New South Wales Climate Impact Profile
Technical Report

Potential impacts of climate change on biodiversity
Cover photos (main image, clockwise):
Aerial view of Lane Cove River (Andrew Duffy);
Helensburgh fires (Allan House);
Redhead Bluff (Brook Lesley);
White-bellied sea eagle (Joel Winter).

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1 Project overview

In 2008, the then NSW Department of Environment and Climate Change (DECC), with the support of the NSW Department of Water and Energy, undertook an initial biophysical ‘exposure scan’ of the regional impacts of climate change on NSW. The project identified a potential range of changes in the environment that may result from predicted (modelled) changes in climate. The potential vulnerabilities of biodiversity, soils, hydrology, coastal processes (including potential inundation) and terrestrial drainage patterns (including during flood events) were assessed at a regional scale.

The assessment was undertaken as a first step in providing information for government planning and decision-making. It was not designed to be a comprehensive risk assessment or to develop a risk management framework. Biophysical projections, like climate projections, cannot be definitive. They represent a range of probabilities based on the projections of climate data that also represent a range of probabilities. These projections represent a best guess at this time. Some species are mentioned frequently throughout the text. This is because they serve as a useful case study of representative NSW species; it is not a reflection of agency biodiversity priorities.

1.1 Biodiversity assessment: expert workshops

To help in the biodiversity component of this project, DECC undertook a series of regional workshops in 2008–09. The workshop discussions were used as a basis for developing regional impact statements for each State plan region in NSW. This report records the discussions of those workshops, plus additional comments made by the participants subsequent to the workshops.

An expert panel for each region was asked to provide its best estimate of the impact of projected climate change on the biota and ecological processes in the region. The panel members were asked to use their knowledge of the ecosystems of the region, in conjunction with the projected A2 climate change scenario (see DECCW 2010 for details), to make informed estimations about the type and degree of change that is likely to occur. This was based on the panel’s understanding of the important ‘drivers’ in ecosystems and how the component species may respond to projected changes. The results were an annotated assessment (including specific regional examples and case studies) of the potential changes to ecological processes and functions as a result of the given climate scenario for each ecological community in each region.

For the purpose of this project, ecosystems were defined as the vegetation formations identified by Keith (2004) for NSW. These formations represent broad categories of climate, soils and habitat components of the NSW environment on a state-wide scale. They are the units that are being used to report on the impacts of climate change in each region. For the purposes of this assessment, each formation was considered to consist of all its biological elements, such as flora, fauna (vertebrate and invertebrate) and microbial species. These formations comprise a number of finer scale ecological communities that further describe the character of the formations in each region.

It was recognised that this approach would not produce definitive outcomes, but rather a qualitative estimate of likely impacts.

The following sections of this report describe the region or regions considered by each of the panels, the climate projections for these regions (as provided by DECC to the panels) and panel discussions regarding the potential impacts. Additional comments made by the participants or reviewers subsequent to the workshops have
also been incorporated. A list of participants and reviewers on each panel is presented in Appendix 1.

1.2 Summary of regional climate projections for NSW

Projections for the change in rainfall and temperature have been modelled across NSW for this project. These projections have been produced by using a subset of the global models developed for the Intergovernmental Panel on Climate Change (IPCC; 2007a). These models were selected by UNSW (under contract to DECC) for their reliability for NSW. The modelled projections are based on the A2 scenario for the period 2040–2060. These projections deal only with seasonal means for rainfall and minimum and maximum temperatures.

**CO₂ concentrations**

Current CO₂ levels in the atmosphere are the highest for at least 2 million years. The levels have increased by 35% since 1750, with 70% of this change occurring since 1970. The levels are likely to continue to rise at an increasing rate until global action is taken.

### Limitations of climate projections

- **Comparisons were made against the period 1980–2000, and 2050 estimates were based on the A2 scenario using the 4-model average described in DECCW 2010.**
- **Comparisons were made with 1900–2000 rainfall periods based on Bureau of Meteorology observation data from weather stations within the climate regions shown on the map for that period (see DECCW 2010 for more details regarding the zones).**
- **Missing data: the scenario models are based on monthly or seasonal mean data. They do not include extreme events (i.e. extreme maximum or minimum temperatures). These events may have a large impact on biodiversity.**
- **Wind and evaporation data are not available. It is difficult to predict what will happen with evaporation; increased temperatures, particularly if combined with more wind, would increase evaporation, but increased summer humidity may decrease evaporation.**

1.3 How to use this report

This report should be used as a ‘workshop summary’; it is essentially a documentation of the expert workshops held in the various regions. It should not be considered a comprehensive coverage of the issues, topics or possible outcomes of climate change on biodiversity in NSW; instead, it is a summary of the results of the discussions that took place during the workshops.

