# Terrestrial Report Card 2013:

## Climate change impacts and adaptation on Australian biodiversity

Summarising knowledge on climate change impacts in Australian terrestrial and freshwater systems, and identifying knowledge gaps and adaptation responses

Australia's unique biodiversity has been shaped by the history of the continent and has significant social and economic value.

In 2007, the Intergovernmental Panel on Climate Change (IPCC) identified natural ecosystems as being the most vulnerable sector in Australia to the negative impacts of climate change.

Ecosystem health contributes to human health and well-being and provides essential resources including clean water and air, and supports major Australian industries including agriculture, tourism and fisheries.

Historical features, coupled with human changes to the environment, will influence the magnitude of future climate impacts. The reduction of greenhouse gas emissions is critical for reducing future biodiversity loss.

Adaptation management actions aim to minimise or avoid the negative impacts of climate change on biodiversity and ecosystem processes, and will need to be implemented, in association with, the reduction of greenhouse gas emissions.

### Key Findings

- ***Changes in the Australian climate have already been observed. Average annual temperatures on land have increased by nearly 1°C over the past 100 years.***
- ***Changes that are consistent with a climate change 'signal' are already discernible at the genetic, species, community and ecosystem levels across the continent.***
- ***Population losses and species extinctions are predicted, through a variety of direct and indirect impacts.***
- ***Climate change will likely interact with other stressors already experienced by our biodiversity.***

# The Australian **Climate**

| | What has happened | What is likely to happen this century |
|---|---|---|
| **Climate and Physical Changes** | | |
| **Atmospheric $CO_2$** | + $CO_2$ emissions have risen from ~280 ppm since ~1850 to ~400 ppm in 2013<br>+ The rate of emissions is accelerating, from ~1% p.a. in the 1990s, to nearly 6% in 2010[1] | + Emissions trajectories will depend on global mitigation efforts but the general expectation is for a doubling of pre-industrial levels by the end of the 21st century[2]. Emissions are currently tracking the highest emissions scenario described by the IPCC in 2007 |
| **Temperature** | + Average annual surface temperatures in Australia have risen +0.94ºC over the past 100 years[3] | + It is likely that warming will be greatest over inland Australia[4,5], however, coastal regions are predicted to experience the greatest change relative to current climate[208] |
| **Rainfall** | + SW Australia has become drier since the 1970s and autumn/winter rainfall has declined in the SE since the mid-1990s[6]<br>+ The NW has become wetter since the 1950s[7] | + There is high probability that rainfall will decline further in the SW and potentially in the SE[4,5,8]<br>+ In eastern and northern Australia, the direction of future rainfall change remains uncertain[4,5,9] |
| **Snow and frost** | + Late-season snow depth has declined significantly in the Snowy Mountains since the late 1950s[10] | + Models predict a very high probability that both snow depth and area will decline - e.g.: the area in mainland Australia with an average annual snow cover of at least thirty days is projected to decline by 14 - 54% by 2020, and by 30 - 93% by 2050[10] |
| **Sea level** | + Mean sea level has risen by around 1-2mm/year around Australia over the past century with rates of over 6 mm/year in northern Australia over the last 20 years[11] | + There is a high probability that sea level will rise, e.g.: up to 80cm this century, and continue to rise for at least several more centuries[12] |
| **Extreme events*** | | |
| **Temperature extremes** | + Hot days (>35ºC) have become more frequent and cold days (<0oC) have declined[13,14,15,16] | + Increased numbers of warm nights, fewer frosts and longer heat-waves are predicted to be very likely[13,14,17] |
| **Precipitation extremes[5]** | + There has been a strong decrease, since 1910, in the intensity of rain falling on very wet days, and in the number of very wet days, in south-west Australia. There has been a strong increase in the proportion of annual rainfall falling on very wet days in the north-east[18] | + Extreme rainfall events are projected to increase[5], although considerable spatial variation is expected[18] |
| **Drought** | + Regional warming has increased the intensity of recent droughts in south-eastern Australia[19,20,21] | + Climate models project that drought occurrence is likely to increase in southern Australia[22,23,24,25] |
| **Tropical cyclones** | + There has been no significant change in the number of tropical cyclones or the proportion of intense storms since the 1980s[26] | + It is possible that tropical cyclones may increase in intensity but decrease, or stay similar, in frequency[27] |
| **Fire** | + Extreme fire weather has increased since the 1970s especially in the southeast of the continent[28] | + It is highly likely that the number of very high fire danger days will increase in the south-east. Less certain projections are for no change or a decrease in the north-east)[29,30]<br>+ The effects of fire regimes will depend on interactions between weather, fuel mass and moisture, and ignition events[31,32,33] |
| **Extreme sea level events** | + There is some evidence of an increase in the incidence of extreme high sea levels (excluding tsunamis)[34] | + Projected sea level rise is highly likely to lead to large increases in the frequency of extreme sea level events[12,35] |

