Table 14.1. This summary was prepared for the northern cattle industry, and the information broadly applies to cattle producers in the Desert Channels (Queensland), Tablelands and Arid Lands sub-regions of the NT and the Pilbara (WA Rangelands). The information presented should be cautiously extrapolated to more southern parts of the Rangelands Cluster.

The table indicates that hotter temperatures and changes in rainfall variability are likely to have the most profound effects on cattle production. Direct effects include magnified pasture responses to rainfall changes, for both increases and decreases. For example, a 5% decline in rainfall could reduce pasture production by 7% (see McKeon et al. 2009 for further information). Changes in rainfall variability will indirectly affect the security of stock water supply (Table 14.1).

14.5.1 Adaptation responses

A wide range of tactical responses to projected climate change relevant to pastoral production is listed in Appendix A. These are arranged by the anticipated major components of climate change. As argued above, individually selected tactics are unlikely to be successful in isolation. Rather, a systems approach to devising strategic responses founded on an owner's (or manager's) fundamental philosophy to managing natural resources in a highly variable climate is required. Logically related management actions (or tactics, tools) should then follow. This is illustrated with broad guidelines for northern cattle producers in Table 14.2 and more specifically (Table 14.3) for a family-owned cattle station in the Arid Lands sub-region of the southern NT.

A further consideration is the time frame over which management philosophies and the cascading assemblage of related strategies and tactics (i.e. responses) apply. In the short to medium term (10–30 years), largely reactive responses that counter increasing vulnerability may be more appropriate (Maru et al. 2014, illustrated in Figure 14.1 for merino wool growers in the southern Rangelands Cluster region). Longer term, systemic or major structural changes are probably required at both enterprise and regional scales to enhance environmental, economic and social components of resilience. For some regions, this may amount to transformational change, for example, movement from traditional wool production based on merinos to meat sheep (Dorpers, Damaras, etc.) or, more radically, breeding tropically adapted beef cattle for fattening beyond the rangelands (Figure 14.1). Such change has already occurred in the Pilbara, is ongoing in the Gascoyne–Murchison region of WA and may be the future for a large part of western NSW.

Table 14.1 Summary of climate change impacts on livestock production systems.

This table is adapted from material prepared for the northern cattle grazing lands (Stokes et al. 2012) and is most appropriate to the northern half of the Rangelands Cluster region.

PLANTS AND NATURAL RESOURCES	LIVESTOCK
Carbon dioxide	
Increased pasture growth per unit of available water and nitrogen (and light)	No direct effects
Reduced forage quality (protein and digestibility)	
Species-specific CO_2 responses cause shifts in vegetation composition (e.g. favour nitrogen fixers and deep-rooted plants)	
Temperature	
Reduced water use efficiency and increased evaporation	Increased heat stress and greater water requirements
Decreased forage quality (digestibility)	Livestock concentrate more around water points
Earlier start to spring growth in cooler climates	
Southern expansion of weeds and pasture species (e.g. less nutritious tropical grasses)	Southern expansion of tropical pests and diseases
Rainfall and other changes in climate	
Changes in forage production magnify percentage changes in rainfall	Changes affect availability of water for livestock
Changes in seasonal rainfall affect seasonality of forage availability (e.g. declining spring/autumn rainfall would reduce the length of growing seasons)	
Increased rainfall intensity and inter-annual variability create greater challenges for managing forage supplies and limiting soil erosion	
Greater risks of flooding in some areas	
Broader context and other issues	
Uncertainty over climate change impacts and adaptation options could create reluctance and delays in taking pre-emptive action, exacerbating impacts	
Changes in regional/international competition from geographic differences in effects of climate change (magnitude of impacts/benefits and adaptability of beef industry)	
Changing demand for livestock products as a result of climate change and consumer attitudes to greenhouse gas (GHG) efficiency of food products (i.e. methane emissions by ruminants)	
Cost-price squeeze from GHG reduction measures that increase input and processing costs (indirect)	
Potential shifts in land use and competition between land uses (e.g. biodiversity conservation, loss of land for carbon sequestration and renewable energy generation)	
Conflicts and synergies with other public and private policies and initiatives (especially drought, water, natural resource and GHG emission policies)	

Table 14.2 Options for adapting to climate change in the livestock industry

ADAPTATION OPTION
Grazing and pasture management
Introduce stocking rate strategies that are responsive to seasonal climate forecasts and track longer term climate change trends
Redefine safe stocking rates and pasture utilisation levels for climate change scenarios
Improve on-property water management, particularly security of supply and placement with regard to forage supply (i.e. distance to water)
Develop software to assist proactive decision making at the on-farm scale
Accept climate-induced changes in vegetation and modify management accordingly
Expand routine record keeping of weather, pests and diseases, weed invasions, inputs and outputs
Diversify on-farm production and consider alternate land uses
Managing pests, diseases and weeds
Improve predictive tools and indicators to monitor, model

and control pests
Increase the use of biological controls (with caution)
Incorporate greater use of fire for controlling weeds and woody thickening
Livestock management
Select animal lines that are resistant to higher temperatures but maintain production
Adjust use of supplements to offset declines in diet quality
Modify timing of mating, weaning and supplementation based on seasonal conditions
Provide extra shade using trees and constructed shelters
Broad-scale adaptation (variously relevant to government, industry bodies and NRM regions)
'Mainstream' climate change considerations into existing government policies and initiatives (particularly those relating to drought, GHG emissions and natural resource management)
Encourage uptake of 'best practice' in livestock enterprises as a short-term strategy (e.g. 2030 planning). However, current best practice recommendations should be evaluated to ensure benefits will continue as climate change progresses towards the end of this century
Work with the livestock industry to evaluate potential adaptive responses to the system-wide impacts of a range of plausible climate change scenarios
Provide adequate buffering to dampen the unforeseen effects of possible adaptation failure undertaken by early adopters
Modify transport networks to support changes in agricultural production systems
Continuously monitor climate change impacts and adaptation responses, adjusting actions to support and ensure effective and appropriate adaptation

Such changes can have undesirable consequences for those continuing with wool growing (e.g. need to upgrade boundary fencing, increased predation because cattle producers place less emphasis on baiting dingoes and wild dogs), and there are advantages to regionally facilitating such change to better manage adverse and unexpected consequences.