It should also be noted that other assessments (i.e. hydrology, flooding, soils) ran concurrently and that the information generated by these assessments (and also additional information on fire regimes and other relevant topics) may have changed since the time of the workshops. Thus the comments of the panel may differ in some cases from the final outputs reported in the NSW Climate Impact Profile (DECCW 2010).
2 South Coast region

2.1 Description of the region

The South Coast region (Figure 1) includes the coastal plain, the great escarpment and the nearby ranges from the Shoalhaven River to Victoria. It does not include the Tablelands. It generally comprises a reasonably narrow coastal plain and foothills, which rise sharply into the great escarpment. The heavily dissected escarpment and nearby ranges then gradually merge with the more rolling topography typical of the Tablelands. Elevation in the area ranges from sea level to 1200 metres south of Captains Flat. The main population centres include Nowra (20,000), Batemans Bay and Ulladulla (both 7000) and a number of smaller towns, all near the coast. The largest hinterland town is Braidwood, with a population of about 1000. Agriculture is mainly restricted to the more fertile soils along the coastal plain and foothills. The main catchments are the Shoalhaven, Clyde, Moruya, Tuross and Bega Rivers. The escarpment and ranges are mostly conservation reserves or State forests.

The coastal foothills south of Narooma largely support dry sclerophyll forest. Smaller patches of heath are interspersed among the dry forests, with the main occurrences in Nadgee Nature Reserve and Ben Boyd National Park and on the headlands of Jervis Bay. North of Narooma, the coastal foothills often support a wet sclerophyll forest, often characterised by spotted gum. The escarpment supports a mosaic of dry and wet forest as a result of factors such as soil type and aspect. Rainforest occurs in small patches in most sheltered locations along the great escarpment. Montane heaths occur in localised patches, such as along the Kybean Range. Grassy Woodlands were once extensive in the Bega and Araluen valleys and to the south of Braidwood. Forested wetlands are present along the major rivers, such as the Bega, Tuross and Moruya rivers and on the Shoalhaven floodplain. Saline wetlands are present in most of the estuaries. Freshwater wetlands are more restricted, with examples occurring among the sand dunes at Cape Howe and on the floodplains of the Shoalhaven and Moruya rivers.

Figure 1. The South Coast region
2.2 Climate projections presented to the expert panel

The projections suggest that there will be an increase in temperature across the study area. The projected increase in mean daily minimum temperature (1.8 to 2.6 °C) is slightly higher than for mean maximum temperature (1.5 to 2.4 °C). The projected increase is largest in winter and smallest in summer for both maximum and minimum temperature. The increases in maximum and minimum are slightly higher in the northern part of the study area. The projected increases in temperature largely appear to be outside the 30-year monthly means observed in the last 90 to 120 years. However, it is worth noting that the 30-year mean maximum temperatures for Bega (1911–1940) and Moruya (1881–1910) were 0.6 to 1.5 °C above the 1970–2000 mean maximum temperatures in the summer months.

The rainfall projections are closer to the observed data, but there are some seasonal differences. Rainfall in summer is projected to increase across the study area by 24% to 31%. A smaller increase in autumn rainfall is predicted for coastal sites. Winter rainfall is predicted to decrease in the southern hinterland by 12% to 15%. Otherwise, winter and spring rainfall appears to be close to recorded variations. The trend in annual rainfall is that the northern part of the study area may be about 10% wetter, but there is little overall change in the south.

A number of climatic parameters in addition to rainfall and temperature will affect biodiversity. The likely changes in the following parameters have largely been drawn from reviews by Dunlop and Brown (2008) and Hughes (2003).