*Changes in the El Niño Southern Oscillation (ENSO) phenomenon in response to anthropogenic climate change are uncertain but could significantly influence rainfall and temperature extremes, droughts, fire danger, tropical cyclones, and marine conditions.

# Impacts on Terrestrial and Freshwater Biodiversity: **Species**

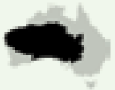
| | What is happening | What might happen* |
|---|---|---|
| **Mammals** | + Mass die-offs of flying foxes in extreme heat[36]<br>+ Reduction in occurrence of platypus linked to increased maximum temperatures[37]<br>+ Decline in koala distribution and density associated with drought[38] | + Population declines, and distribution shifts - most likely poleward and/or to higher altitudes[39,40,41,42,43]<br>+ Changed community dynamics as species distributions and life cycles change[44]<br>+ Decline in palatability of leaves for species such as koalas[45]<br>+ Increased mortality due to extreme heat stress, e.g. in tropical montane marsupials[46] |
| **Birds** | + Changes in timing of life cycle events, including breeding and migration[47,48,49,50]<br>+ Breeding failures in a number of species[48,51,52]<br>+ Shifts in average body size, some passerine species becoming smaller[47,53]<br>+ Heat-related deaths in Carnaby's cockatoos[54]<br>+ Decline in wetland bird populations associated with reduced flooding extent and frequency[55]<br>+ Shifts in distributional and altitudinal ranges, most commonly to higher latitudes and altitudes[49,56] | + Negative impacts on foraging behavior and success with seasonality changes[57,58]<br>+ Reduced breeding success in beach nesting species with sea level rise[50]<br>+ Increased heat-related deaths[59]<br>+ Declines in fire sensitive birds[60] as a result of changed fire extent, frequency and intensity |
| **Reptiles** | + Shifts in sex ratios (less males in warmer conditions) in a live-bearing skink[61]<br>+ Indirect effects on survival due to impacts on prey species[62]<br>+ Declines in freshwater turtles associated with drought and habitat drying[63] | + Altered thermoregulatory behavior and microhabitat use in oviparous species with temperature dependent sex determination[64]<br>+ Reduced breeding and offspring success due to higher incubation temperatures[65]<br>+ Reduction in growth rates in juvenile Western Swamp Tortoise[66]<br>+ Estuarine crocodiles could move southward, increasing human-crocodile conflict[67] |
| **Amphibians** | + Population declines associated with drought[68] | + Alpine, bog and peatland species threatened by drying and fire impacts[69,70]<br>+ Tropical and high elevation species negatively affected by changes to seasonal rainfall and increased temperatures[71]<br>+ Reduced soil moisture may decrease egg survival and fitness[72,73]<br>+ Loss of ephemeral breeding ponds and sites[74]<br>+ Increasing temperatures could result in faster development and emergence times in some species[75]<br>+ Terrestrial breeding frogs vulnerable from delayed Autumn rains[76]<br>+ Potential for climate change to increase the prevalence of the amphibian chytrid fungus[77] |
| **Invertebrates** | + Genetic and distribution changes, reflecting a warmer climate, in *Drosophila* (fruit fly)[78,79]<br>+ Earlier emergence time of the common brown butterfly[80] | + Shifts in community composition - higher species richness at more temperate latitudes[81,82]<br>+ Disruption and mis-timing of plant-pollinator relationships[83]<br>+ Mismatch between pest species and their natural enemies[84] |
| **Freshwater Fish** | + Decline in five fish species of conservation significance, associated with prolonged drought, in the South Australian Murray-Darling Basin[85] | + Range contractions as a result of rising water temperature, altered flows and habitat loss[86]<br>+ Invasive species predicted to increase and spread[87]<br>+ Increases in salinity expected to negatively affect species in the Murray-Darling River[88], South-West Western Australia[89] and Kakadu[88]<br>+ Species preferring cold-water most likely to be under stress in Murray-Darling Basin, especially in Lower Murray Region[90] |
| **Freshwater Invertebrates** | + Decline in ecological condition, as measured by macroinvertebrates, in Victoria[91]<br>+ Widespread reduction in species that prefer cooler, fast-flowing water bodies[92] | + Decline in warm temperature intolerant species[93]<br>+ Increased distribution of invasive New Zealand freshwater snails[87]<br>+ Loss of habitat for burrowing crayfish[94] |