Table 14.3 Plausible management responses to predicted climate change of a currently viable cattle breeding and opportunistic fattening property north of Alice Springs.

Climate change projections that are most likely to impact cattle enterprises in the NT Arid Lands NRM sub-region:

- Hotter summers and more frequent and longer heatwaves
- Continuing episodic rainfall – timing and amount uncertain
- More intense storms
- Recurrent drought – but timing and duration uncertain
- Increased fire danger resulting from hotter temperatures and reduced humidity.

CURRENT AND PROBABLE MORE IMMEDIATE VULNERABILITIES	PLAUSIBLE RESPONSES (EXAMPLES PROVIDED – NOT A COMPLETE LIST)
Reduced herd productivity	Consider introducing tropically adapted (i.e. *Bos indicus*) genetics to the herd (or increasing their component if already running hybrid cattle). Select for short-haired coats. Where coat colour is not a marketing issue, select for lighter colours that better reflect heat. Wean rigorously to reduce nutritional stress on breeders and improve re-conception. Increased awareness of animal welfare issues required when handling cattle during very hot weather and when stock are weakened by drought (particularly with regard to long-distance transport).
Reliable water supply, particularly in hotter months	Watersmart principles (reduce evaporation from dams, deeper dams with steep batters that store >1 year's water supply, telemetry for remote and continuous monitoring of water supply).
Year-to-year variation in forage supply	Use reliable sources of information for forward planning (e.g. climate forecasts). Close monitoring of useful pasture supply and its quality, with timely

CURRENT AND PROBABLE MORE IMMEDIATE VULNERABILITIES	PLAUSIBLE RESPONSES (EXAMPLES PROVIDED – NOT A COMPLETE LIST)
	destocking as forage availability declines. Feed supplements (urea, phosphorus) to improve the nutritional value of poorer quality pasture. Manage existing buffel grass in the pasture (provided palatable varieties are present) and control its spread to areas with conservation value. Recognise that buffel grass poses a real threat to biodiversity. Where palatable species can be managed to contain their spread, they provide a passive and cheap opportunity for increasing the palatable perennial component of pastures. Remove unwanted herbivores (brumbies, camels). Additional water points so that water supply is closer to available forage. Drought preparedness – have a plan for appropriate destocking and act on it following failure of summer rainfall.
High fire risk following successive wetter years (approximate decadal time scale)	Identify key assets, have a plan (infrastructure, pasture resources, etc.) and seek to protect with suitable fire breaks, short-term heavy grazing, patch burning, etc. (let the rest burn if not able to safely manage wildfire). Where possible, learn from experience (what worked in the last major fire season and what would I do differently next time with regard to protecting life and assets – on property, working with neighbours and relevant government agencies). Not all fire is bad – intense wildfires might provide the ideal opportunity to control thickening scrub that threatens future pastoral

CURRENT AND PROBABLE MORE IMMEDIATE VULNERABILITIES	PLAUSIBLE RESPONSES (EXAMPLES PROVIDED – NOT A COMPLETE LIST)
	productivity. Recognise that further small-scale managed fire may be necessary to control woody regeneration following wildfire.
Labour – particularly OH&S issues	To the extent possible, confine stock work to the cooler months. Where summer mustering is required, start early and rest up during the hottest part of the day. Perhaps make greater use of contractors for infrastructure development and maintenance freeing up family labour for more concentrated periods of stock work. Alternatively, use a contractor for the main mustering round(s), again to concentrate this labour-intensive activity.

Longer term climate change adaptations that could improve the resilience of the cattle enterprise:

- Increase drought robustness: re-assess long-term stocking rates according to land type; increase the native perennial (and palatable) component of pastures through more conservative stocking and regular paddock spelling; reclaim formerly productive, but now degraded, areas (e.g. ponding banks on better soil types to repair leaky landscapes); use fire following better seasonal conditions to control woody thickening, etc.
- Increase the security of stock water supply (examples in Appendix A): this may require a degree of over-engineering but is warranted in reducing management stress and potential animal welfare issues associated with water-point failure during extended heatwaves.
- Adopt a more risk-averse approach to protecting infrastructure (relevant to increased rainfall intensity): relocate fencing, main station roads/tracks, waterpoints (and associated pipelines), etc. away from flood-prone areas and highly erodible soil types; use graders minimally and

carefully; insure key infrastructure against flood damage (or increase premiums if currently insured).

- Diversify sources of income: off-farm investments or another business; a station somewhere else that spreads the drought risk (but is a logical extension of the existing enterprise).

14.6 Key adaptation strategies

Systemic and managed/facilitated change that achieves regionally stronger and more resilient pastoral businesses in the face of projected climate change is preferable to ad hoc, enterprise-level application of management tactics that address short-term vulnerabilities to climate variability and the more obvious components of climate change (mainly increasing temperature and heatwaves). This approach should not deny opportunities for innovative responses to climate change, provided such innovations also address the need for enhanced industry resilience to a more extreme climate.