Table 1 Temperature and rainfall summary for the South Coast Region of NSW (2050 A2 Scenario)

<table>
<thead>
<tr>
<th>Minimum Temperature</th>
<th>Maximum Temperature</th>
<th>Precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.8–2.6°C warmer (larger increase in winter, smaller increase in summer).</td>
<td>1.5–2.4°C warmer (larger increase in winter, smaller increase in summer).</td>
<td>24–31% increase in summer rainfall.  12–15% decrease in winter rainfall in Southern Hinterland.  Overall 10% wetter in north, little change in south.</td>
</tr>
</tbody>
</table>

Sea-level rise

The expert panel was asked to consider a sea-level rise of 0.5 metres by 2050 and the combined effects of sea-level rise and storm surges resulting in recession of 30 to 50 metres where unconsolidated sediments are present along the coastline. Subsequent to the expert panel’s consideration of climate change impacts on biodiversity, the NSW Government has released a policy statement advising that a sea-level rise of 0.4 metres by 2050 be considered for planning. Because of the qualitative nature of this assessment, the difference between these two figures does not affect the regional impact statements made in this report.

El Niño Southern Oscillation

Since the 1970s, El Niño events have increased and La Niña events have decreased. There is debate about whether this is associated with climate change or whether it is natural decadal-scale variability. However, it is clear that it will be warmer during both El Niño and La Niña events.
Evaporation
Some initial modelling of net water balance (i.e. rainfall minus evaporation) for NSW was undertaken for this project. Modelling evaporation is more difficult than rainfall or temperature, because it depends on a number of factors such as temperature, wind speed and humidity. A decrease in net water balance of 15 to 160 mm has been predicted for much of Australia by 2030. The initial modelled results for this region are at the lower end of this range.

If there is a decrease in the net water balance, soil moisture and runoff to streams and stream flow are also likely to decrease. Predictions of annual runoff suggest a decrease of between 0% and 20% for south-eastern Australia. The initial results for net water balance suggest that any change may likewise be towards the lower end of the predicted range for this study area.

Fire risk
Models considering temperature, relative humidity, days since rain and fuel load predict an increase in the number of days with very high or extreme fire danger over much of Australia. Typical predictions for the increased frequency of high fire risk days are between 4% and 25% by 2030.

Extreme events
The return times for heavy rainfall events and flooding are projected to decrease in south-eastern NSW. For temperate regions, the number of days a year that are hotter than 35 °C is expected to increase by 4 to 18 by 2030.

2.3 Overall impacts on the region’s ecosystems
1. Climate change is unlikely to lead to significant changes in growing season in this region. (The agro-climatic zone to the south and west could well see trends towards increased summer growth, which could lead to many significant impacts.)

2. Ecosystem types in the region tend to be determined by coarse topographic and geographic features (protection from fire, moisture availability, shallow substrate, salt exposure). These features are unlikely to change significantly as a result of climate change. Therefore, the broad pattern of ecosystems across the landscape could remain broadly stable.

3. Certain ecosystems might experience significant change:
   - Ecosystems dependent on mobile substrates, such as freshwater and saline wetlands, littoral rainforest, mudflats, heath, and forests on sands are likely to be vulnerable to change. Unconsolidated substrates near the sea are highly prone to erosion with changes in sea level. Riverine sediments are vulnerable to erosion because of increases in peak stream flow. New habitat is likely to be formed, but the ability of the biota to colonise it depends on its physical characteristics and on dispersal and recruitment events.
   - The ecosystems vulnerable to saline intrusion to ground water are similar to those vulnerable to coastal erosion.
   - Riverine ecosystems may undergo composition changes because they are strongly affected by water temperature and flow regimes.
   - Grasslands surrounding montane bogs and grassy woodlands in valley floors may undergo structural and composition changes because of decreased frost and grazing and increased temperature and rainfall. Such changes include shrub or tree establishment and invasion by weeds and other shrubby native species. The extent of these changes is quite uncertain.
• Cool temperate rainforest that is dependent on cloud for moisture and vulnerable to intense or extensive fires is likely to suffer change. Although increased rainfall in northern part of region may decrease likelihood of fire.