| | | |
|---|---|---|
| **Plants** | + Phenological shifts including earlier flowering times[95,96,97]<br>+ Drought-related death in the Tasmanian Miena Cider Gum[98]<br>+ Decline in sphagnum moss in the Australian Capital Territory, New South Wales and Macquarie Island[99,100]<br>+ Morphological shifts in leaf traits linked to warming climate[101] | + Preferred climate for seedling development may move beyond dispersal distance, resulting in seedling establishment failure[102]<br>+ Weed species will shift range, altering community dynamics and competitive Interactions[103,104]<br>+ Increased mortality during drought of heat-sensitive species[105]<br>+ Further shifts in flowering times - most predicted to flower earlier[96]<br>+ Breeding failures due to loss/mis-match of pollinators[106]<br>+ Some obligate seeding species may experience temperatures too high for germination to occur[107]<br>+ Potential negative impacts of wildfires on long-lived endemics[108] |

* There is a very real potential for the extinction of many species, particularly endemic species in mountain ecosystems. Predicting extinction is difficult, however, many studies in Australia, and globally, predict extremely severe declines and potential extinctions across a wide range of taxonomic groups and ecosystems[209,210,211,212,213,214]

## Impacts on Terrestrial and Freshwater Biodiversity: **Habitats and Ecosystems**

| | What is happening | What might happen |
|---|---|---|
| **Australia wide** | + Woody thickening - an increase in the density of trees and shrubs at the expense of grassland species - is occurring across all major Australian ecosystems[109]<br>+ For some terrestrial species, increased woody vegetation may provide more habitat, but other species that rely on open habitats could be threatened or outcompeted by encroaching shrubs and trees[110] | + Thickening is predicted to be a major issue as climatic changes progress[109]<br>+ Some species will be directly threatened by woody thickening - the endangered golden shouldered parrot, endemic to Cape York Peninsula, is threatened by increased predation risk and impacts of thickening on seasonal food availability[111]<br>+ Prescribed burning can stall thickening but timing of the burn is vitally important - in the north, burning in the late dry season and storm-season favours the maintenance of grassland, while burning at other times favours the woody species[112] |
| **Mediterranean forests, woodland and shrublands**  | + Lower annual rainfall and increased water abstraction have lowered groundwater levels and negatively affected native vegetation[113]<br>+ Tree mortality and progressive floristic change towards drought tolerant species in *Banksia* woodlands[114,115,116]<br>+ Extreme drought and heat resulted in tree crown dieback in eucalypt forest[117]<br>+ Lower rainfall and seasonal shifts in intensity have resulted in declines in streamflow, soil water storage and groundwater levels, affecting flora[118,119] | + Projected declines in rainfall,[120] streamflow[121] and groundwater levels[122] resulting in ecosystem stress and changes in community composition[123,116,124]<br>+ Projected temperature increases and rainfall declines may negatively affect South West Australian Floristic Region's endemic and Australian wide plant diversity[125,126,127]<br>+ Suitable habitat will decline for many endemic *Banksia* species[126,127]<br>+ Community composition changes as susceptible species decline in Western Australia[126] |
| **Temperate forests, woodlands and grasslands (including montane and rainforest)**  | + Increase of mire wetland associated with contraction of eucalypt woodland in south-east Australia[128] | + Production could increase where rain is not limiting, due to increased $CO_2$[129,130]<br>+ Reduced forest cover associated with soil drying[129]<br>+ Generally earlier grass [130] and tree flowering[132]<br>+ Loss of carbon stocks through changed fire regimes and drying[133,134,135] |
| **Tropical savanna and grasslands**  | + Plant mortality following drought[136,137]<br>+ Expansion of rainforest at expense of eucalypt savanna and grassland in Northern Territory and Queensland associated with increased rainfall and $CO_2$ [138,139]<br>+ Increasing canopy cover in tropical savannas[140] | + Shift in composition could occur from perennial Mitchell grasses to annual grasses or forbs[141]<br>+ Shift from C4 to C3 plants[142] |
| **Tropical and sub-tropical rainforest** | + No reported impacts at time of press. | + Increasing floristic turnover for species at the altitude of the cloud base[143]<br>+ Changes to structure of rainforest canopy[144] |