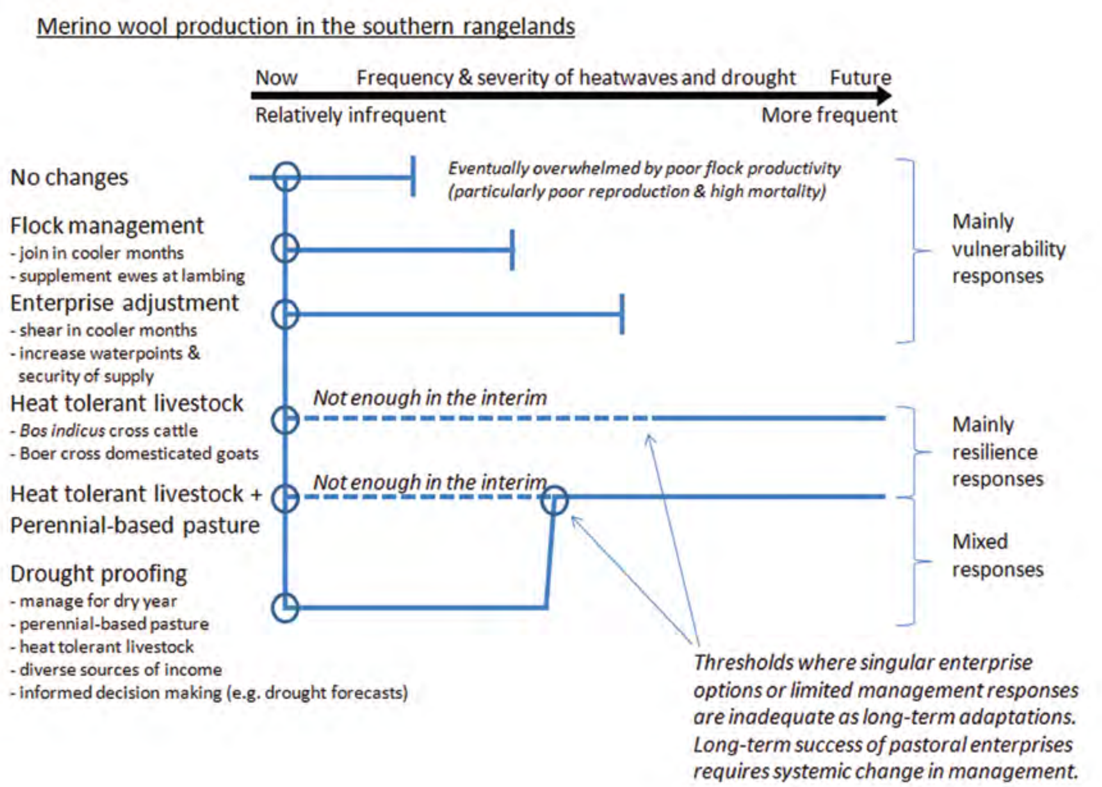

Figure 14.1 Potential adaptation pathways to address climate change impacts for merino wool producers in the southern rangelands.

Source: Figure adapted from Maru et al. (2014).

Issues associated with adaptation that are relevant to NRM planning include:

1. To what extent is gradual adaptive change relevant and when should appropriate transformational change be encouraged and facilitated? Broader uptake of regional best management practice by the pastoral sector may be appropriate for the next 15+ years (e.g. to 2030) but the utility of existing strategies and technology alone may have diminishing value as the effects of climate change intensify in the rangelands.

   Appropriate transformational change is likely to require a shift in mindset towards more conservative use of natural resources (particularly stocking rate and safe utilisation levels of pasture) rather than simply rapid adoption of new technology as it becomes available.

   The grazing industry and its advisers should be encouraged to think of, and implement, required transformational changes that will allow pastoralists to better manage livestock, people and the natural resource base in a hotter climate that has continuing highly variable rainfall and possibly more frequent and intense droughts.

2. Management of natural resources by the pastoral industry may become increasingly contested by other interest groups. Examples of current and likely emergent contestation include:

   – Continuing dissension among stakeholder groups of the value of buffel grass as a valuable forage species and its threat to biodiversity through direct competition, altered fire regime, etc.
   – Provision of additional waterpoints to reduce grazing distance in the hotter months and consequent negative impacts on parts of the native biota (i.e. the results from Biograze research: James et al. 1999, Landsberg et al. 2003).
   – The extent to which feral goats continue to be harvested in the southern rangelands or, alternatively, domesticated, genetically improved and sustainably managed to provide an alternative income source to wool production. The feral versus managed value of camels may also emerge as the climatic and nutritional challenges for continued grazing of sheep and cattle intensify. The long-term successful husbandry of both species will require the same attention to conservative management of natural resources as described above for sheep and cattle.

Appendix A Possible management responses by the pastoral industry to address climate change impacts in the Rangelands

The following table summarises those components of pastoral management in the Rangelands Cluster NRM regions which we understand are most likely to be impacted by projected climate change. It also describes probable required adaptation responses and suggests examples as to how these might be implemented. The list of responses and examples is not meant to be exhaustive. A key component of adaptation is innovation: pastoralists themselves are likely to implement novel ideas or combinations of tactics for addressing climate change.

CLIMATE CHANGE ISSUE	COMPONENT OF PASTORAL MANAGEMENT	ELEMENT OF PASTORAL MANAGEMENT	LIKELY IMPACT	ADAPTATION RESPONSE	EXAMPLES
More frequent and extended heatwaves	Labour	Occupational health and safety (OH&S)	More difficult to find and keep suitable staff	Shift critical management practices (shearing, branding, etc.) from summer months	
			Acute: staff (including family members) are endangered while working outdoors (heat stress, etc.); Chronic: staff working under duress, including possible mental stress	Ensure that appropriate OH&S procedures are in place, training has occurred and practices are rigorously followed; ensure all staff (including the owner/manager) have time off in a cooler environment; build a swimming pool, etc.	
				Restrict activity to relatively cooler periods	Start early and rest during most intense heat