4. Within coarse types of ecosystems, there could be considerable changes in composition, abundance and possibly structure because of changes in:
   • moisture availability (which may affect the dynamic between dry and wet sclerophyll, rainforest and wet sclerophyll)
   • fire frequency and intensity
   • the mortality, growth and phenology of individual species because of changes in rainfall, evaporation, temperature and CO2
   • the frequency and timing of recruitment events favouring different species, especially after fire
   • the palatability and nutritional value of plants for herbivores.

5. There is much local-scale spatial heterogeneity of communities within ecosystem types (e.g. different types of sclerophyll forest intermingled), leading to high levels of landscape-scale species diversity. This means there is considerable opportunity for species to move small distances into different microhabitats. There are likely to be well adapted species nearby should a location dry out or moisten, or be exposed to more or less fire, or should CO2 alter the species’ response to moisture. However, fully aquatic species have limited capacity for dispersal, being confined to movement via the stream network, which mostly runs east-west and has little north-south connectivity.

6. Weeds may be advantaged, particularly in fertile ecosystems, including rivers and wetlands with anthropogenic nutrient enrichment and grasslands or grassy woodlands.

Potential impacts with too much uncertainty to make predictions

1. Factors that are speculated to increase the mortality of some species or greatly affect recruitment could also affect composition and possible structure. Such factors might include:
   • long, hot droughts (or the converse in good seasons)
   • frequency and intensity of ENSO events
   • dry winters after fire
   • very frequent fires (or very infrequent fires)
   • interactions among insects, pests, pathogens and grazing species, and among species in general.

Fire could have many impacts, but the changes are quite uncertain in this region. Fuel dynamics will be important and will be affected by rainfall, CO2, temperature and climate variability. The region already has fairly rapid fuel build-up, so a change in growth may not have much impact. In addition, increased rainfall in warmer months may prevent too much drying.

There is huge uncertainty about the impacts on plants of changes to the populations of insects, pathogens and grazing species:

• Temperature will increase life cycles, possibly increasing recruitment.
• CO₂ can affect foliage and is expected to affect grazers, but will they eat more or less?
• Changes in insect populations, pathogens and grazing species will affect the establishment, mortality and competitive dynamics of plants.
• Potential for asynchrony between host plants and insects

Similarly, the impacts of changes in plants on grazing species are quite uncertain. Such plant changes may include changes to:
• foliage quality
• abundance of food species
• structure, defensive toxins, affecting protection from predation.

The extent to which changed climatic conditions will facilitate outbreaks of disease is quite uncertain. Changing climatic conditions in tropical and cool montane regions may be favouring the chytrid fungus. There is little information available for temperate regions, and there are many other pathogens for which there is little available information.