| | | |
|---|---|---|
| **tropical rainforest**<br> | | + Changes to structure of rainforest canopy<br>+ Damage to susceptible species from high-intensity cyclones[145] - and subsequent potential for weed invasion[146]<br>+ Increased growth of vines with increased $CO_2$, leading to tree mortality[147]<br>+ Drying of tropical montane cloud forest, reducing productivity[148]<br>+ Rainforest contraction with increased fire frequency, favouring fire-tolerant species[149]<br>+ Short term heat events and drought likely to affect cool rainforest species more than dry rainforest species[150] |
| **Arid and semi-arid regions**<br> | + Vegetation thickening in semi-arid mulga woodlands in southwest Queensland[151] | + Altered competition between C3 and C4 grasses, favouring C4 species[142]<br>+ Relatively flat landscape may mean community change will be widespread and more extensive than in other regions, as there is little opportunity for altitudinal shifts[152]<br>+ Reduction in patches of fire-sensitive mulga in spinifex grassland could lead to increase in spinifex[153] |
| **Alpine regions**<br> | + Decline in depth and duration of snow cover[154]<br>+ Tree line shifts of 30-40 m in altitude in 25 years in Victoria[155]<br>+ Increase in shrub cover and decrease in grass cover particularly in response to drought[156] | + Decline in specialist alpine ecosystems e.g. snow patch herb fields, cushion plants[157]<br>+ Contraction of fens and bogs[158]<br>+ Some native and feral mammals projected to move to higher elevations[159]<br>+ Encroachment of snow gums into subalpine grassland and higher elevations[155]<br>+ Frost damage in snow gums due to interaction between warming and increased $CO_2$[160]<br>+ Generally earlier time of flowering, seed set and budding with associated fitness effects[161,162] |
| **Inland wetlands and waterways (including peatlands)**<br> | + General reductions in flow and changed seasonality of flow, causing drying[163,164]<br>+ Contraction of *Melaleuca* swamp forests in Kakadu due to intrusion of salt water[165]<br>+ Drought-related mortality in floodplain forests[166] | + Degradation and drying of peatlands[127]; drying of wetlands; loss of seasonal ponds[127]<br>+ Drought conditions likely to become more common in Murray-Darling Basin, south-east and south-west Western Australia[163]<br>+ More frequent burning of peaty sediments in wetlands[167]<br>+ Loss of taxa intolerant of temperature rises[168]<br>+ Shifts to species-poor, salt-tolerant biota in southern wetlands with drying climate[164]<br>+ Saltmarsh and wetlands affected by landward movement of mangroves[138] |
| **Islands***<br> | + Faster seed maturation with increased warming[169] | + Change in mossy cloud layer may lead to reduced occult precipitation which affects the ability of vegetation to harvest moisture[109]<br>+ Changes in vegetation cover and loss of endemic flora and fauna[170,171]<br>+ Erosion of dunes, coastal cliffs and rocky shore platforms[172]<br>+ Changed fire regimes[173]<br>+ Deglaciation; establishment of introduced species in ice-free ground[174]<br>+ Fundamental changes in the condition of subantarctic lakes and ponds[109] |
| **Coastal** (estuarine, sandy, rocky)<br> | + Increase in mangrove extent (1974-2004) in Northern Territory, likely due to rising sea levels and increased $CO_2$[175]<br>+ Landward mangrove expansion linked to increased rainfall in the North east[176]<br>+ Change to structure and composition in Tasmanian saltmarsh community[177] | + Marine inundation of terrestrial systems with sea level rise[178]<br>+ Rocky shore and saltmarsh species vulnerable to total loss of habitat[179]<br>+ Coastal squeeze - coastal habitats trapped between landward boundaries and rising sea level[180] |

* Include: Heard, McDonald, Macquarie, Frasier, Christmas, Torres Straits; Lowe Howe and Norfolk Island groups