CLIMATE CHANGE ISSUE	COMPONENT OF PASTORAL MANAGEMENT	ELEMENT OF PASTORAL MANAGEMENT	LIKELY IMPACT	ADAPTATION RESPONSE	EXAMPLES
		Infrastructure	More frequent (and perhaps severe) crises (e.g. water supply issues)	Copper-plate water supplies for livestock (see relevant information from the DKCRC WaterSmart project, e.g. James and Bubb 2008)	Back-up and suitably equipped bores where continuous supply is problematic; provide additional storage volume; shift stock to areas with more secure supply, etc.
	Stock welfare	Infrastructure	Access to stock waters may need to be increased (walking distances reduced); shade structures over water troughs may be required; previously marginal stock waters may become unusable (salt levels or supply rates)	As above (i.e. increase security and quality of water supplies for livestock)	Shade structures; more water points (less walking distance)
		Land management – shade trees?	Stock may become stressed and seek increased shade – availability needs to match numbers	Manage land to ensure tree replacement (in open country) occurs regularly	
	Livestock production	Water points	Reduced grazing distance – stock seek shade and graze a shorter distance from water	Increase water supply	Pipe water closer to sources of useful forage (but don't increase total stock numbers)
Warmer in all seasons	Livestock water supply	Dams and earth tanks	Increased evaporation and less secure supply	Replace dams having limited catchments (i.e. poor supply) with piped water from reliable bores	

CLIMATE CHANGE ISSUE	COMPONENT OF PASTORAL MANAGEMENT	ELEMENT OF PASTORAL MANAGEMENT	LIKELY IMPACT	ADAPTATION RESPONSE	EXAMPLES
				Where catchments suitable, sink deeper dams with steep batters to extend supply and reduce evaporation	Useful information in the WA Department of Agriculture technical bulletin *Dam design for pastoral stock water supplies* (Addison et al. 2003)
				Cover water surface to reduce evaporation	Plastic film, tyres, etc. as per WaterSmart project
	Livestock production	Livestock nutrition – more grass and less herbage (C_3 to C_4 pasture compositional change)	Reduced palatability and nutritional value (lower digestibility and protein content)	Provide supplements to increase intake and forage value	Urea, non-protein nitrogen (cottonseed meal, etc.)
			Possible increased pasture biomass (albeit of lower quality)	Change livestock enterprise (different type and/or class of livestock)	From sheep to cattle or goats; from fattening to breeding, introduce *Bos indicus* genetics, etc.
				Possibly increase stocking rate to utilise increased forage supply (when available)	
				Maintain existing stocking rate and improve drought buffering	Carry-over of low-quality forage (mainly dry grasses) heading into drier years
		Nutrition of lactating cows and/or ewes	Reduced reproduction rate; increased mortality	Wean rigorously and regularly	

CLIMATE CHANGE ISSUE	COMPONENT OF PASTORAL MANAGEMENT	ELEMENT OF PASTORAL MANAGEMENT	LIKELY IMPACT	ADAPTATION RESPONSE	EXAMPLES
		Reproduction rate	Reduced fertility due to longer exposure to higher ambient temperatures	For merino sheep, join and lamb in cooler periods of year (success of this tactic will be related to adequate nutrition)	
				Alternatively, shear ewes prior to lambing?	
			Heat stress	Change livestock enterprise (different type and/or class of livestock)	Tropical adapted cattle breeds; short-haired, light-coloured coats; wooded/ timbered paddocks for joining and calving (i.e. ample shade)
					Meat-sheep breeds that shed wool/hair rather than merinos; wooded/ timbered paddocks for joining and lambing
				Actively develop markets for alternative, heat-tolerant species	Camels, goats??; this requires a long-term strategy and persistence
		Water supply	Tolerance for poor quality water reduced	Provide secure sources of clean water for livestock	Lids on tanks; pump out of dams to tanks and troughs; reduce reliance on salty bore water (where possible)

CLIMATE CHANGE ISSUE	COMPONENT OF PASTORAL MANAGEMENT	ELEMENT OF PASTORAL MANAGEMENT	LIKELY IMPACT	ADAPTATION RESPONSE	EXAMPLES
		Distance to water	More energy (and time) required for walking as forage supplies dwindle and livestock have to graze further from water	Take water to the feed (i.e. reduce grazing distance)	Additional waterpoints by piping; increase number of tanks and troughs, dams, etc.
Increased rainfall variability	Drought preparedness (drought likely to be more frequent and severe)	Stocking rate	More variable forage supply	Stock conservatively (manage for the next year being dry)	More conservative levels of safe pasture utilisation (e.g. 15% reduced to 10%); lower defoliation rates (increased grazing height) for palatable perennial grasses
				Recognise/accept deteriorating seasonal quality early and reduce livestock numbers accordingly	Trader approach to forage supply; use agistment to utilise additional forage following infrequent wetter periods
				Change enterprise to an agistment-based operation	
		Feral animal control	Increased grazing pressure	Ruthlessly control manageable feral herbivores (i.e. total grazing pressure)	
	Drought policies – State and Federal	Economic stability	Drought relief may become too expensive for Governments to continue	Landholders become dependent on their own management actions (a desirable outcome)	

CLIMATE CHANGE ISSUE	COMPONENT OF PASTORAL MANAGEMENT	ELEMENT OF PASTORAL MANAGEMENT	LIKELY IMPACT	ADAPTATION RESPONSE	EXAMPLES
	Maximise rain use efficiency	Land condition	Land in poor condition has reduced opportunities for effective growth of productive pasture	Repair leaky landscapes	Ecosystem Management Understanding™ (EMU) principles; ponding banks and other land reclamation activities as appropriate; paddock rotation to allow pasture regeneration through resting, wet season spelling, etc.
				Where feasible, increase palatable perennial component of pasture (i.e. critical stock forage)	Apply grazing land management principles and related strategies and tactics as regionally appropriate
				Reduce competition from woody weeds (invasive native scrub)	Maximise opportunity for, and effectiveness of, managed fire following infrequent wetter periods; implement other cost-effective options for reducing woody density as regionally and legally appropriate
Lower winter rainfall	Opportunistic cereal cropping on eastern and southern margins of rangelands	Soil management	Reduced opportunities for a successful crop	Implement best practice from adjacent non-rangeland cropping areas	Seasonal forecasts as an integral part of cropping program; zero-till; maximise soil protection through stubble management