Table 2  Summary of impacts by ecosystem: South Coast Region

<table>
<thead>
<tr>
<th>Ecosystem</th>
<th>Community</th>
<th>Main reasons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainforest</td>
<td>Littoral</td>
<td>Highly vulnerable to inundation from sea-level rise, coastal erosion and rising groundwater tables.</td>
</tr>
<tr>
<td>Cool temperate</td>
<td></td>
<td>Susceptible to fire, limited capacity to adapt to change due to low species diversity and distribution.</td>
</tr>
<tr>
<td>Warm temperate/ dry/subtropical</td>
<td></td>
<td>Likely to expand into the niche of cool temperate forests. Prone to fires and weeds</td>
</tr>
<tr>
<td>Freshwater wetlands</td>
<td>Montane bogs and fens</td>
<td>Prone to dessication and fire. Potentially vulnerable to step-wise change.</td>
</tr>
<tr>
<td>Coastal freshwater lagoons</td>
<td></td>
<td>Likely to be adversely affected by sea-level rise.</td>
</tr>
<tr>
<td>Coastal heath swamps</td>
<td></td>
<td>Prone to fire resulting in species mortality and more open vegetation structure.</td>
</tr>
<tr>
<td>Floodplain</td>
<td></td>
<td>Likely to be lost in areas affected by increased salinity.</td>
</tr>
<tr>
<td>Casuarina glauca</td>
<td></td>
<td>Changes to inundation regimes and sea level will affect these communities.</td>
</tr>
<tr>
<td>Coastal swamp forests</td>
<td></td>
<td>Changes to ground water are likely to kill some eucalypts and change community composition.</td>
</tr>
<tr>
<td>Eastern riverine forests</td>
<td></td>
<td>Prone to weed invasion.</td>
</tr>
<tr>
<td>Ecosystem</td>
<td>Community</td>
<td>Main reasons</td>
</tr>
<tr>
<td>-------------------------</td>
<td>----------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Saline wetlands</td>
<td>Mangroves</td>
<td>Loss of some communities due to sea level rise and coastal erosion. Possible expansion into other areas.</td>
</tr>
<tr>
<td></td>
<td>Salt marsh</td>
<td>Prone to inundation and may become vulnerable to invasion.</td>
</tr>
<tr>
<td></td>
<td>Seagrass</td>
<td>Risk of a decline in extent and or compositional change with sea level inundation.</td>
</tr>
<tr>
<td>Rocky platforms and mudflats</td>
<td>Rocky platforms</td>
<td>Likely to be lost through inundation or storm activity</td>
</tr>
<tr>
<td></td>
<td>Mudflats</td>
<td>Both increases and decreases in expected due to increased inundation and erosion and sediment deposition.</td>
</tr>
<tr>
<td>Wet sclerophyll forests</td>
<td>Montane and Southern Tableland</td>
<td>Small patches may be prone to fire.</td>
</tr>
<tr>
<td></td>
<td>Coastal communities</td>
<td>More at risk from increased fire frequency and weeds.</td>
</tr>
<tr>
<td>Dry sclerophyll forests</td>
<td>Coastal communities</td>
<td>May be affected by inundation by sea water.</td>
</tr>
<tr>
<td></td>
<td>Sydney coastal communities</td>
<td>Likely not affected greatly by climate change.</td>
</tr>
<tr>
<td></td>
<td>Southern wattle forests</td>
<td>Sensitive to drought and likely to become stressed during long dry periods.</td>
</tr>
<tr>
<td></td>
<td>Southern hinterland</td>
<td>Certain species are sensitive to prolonged dry periods.</td>
</tr>
<tr>
<td></td>
<td>Sydney montane</td>
<td>Increased fire frequency may decrease floristic diversity.</td>
</tr>
<tr>
<td></td>
<td>Sydney hinterland</td>
<td>Changes in fire and rainfall patterns may cause changes in species composition.</td>
</tr>
<tr>
<td></td>
<td>South east</td>
<td>Long dry spells may affect some species.</td>
</tr>
<tr>
<td>Heathlands</td>
<td>Coastal heaths</td>
<td>Risk of increased fire frequency.</td>
</tr>
<tr>
<td></td>
<td>Coastal headland heaths</td>
<td>Risk of more frequent burning.</td>
</tr>
<tr>
<td></td>
<td>Montane heath</td>
<td>Likely to be fairly resilient to expected changes in climate.</td>
</tr>
<tr>
<td>Grasslands</td>
<td>Maritime</td>
<td>Likely to be affected by coastal erosion and inundation.</td>
</tr>
<tr>
<td></td>
<td>Temperate grassland</td>
<td>Susceptible to changes in water balance.</td>
</tr>
</tbody>
</table>
2.4 Assessment of impacts on each ecosystem

A brief description of each ecosystem precedes the discussion of the likely impacts of climate change. A more detailed description of each ecosystem of the region, including the sub-formations under each ecosystem, is presented by Keith (2004).

Rainforests

There are five types of rainforest in the South Coast region. They all occur in small patches, with warm temperate rainforest and dry rainforest being moderately extensive. Subtropical rainforest, cool temperate rainforest and littoral rainforest are more limited in extent. Rainforests are generally found in reliably moist and fertile locations that offer topographic protection from fire and wind.

Littoral rainforest

These communities are patchy in occurrence and are located on low-lying sandy substrates behind coastal dunes or on rocky headlands. They are currently listed as an Endangered Ecological Community under the NSW Threatened Species Conservation Act 1995 (TSC Act). In the southern part of the region they are essentially a form of warm temperate rainforest, as they share many of the same species but usually have fewer species in the assemblage. In the Shoalhaven they may have more subtropical affinities. Communities on rocky substrate are less common in the northern part of the region.