Donkey Orchid. Photo: Jo Isaac

Boyds forest dragon. Photo: Steve Williams

c

## Climate Change Adaptation Management

While some terrestrial and freshwater species may have an inherent capability to adapt through evolutionary, behavioural, ecological and/or physiological mechanisms, many more will require management intervention to increase their resilience to the negative impacts of climate change, and to maintain ecosystem services. Adaptation options could include:

### Landscape Management:

- Identifying and protecting climate change refugia[181,208] – refugia are areas in the landscape that are buffered from extreme weather by features such as a dense canopy and heterogenous topography[182].
- Facilitating the inherent adaptive capacity of species and increasing population sizes by habitat restoration[183,184], and by increasing and managing landscape connectivity[183,184].
- Flexible management of protected areas in light of climatic changes – acknowledgement that novel communities will arise due to range shifts in both native and exotic species[185].
- Managing other stressors – such as reducing exotic pest and predator species, soil and water degradation, reversing over-harvesting, managing grazing pressure, and managing risks of adverse fire regimes[186].

### Species-specific Management

- Microhabitat manipulation – such as provision of shaded nest boxes for birds, bats and possums[187] etc, artificial shelters such as log piles and pond sites for reptiles and frogs, and misting/sprinkling for frogs[188].
- Genetic translocation[189,190] – moving individuals/genes between populations to increase genetic diversity and resilience to environmental change. Assisted colonisation[191,192,193] – moving plants or animals from areas which have become climatically unstable to a new sites, outside their current range, where conditions are expected to be suitable.
- *Ex-situ* conservation strategies[194] – seedbanking (storing seeds or other germplasm in vaults for future replanting), captive breeding of endangered species[60].

## Interactions between Climate Change and Other Stressors

Identified climate change impacts will likely be exacerbated by acting synergistically with other threats to biodiversity such as habitat loss and land-use change, introduced species and diseases, and altered water resources[195].

### Habitat loss and land-use change:

Increasing urbanization, farming and other land-use changes will potentially act as barriers to distributional shifts as species respond to the changing climate. Many species will be unable to cross modified habitats, potentially leaving them stranded in habitats that will increasingly become climatically unsuitable[196].

Additionally, climate change will itself result in the loss of habitats in certain regions, such as montane areas and coastal fringes.

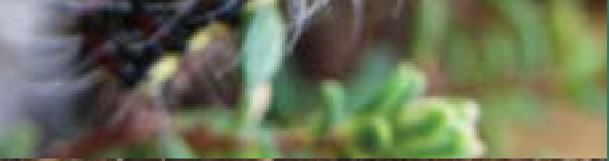
These interactions will increase extinction risk for many species, and potentially contribute to a more homogenized flora and fauna. Habitat restoration and increasing connectivity of habitats is key to reducing this risk, along with ensuring remaining habitats remain intact. More active interventionist

bats, and rodents also have the potential to affect the distribution and spread of diseases[204,205,206].

Adaptation strategies in the face of these threats will include control and possible eradication of introduced species, tightening of quarantine and biosecurity measures, and education of landowners about introduced species and their impacts.

### Water extraction and pollutants:

As some regions of Australia become hotter and drier, the volume, quality, and seasonality of river flows will be affected, in turn affecting the ecological integrity of catchments and associated biodiversity, and exacerbating the existing conflicts between environmental and human needs. Any increase in water extraction, diversion and storage to increase water



**Caterpillar.** Photo: Jo Isaa

**Echidna, Warrandyte.** Photo: Lynda Chambers

**Nymph.** Photo: K Martin-Smith

methods such as assisted colonization may be a suitable strategy for a limited number of vulnerable species[197].

### Introduced species, pests and disease:

Climate change will likely interact with introduced species, including weeds and feral animals. Problem species such as buffel grass[198], fire ants[199], prickly acacia[200] and cane toads[201], may expand their range, with implications for biodiversity. Introduced species that are not currently causing significant problems (such as so-called 'sleeper' weeds) may become problematic if climate change results in expanding populations[202]. However, the range of some pest species may decline, and management efforts should adapt accordingly.

Additionally, climate change may influence the prevalence and virulence of some diseases. Changes in climate and urban water storage practices may advantage some disease-carrying mosquitoes[203]. The distribution and impact of the amphibian chytrid fungus[77] and phytophthora (a fungus that causes die-back in plants), may be affected, and changing distributions of birds,

in water extraction, diversion and storage to increase water security for agriculture and urban areas will potentially have negative impacts on freshwater biodiversity[207].