CLIMATE CHANGE ISSUE	COMPONENT OF PASTORAL MANAGEMENT	ELEMENT OF PASTORAL MANAGEMENT	LIKELY IMPACT	ADAPTATION RESPONSE	EXAMPLES
	'Abandoned' cropping lands too small to be run as pastoral enterprises, i.e. 'Goyder line' type areas move south	Vegetation and soil management	Cropping could carry on too long and soil loss accelerates and/or overgrazing of pastures results because properties are too small; difficult to re-establish rangeland species in long-term cropping country	Social restructuring may be required – adjoining pastoral properties may have opportunities to increase operational size	
	Livestock production	Livestock nutrition – more grass and less herbage (C_3 to C_4 pasture compositional change)	Reduced palatability and nutritional value (lower digestibility and protein content)	Provide supplements to increase intake and forage value	Urea, non-protein nitrogen (cottonseed meal, etc.)
		Drought resistant perennials (including woody species) advantaged in some instances or drought avoiding plants (annuals) become dominant	Reduced pasture supply for stock over the year.	Use available (and legal) land management and grazing strategies to minimise undesirable changes in vegetation composition (paddock spelling to regenerate desirable species, controlled burning, etc.)	
Increased evaporation (and evapo-	Livestock water supply	Dams and earth tanks	Increased evaporation and less secure supply	As above for climate change issue 'warmer in all seasons'	

CLIMATE CHANGE ISSUE	COMPONENT OF PASTORAL MANAGEMENT	ELEMENT OF PASTORAL MANAGEMENT	LIKELY IMPACT	ADAPTATION RESPONSE	EXAMPLES
transpiration)	Livestock production	Forage availability / budgeting	Shorter growing season following effective episodic rainfall in any season	Maximise rain-use efficiency by encouraging palatable perennials where possible; repair leaky landscapes; maintain optimal ground cover (including litter) to promote infiltration and reduce evaporation	
Generally lower humidity	Uncertain (lower humidity may actually be a bonus: e.g. reduced risk of fly strike in merino sheep)				
More intense rainfall	Infrastructure	Maintenance and repair	Increased requirement – both in amount and frequency (repeat maintenance)	Replace/relocate with more appropriate and robust infrastructure	Better sited fences, waterpoints, yards, roads, etc.; appropriately engineered crossings for watercourses and creeks; rapid response when key fences crossing creeks/ watercourses are lost; humps on roads, tracks and fence lines to divert water flow and minimise erosion; increased safety margins on dam walls and wings; silt traps in front of dams, etc.

CLIMATE CHANGE ISSUE	COMPONENT OF PASTORAL MANAGEMENT	ELEMENT OF PASTORAL MANAGEMENT	LIKELY IMPACT	ADAPTATION RESPONSE	EXAMPLES
		Insurance premiums	Either increased cost of existing premiums or insurance becomes essential (for assets not currently insured)	As for maintenance and repair (above) – on-ground action to reduce risk	
	Long-term productivity	Soil management	Increased risk of erosion (scalding and gullying); productive landscapes that become progressively more leaky	Maintain critical levels of ground cover including plant basal cover; reduce and slow overland water flow and avoid channelling of such flows	Set minimum acceptable ground cover targets for each land type and manage appropriately to achieve these; appropriately sited and maintained infrastructure (particularly fence lines, roads and tracks); minimal and careful use of graders

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Adaptation User Guide

Mary-Anne Healy

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15. Adaptation User Guide

15.1 Introduction

The climate predictions (and observations) show that it is getting hotter. This will impact on people's ability to live and work in the way that they have been able to in the past. It will also impact on plants and animals and their ability to thrive. To help plan for adaptation to those changes, the Rangelands Cluster Project has produced a series of information reports about relevant topics.

This section aims to provide some guidance for bringing the information into regional NRM planning processes.

Table 15.1 outlines the stages that are necessary for planning for climate change adaptation; the rest of the section is based on the five stages outlined.

Table 15.1 Stages in planning climate change adaptation

STAGE	QUESTION
Information	What do we need to know about rangelands resources and climate – both historic and existing data?
Projections	How might the climate change in the future and what impact could that have?
Adaptations	What might be the best/most appropriate adaptations?
Planning	How can we use the information and projections as well as adaptation advice in NRM planning, and what are the short-term (e.g. to 2030) and longer term (e.g. 2090) implications?
Process	What is a process that can use information at hand as well as projections to identify potential impacts and possible actions/adaptations?

15.2 Information

In the Rangelands Cluster Project, the NRM organisations and the researchers worked together to determine what the information needs were related to NRM planning for climate change and to prioritise what work should be done as part of the project. This process is outlined in Chapter 1: Introduction.

A series of subprojects were agreed upon, covering topics including:

- Rainfall and pasture growth
- Meteorological drought
- Heatwaves
- Ground cover
- Fire
- Dust
- Buffel grass
- Feral animals
- Aquatic ecosystems
- Native species
- Pastoral production
- Guidance to support climate change adaptation

Reports were produced for each of the subprojects (the preceding chapters in this document). These reports use existing data and information and relate them to projected changes to provide contemporary, relevant, rangeland-specific information to support NRM organisations to include climate change adaptation as part of their NRM planning. Some subprojects provided tools or other resources to support planning processes at a regional level.

15.3 Projections

The table below includes a summary of the predicted changes in a range of climate variables within the rangeland cluster region by 2090. This information is taken from Chapter 2: Projections from Australia's NRM regions (Watterson et al. 2015).