Littoral Rainforest is at greater risk than other rainforests in the region. Stands on unconsolidated sandy substrates are highly vulnerable and are likely to be lost through inundation following sea-level rise, coastal erosion and rising groundwater tables. The coastline is likely to retreat fairly rapidly, and there will be few opportunities for landward movement of these communities given the presence of infrastructure barriers and the lack of suitable substrates farther inland. An exception may be the situation where the communities follow gully lines inland and gradually grade into warm temperate communities. Some locations currently above the groundwater level will be affected by rising ground water, which will kill the less tolerant species.

Storm damage will open these communities up more making them vulnerable to invasion by weeds (e.g. bitou bush) or to replacement by more tolerant dry sclerophyll species. The proximity of these communities to urban development exacerbates their vulnerability. Warmer temperatures may favour existing weeds such as lantana or offer opportunities for new weeds to enter the system.

Few plant species are restricted solely to these communities, as most also occur in warm temperate or subtropical communities. So overall there will not be a substantial loss of individual species, although the littoral rainforest assemblage will be reduced.

Those communities located on rocky headlands in this region will be more resistant to change, although they could be stressed by more deposition of salt spray on leaves if there is an increased frequency of extreme weather events. Rainforest trees...

<table>
<thead>
<tr>
<th>Ecosystem</th>
<th>Community</th>
<th>Main reasons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grassy woodlands</td>
<td>Subalpine woodland</td>
<td>Risk of invasion by other species into woodlands.</td>
</tr>
<tr>
<td>Coastal Valley</td>
<td>Coastal Valley woodland</td>
<td>Increased vulnerability to weed and pest species</td>
</tr>
<tr>
<td></td>
<td>woodland</td>
<td>invasion.</td>
</tr>
</tbody>
</table>
in these situations often have some leaf damage, suggesting that they are possibly already close to their limit of tolerance for salt in these situations.

Flying-fox colonies currently located in the littoral rainforest in the north of the region may be forced to relocate, given the potential changes discussed above; they are also highly susceptible to extreme temperatures. They are likely to find alternative suitable habitat for roosting, but their movement to surviving littoral rainforest remnants and the risk of foliage degradation might place the remaining remnants under further pressure.

Cool temperate rainforest

These forests are generally located on top of the escarpment and exist where wet and misty conditions prevail because of the uplifting of moisture-laden air. They are heavily reliant on orographic rainfall. They may also be found at lower altitudes where cold sinks run down from the escarpment along moist gully lines. They occur in small pockets in Monga, Morton, Budawang, Deua, Wadbilliga and South East Forests national parks.

An increase in temperature is unlikely to favour these communities. In hot, dry years, fire frequency is likely to increase in the surrounding communities, which will start to have an impact at the edges of the cool temperate rainforests. The canopy species in these communities are susceptible to fire. Along the top of the escarpment they are less well protected from fire by their surrounding topography than are the species in deep gullies. Cool temperate rainforests have a limited capacity to adapt to change, as species diversity is low and they occur in isolated pockets across the landscape. Within this region, retreat of temperature-sensitive species to higher altitudes or to areas protected from fire and water loss will not be possible, as these communities already occupy these refuges. Overall, these communities are likely to be less resilient to episodic changes and are likely to gradually retract as plants around the edges are killed off or outcompeted by more fire-tolerant wet sclerophyll species. Small isolated patches will be vulnerable, and some may be completely replaced by other communities.

With warmer temperatures in the drier El Niño periods, cloud cover and wet misty conditions may not occur to the same extent or with the same frequency along the escarpment. The prevailing winds may also change. Loss of cloud cover is likely to result in an increase in exposure to solar radiation, which may affect some species. Increased temperatures and increased evaporation will reduce moisture availability in dry years. These communities are likely to be adversely affected by intense droughts, with some canopy species dying off. All of these pressures on cool temperate rainforests are likely to result in a contraction of their extent, as well as a retreat from lower altitudes as conditions in these locations become more suited to Warm Temperate Rainforest species. Alternatively, in wet years, in the absence of fires, species from these communities may spread from the edges or be carried by dispersal agents to new locations.

Replacement of rainforest plant species by species adapted to drier climates or to more frequent burning would be likely to exacerbate the impacts of rising temperature and declining winter rainfall on in-stream communities by reducing the cooling effects of canopy shading and moist riparian microclimates.