Ensuring adequate water resources for biodiversity, agriculture, and urban needs will require adaptation strategies such as using pipelines instead of open channels, adopting water efficient agricultural practices, recycling water, and pollution control. Restoration of riparian vegetation can potentially reduce bank erosion, as well as contributing to cooler water temperatures[207].

*Cophixalus concinnus*. Photo: Steve Williams

## Knowledge gaps

An extensive review of the literature has identified a number of gaps in our knowledge, both on the potential impacts of climate change on terrestrial and freshwater biodiversity, and the potential for natural adaptation in species and ecosystems.

### What we don't know – Species

- The thermal and physiological tolerances, and natural resilience and adaptive capacity, of most species
- How changes to the timing of life history processes (such as breeding and migration) will affect survival, reproduction, and species-interactions
- How to ameliorate the cascading effects of mismatches between interacting species (predators and prey, flowers and their pollinators, etc).
- Where taxa will retreat to (refugia) and how these areas can be best managed
- The ability of species to resist and/or recover from extreme events

### What we don't know – Ecosystems

- The best way to maintain/restore habitats to increase resilience to climate change
- How changes in palatability of grass and leaves (associated with changing $CO_2$) will affect native and non-native herbivores
- How interactions among invasive species, grazing and land use change will affect vulnerability
- How climate and enhanced $CO_2$ will interact to affect fire regimes, and how fire regimes will interact with invasive species
- How changes in the cloud layer will influence communities in high elevation regions
- Short and long-term impacts of extreme events such as heat waves, storm surges and cyclones

Photos: Pandani (Mount Field Tasmania) - Lynda Chambers; Bettle - Lynda Chambers

## Summary


This report card represents a first attempt at summarising current knowledge of climate change impacts on terrestrial and freshwater species and ecosystems, and identifies potential adaptation responses and knowledge gaps in Australia.

The potential impacts of climate change on terrestrial and freshwater systems in Australia are immense. We have already seen shifts of species distributions across elevational and latitudinal space, and this is expected to continue. Population losses and species extinctions are predicted, through a variety of direct (such as heat stress and drought) and indirect impacts (including phenological mismatch, pollinator loss, etc). Our World Heritage Areas and their associated biodiversity are at risk, and we can expect declines in ecosystem function in many areas.

While mitigation measures, in the form of a reduction in greenhouse gas emissions, remain the front line strategy against the impacts of climate change, adaptation management actions need to be implemented now to minimise biodiversity loss and manage the ecological transformation we face.


+ This report card is also downloadable as a PDF or can be viewed electronically at: **www.terrestrialclimatechange.org.au**
+ All references for this report can be found electronically at: **www.terrestrialclimatechange.org.au/references**

## Contributors


**David Bowman**; University of Tasmania
**Kerry Bridle**; Tasmanian Institute of Agriculture
**Barry Brook**; University of Adelaide
**Samantha Capon**; Griffith University
**Lynda Chambers**; Australian Bureau of Meteorology
**Stephen Garnett**; Charles Darwin University
**Jean-Marc Hero**; Griffith University
**Lauren Hodgson**; James Cook University
**Ary Hoffmann**; University of Melbourne
**Lesley Hughes**; Macquarie University
**Joanne Isaac**; James Cook University
**Craig James**; CSIRO
**Roger Kitching**; Griffith University
**Andrew Lowe**; University of Adelaide
**Tara Martin**; CSIRO
**Nicola Mitchell**; University of Western Australia
**Elvira Poloczanska**; CSIRO
**Hugh Possingham**; University of Queensland
**Grant Wardell-Johnson**; Curtin University
**Dick Williams**; CSIRO
**Stephen Williams**; James Cook University
**Yvette Williams**; James Cook University
**Colin Yates**; Department of Parks and Wildlife (WA)


## Reviewers:


**Mark Stafford Smith**; CSIRO
**Alistair Hobday**; CSIRO
**Justin Welbergen**; James Cook University



NCCARF
National
Climate Change Adaptation
Research Facility
Adaptation Research Network
TERRESTRIAL BIODIVERSITY


Cover photos: Rainforest - Steve Williams; Southern Brown bandicoot - Jo Isaac; Bushfire - Lynda Chambers