Table 15.2 Predicted changes in climate variables

CLIMATE VARIABLES	PROJECTED CHANGE	CONFIDENCE
Temperature	Increase in all seasons	Very high
Extreme temperatures	Increase in hot days and warm spells Decrease in frosts	Very high High
Rainfall variability	Remain high	High
Extreme rainfall events	Increase in intensity	High
Winter and spring rainfall	A decrease in the south likely	High
Summer and autumn rainfall	Trend is unclear	
Drought	Increase over the course of the century	Medium
Potential evapotranspir ation	Increase in all seasons	High
Mean sea level	Continue to rise	Very high
Height of extreme sea-level events	Increase	Very high

15.4 Adaptation

Adaptation to climate change in the rangelands will depend to some degree on land use. The predicted changes will impact across the landscape and all major land uses/activities in the rangelands, including:

- Pastoral production
- Mining
- Conservation and Indigenous Protected Areas
- Towns/communities
- Tourism

The information contained in this document is focused on the management of natural resources and their use for pastoral production and nature conservation. Considering the information in the chapters included in this report, in the rangelands the key climate change adaptation messages in relation to natural resource management are:

- Manage grazing pressure and maintain ground cover
- Preserve and manage refugia for native flora and fauna
- Be prepared and flexible: use all available climate and forecasting information when planning
- Keep people in the landscape to manage and maintain natural resources

A major challenge is how to use the information available to plan for uncertainty. Pastoralists are generally skilled at doing this in the short term, as the climate and seasons are always unpredictable. It will become important for NRM managers and planners to gather up available current information and examples to help with this planning and to help identify thresholds where changes in management responses or even systems are required.

Each chapter has provided adaptation options relevant to the topic under consideration.

In Chapter 13, Tom Measham provided a framework for assessing vulnerability and considering potential responses (Measham 2014).

In Chapter 14, Gary Bastin and others used the framework to suggest impacts of climate change on pastoral production and to suggest adaptation responses, including specific examples (Bastin et al. 2014).

The remainder of this chapter aims to assist NRM planners and NRM groups to use the information included in the preceding chapters, as well as other data and information available to them, in a methodical way to consider the potential impacts of climate change and what actions need to be built into NRM plans.

15.5 Planning

15.5.1 NRM Adaptation Checklist

Nationally, the AdaptNRM project has been working on an NRM Adaptation Checklist to support climate adaptation planning and decision-making (Rissik et al. 2014). This information can be found at: http://adaptnrm.csiro.au/adaptation-planning/.

The NRM Adaptation Checklist has been developed to support NRM planners to take stock of their plans, evaluate the degree of climate readiness and assess the actions that are required to develop a climate-ready plan. The approach has been designed to be consistent with planning approaches used by NRM groups, from adaptive management to resilience and risk management frameworks. The approach is developed to be fit for purpose and not to prescribe how to deal with issues, but rather to highlight the main issues and support gradual improvement.

To achieve this, the authors outline four key challenges associated with adapting to climate change in NRM planning. These include:

1. Making decisions for multiple possible futures: NRM planners must find ways to plan that are consistent with the range of likely futures and possible desired outcomes. This necessarily involves a degree of uncertainty, but this need not be a barrier to planning.
2. Employing flexible and adaptive planning processes: New information will continue to emerge about the likelihood of future climates and consequences, and planners may need to develop plans that are even more flexible and/or more rapidly adapted to incorporate this new information.
3. Explicitly identifying and preparing for likely future decisions: Plans need to prepare for future decisions, including understanding which decisions need to be made now and which could or should be made later, identifying and monitoring the triggers that indicate when a decision needs to be made, and planning to gather information to support future decision-making.
4. Strengthening the adaptive capacity of people and organisations: There are many people and organisations that manage and depend on natural resources. Successful development and implementation of plans ultimately depends on the capacity of people to be flexible and adaptive throughout all phases of the planning process.

The checklist for NRM planning frameworks developed in the guide is intended to support self-evaluation by NRM groups of their current ability to meet these four challenges. It is built around five common stages or components: (i) assessment, (ii) strategic planning, (iii) implementation planning and action, (iv) monitoring, and (v) reflection. These are built into an iterative process, which is necessary because the most effective responses to climate change problems may not be known, and outcomes may only be achieved after trying a range of options, assessing the responses and making appropriate changes. From this, a series of self-reflective questions are posed to discuss the ways in which planning to adapt to climate change may need to be done differently compared with what might have been done traditionally. The generic approach taken ensures that the guidance is relevant to all NRM groups, regardless of the specific planning approaches that have been followed to date.

15.5.2 Timeframes

In the projections information, two timeframes are used: 2030 and 2090. These are to enable both shorter term responses and to plan for the transformational changes that will be required by 2090 under even moderate projections scenarios.

- **2030** – In this nearer timeframe, the focus is still on good rangeland management as a way to achieve outcomes of sustainable pastoral production, conservation of habitat, refugia, sustainable water resources

- **2090** – In this more distant timeframe, the climate may be considerably different; transformational changes in management will need to have happened. In some parts of the rangelands, this will mean changing industry in response to limits.

The guidance included in this chapter is primarily directed at the shorter term planning and timeframe. But part of the planning in the short term is to gain a better understanding of likely impacts and options over the long term and when changes must occur.

15.6 Process for planning for adaptation in the rangelands

Planning for climate change adaptation in the rangelands encompasses many unique challenges including:

- small (and declining) populations
- poor institutional and governance capacity, struggling to implement delivery models based on closer settled coastal communities
- limited investment in and access to rangelands-specific information and expertise
- low socio-economic status communities
- large distances
- different seasonal 'cycles' from temperate Australia (i.e. not four seasons)
- production systems that mostly rely on managing naturally occurring systems for production outcomes.

It involves taking what is known (the information provided from observations and interpretation), considering the likely impacts of the projected changes and the risks associated with those impacts and deciding what actions should occur. Layered with this is the need to prioritise according to what is important to communities and NRM organisations and how much funding is available to carry out actions.

The Introduction (Chapter 1) of this document outlines the process of deciding what topics (subprojects) were considered important to be included in the Rangelands Cluster Project. Once the subprojects were completed, further discussions were held with NRM planners, program managers and other experienced practitioners. Their concern was how to incorporate the information that was available, both through the Rangelands Cluster Project and other information and research they had commissioned, into their NRM plans; that is, how to develop meaningful management action and resource condition targets.

Different concepts were tested and trialled, resulting in the Impact–Action Framework (also nicknamed the 'Dubbo framework' after the place where the framework was developed). The framework was found to be flexible, adaptable and able to operate at different levels: an NRM Board could have a high-level strategic discussion about the issues, while a group of technical experts could have a much more detailed discussion and populate the table at a more detailed level. It was felt that the simplicity of the model was its strength.

The following steps outline how to use the framework, and the content from these steps is placed into the framework (as shown in the partially worked example following the list of steps).

15.6.1 Impact–Action Framework

Methodically working through the information available and considering each of the likely climate impacts enables a process of identifying risks and impacts and ultimately establishing priority actions.

Each of the previous chapters in this document includes relevant information for each step. Chapter 2 contains the projected climate impacts for Step 1 (with more detail available at: http://www.climatechangeinaustralia.gov.au/en/). Chapters 3–14 include issue-specific information for Step 2. Each of these may or may not be relevant to your region.

The projected/likely climate impacts derived from Step 1 are placed down the left-hand side of the framework on the next page. Then along the top of the framework, the different attributes or issues for which adaptation information and options were available are listed. Along the bottom is a row to put priority actions that came out of the discussion and that may become management action targets in the NRM plan.

Working through the framework, each topic is looked at and the likely risks and impacts of the climate projections considered. As the example is worked through, the priority action for some issues becomes very clear, as a focus on a particular action will support adaptation in a range of areas. This may be supported by the suggested adaptations included in the various reports produced as part of the Rangelands Cluster Project.

The partially worked example on the following page shows this process as worked for the Western Local Lands Services.

For your region:

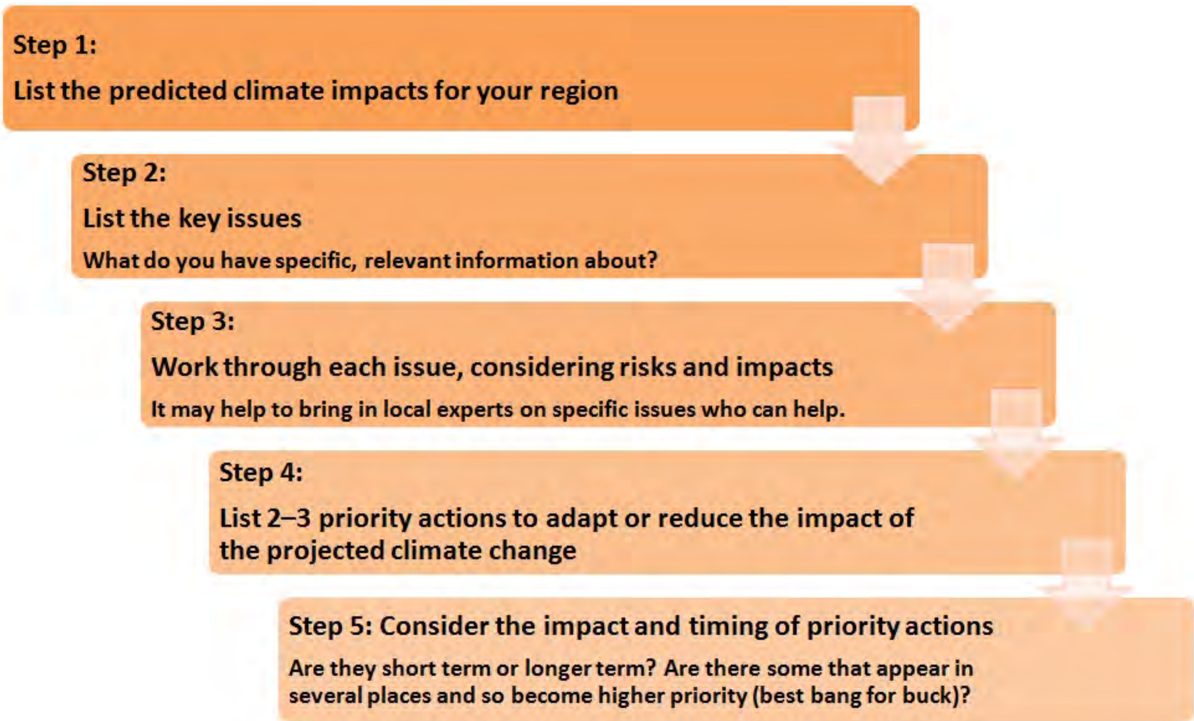

Figure 15.1 Steps to filling in the Impact–Action Framework

Table 15.3 The Impact–Action Framework, including a partially worked example using Western Local Land Services region

	RAINFALL AND PASTURE GROWTH	METEOROLOGICAL DROUGHT	HEATWAVES	GROUND COVER	FIRE	BUFFEL GRASS	DUST	AQUATIC REFUGIA	NATIVE SPECIES	INVASIVE ANIMALS	PASTORAL PRODUCTION
Increased temperatures				• Shorter growing period • Quicker breakdown	Increased: • Risk • Fire season • Intensity • Impact on refugia • Rate of spread • WHS risk control			Reduced refuges/ quality			
Increased extreme temperatures				• Shorter growing period • Quicker breakdown	Increased: • Risk • Fire season • Intensity • Impact on refugia • Rate of spread • WHS risk control			Reduced refuges/ quality			
Highly variable rainfall				• Reduced perennials • Reduced seedbank • Changed species composition	Shorter recovery period			Reduced refuges			
Increased rainfall intensity				• Increased erosion • Seed movement	• Redistribution of fuel • Reduced continuous fuel • Increased lightning or ignition			Turbidity Sedimentation			
Decreased winter rainfall				• Changed species composition • Decrease in biomass • Decrease perennials	• Reduced fuel • Increased length of fire season			Reduced persistence			
Increased evapotranspiration				• Shorter growing period • Decreased groundcover	• Reduced fuel • Increased fuel curing • Reduced time for prescribed burning			Reduced refuges			
Priority ACTIONS				➢ Total grazing pressure management ➢ Episodic grazing	➢ Protect key assets ➢ Plan ➢ Mosaic landscape ➢ Active preparedness			➢ Prioritisation ➢ ID key refugia			

15.7 Summary

There are many issues that will be impacted by a changing climate. This document includes some of the topics selected by those involved in the Rangelands Cluster Project, providing information and a clearer understanding of likely impacts and potential adaption options.

This chapter has aimed to provide a simple process for use at NRM Board, NRM organisation/staff or community level to incorporate that information, and other information that may be accessible, into regional NRM planning processes by supporting development of priority actions.

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Abbreviations

IN ALL REPORTS IN THE SERIES	
TERM	**DEFINITION**
ABS	Australian Bureau of Statistics
ACRIS	Australian Collaborative Rangelands Information System
AFCMP	Australian Feral Camel Management Project
BoM	Bureau of Meteorology
BS	bare soil
CMA	Catchment Management Authority
DKCRC	Desert Knowledge Cooperative Research Centre
DSI	Dust Storm Index
EI	Ecoclimatic Index
EMU	Ecosystem Management Understanding™
ENSO	El Niño Southern Oscillation
FIFO	fly in, fly out
GAB	Great Artesian Basin
GCM	General Circulation Model
GDM	Generalised Dissimilarity Modelling
GHG	greenhouse gas
GW	Groundwater
GWW	Great Western Woodlands
IBRA	Interim Biogeographic Regionalisation for Australia
ICLEI	International Council for Local Environmental Initiatives
IPCC	Intergovernmental Panel on Climate Change
LEB	Lake Eyre Basin
LGM	last glacial maximum
MOF	manual observation frequency
mya	million years ago
NAFI	North Australian Fire Information
NCCARF	National Climate Change Adaptation Research Facility
NPV	non-photosynthetic vegetation: senescent pasture and litter
NRM	natural resource management

IN ALL REPORTS IN THE SERIES	
TERM	**DEFINITION**
OH&S	occupational health and safety
PV	photosynthetic vegetation: green
RCP	Representative Concentration Pathways
SAAL	South Australia Arid Lands
SDM	species distribution modelling
SW	Surface water
TGP	total grazing pressure
TM	Thematic Mapper
Western CMA	Western Catchment Management Authority
Western LLS	Western Local Land Service

Glossary

IN ALL REPORTS IN THE SERIES	
TERM	**DEFINITION**
Adaptive capacity	The ability to change and therefore reduce gross vulnerability; includes issues such as mobility, financial resources and education
Bioregion	A large, geographically distinct area of land that has groups of ecosystems forming recognisable patterns within the landscape
C_3 and C_4 plants	The different methods plants use to convert carbon dioxide from air into organic compounds through the process of photosynthesis. All plants use C_3 processes; some plants, such as buffel grass and many other warm climate grasses, also use C_4 processes. C_4 plants have an advantage in a warmer climate due to their higher CO_2 assimilation rates at higher temperatures and higher photosynthetic optima than their C_3 counterparts
Contentious species	A species that presents special challenges for determining the adaptation response to climate change, because it is both a threat and a beneficial species (Friedel et al. 2011, Grice et al. 2012)
Dust Storm Index (DSI)	The Dust Storm Index is based on visibility records made by Bureau of Meteorology (BoM) observers. The DSI provides a measure of the frequency and intensity of wind erosion activity at continental scale. It is a composite measure of the contributions of local dust events, moderate dust storms and severe dust storms using weightings for each event type, based upon dust concentrations inferred from reduced visibility during each of these event types.
DustWatch	DustWatch is a community program that monitors and reports on the extent and severity of wind erosion across Australia and raises awareness of the effects of wind erosion on the landscape and the impacts of dust on the community.

IN ALL REPORTS IN THE SERIES	
TERM	**DEFINITION**
Ecological refugia	Refugia defined according to the water requirements of the species they protect. The conservation significance of ecological refugia, and the priority assigned to their conservation, depends on the level of knowledge available for the species they support.
Evolutionary refugia	Those waterbodies that contain *short-range endemics* or *vicariant relics*. Evolutionary refugia are most likely to persist into the future and should be accorded the highest priority in NRM adaptation planning.
Generalised Dissimilarity Modelling (GDM)	A method of modelling based on compositional turnover of a group of species at a location; it considers whole biological groups rather than individual species
Gross vulnerability of a system	The combination of exposure and sensitivity of system
Heatwave	Continuous period beyond a week when a particular threshold temperature is exceeded
Hyporheic water flows	Below-surface flows
Indicators of exposure	Factors such as days above a certain temperature, days without rainfall, population density
Indicators of sensitivity	How sensitive a system is to hazards; indicators include the types of dwellings people live in and the percentage of the population with certain health characteristics
'No regrets' strategies	These strategies yield benefits even if there is not a change in climate
Novel ecosystem	Species occurring in combinations and relative abundances that have not occurred previously within a given biome (Hobbs et al. 2006)
Rainfall event	One or more closely spaced rainfalls that are large enough to produce a significant vegetation response

IN ALL REPORTS IN THE SERIES	
TERM	**DEFINITION**
Refugia	Habitats that biota retreat to, persist in and potentially expand from under changing environmental conditions
Return period	The number of days from the end of one rainfall event to the start of the next
Reversible strategies	Flexible strategies that can be changed if predictions about climate change are incorrect
Safety margin strategies	Strategies that reduce vulnerability at little or no cost
Short-range endemics	Species that occur only within a very small geographical area
Soft strategies	Strategies that involve the use of institutional, educational or financial tools to reduce species vulnerability to climatic change
Species Distribution Modelling (SDM)	A species-specific approach whereby observational records are used to model the current potential distribution of a species
Species invasiveness	A species that causes environmental or socioeconomic impacts, is non-native to an ecosystem or rapidly colonises and spreads (see Ricciardi and Cohen 2007). In the Invasive animals report it refers to non-native species (that is, those introduced to Australia post-1788) that have caused significant environmental or agricultural changes to the ecosystem or that are believed to present such a risk.
Strategies that reduce time horizons	Strategies that reduce the lifetime of particular investments
Vicariant relicts	Species with ancestral characteristics that have become geographically isolated over time

http://www.climatechangeinaustralia.gov.au
http://www.nintione.com.au