Other warm rainforests

These forests include warm temperate rainforest, dry rainforests, and a small amount of subtropical rainforest in limited areas of highly fertile soils at Kiama, Milton and Little Dromedary. The rainforest at Milton is listed as an Endangered Ecological Community.
With warmer conditions, if these communities continue to be protected from fire they are likely to expand slightly into the niche currently occupied by cool temperate forests in gully lines below the escarpment. Weeds that are currently more common to the north of the region, such as lantana and camphor laurel, may move farther south and start to colonise the edges of rainforest communities. Greater occurrence of lantana at the edges of these communities would increase their flammability.

If temperatures increase during drought periods, then less tolerant species may be lost or outcompeted. Changes to species composition are then likely to result, particularly in the ecotones. Warmer conditions may result in more regular fire in the edges of rainforest. This would favour species that are less susceptible to fire (such as *Backhousia* over *Acmena*). Regeneration will be greatly reduced if a second fire goes through before plants have regrown sufficiently. Drought may also affect regeneration if it follows soon after a fire, or vice versa. A fire in each El Niño dry cycle would be too frequent in these communities. Some areas in the landscape (e.g. linear rainforest patches along creek lines located within large expanses of dry sclerophyll forest) will be more at risk than others. Species that are relatively drought sensitive may be outcompeted in hot, dry spells. Figs appear to be affected by drought, especially if they are competing with the surrounding vegetation for moisture (i.e. if they are embedded in sclerophyll forest rather than in grassy woodland). In drier conditions, rainforest communities may change to be more like those in dry rainforest.

In the absence of grazing and fire, lowland subtropical rainforest near Milton is starting to invade the adjacent red gum grassy woodland. Wetter summers, in combination with warmer temperatures, may favour an expansion of the distribution of warm temperate rainforest species if fire continues to be excluded through topographic protection or the presence of firebreaks such as agricultural land.

Dispersal agents are key components of rainforest communities. Impacts on dispersal agents cannot be clearly gauged. Plant seeds dispersed by highly mobile species such as bats and birds are advantaged in the landscape, as they can move large distances and become established where suitable conditions are present. The capacity to disperse and colonise suitable areas gives rainforest some level of resilience. Subtropical rainforest has a high proportion of widely dispersed species, but the dispersal capacities of cool temperate and some southern warm temperate species that have wind-dispersed seed are lower. It is likely that easily dispersed species will be advantaged relative to taxa with poorer dispersal ability. Rainforest communities will continue to persist under this scenario, but they may comprise different combinations of species.

Some rainforest bird species that are typically more prevalent on the North and Central coasts are being observed more frequently in the north of this region (e.g. while-headed pigeon, noisy pitta, and brush turkey). Fruit-eating bats and birds may be adversely affected by the reduced fruit availability associated with increased storm activity and periods of unusually high temperatures.

Leaf palatability is unlikely to be an issue in this formation, as there are not a lot of vertebrate folivores. The quality, quantity and timing of fruit production may be more important. There is no clear indication of the effect of changes in temperature and CO₂ concentrations on fruit production. If fruit production were to decrease as a result of stress associated with hot or dry spells, there would be a direct impact upon the fauna that feeds upon this fruit and on the plants that rely on these species to disperse their propagules.
Freshwater wetlands
The wetlands of the South Coast include montane bogs and fens, coastal freshwater lagoons and coastal heath swamps.

Montane bogs and fens
These communities, currently listed as an Endangered Ecological Community, are found at the upper ends of most rivers where runoff is limited by low gradients and rainfall exceeds evaporation. Two types may occur: sandstone to the north and peatland on mostly granitic substrates to the south. Wingecarribee Swamp is a peatland swamp that may contain a record of previous climate change. Other examples in the area are Stingray and Budderoo swamps and many smaller swamps west of the Bega Valley, such as Bega, Nunnock and Packers swamps. These permanently wet areas may become drier because of increased seasonality of rainfall, increased evaporation rates, increased temperatures or faster runoff associated with factors such as increased storminess or fire.

These communities are potentially vulnerable to step-wise change. This could be initiated by an event such as fire, feral animal activity (pigs or deer) or heavy rains during storms, causing an erosional nickpoint at the edge of the wetland. Water can then drain rapidly from the area and communities dry out. Without moisture, these ecosystems become prone to fires, further stress in dry spells and increased grazing pressure (macropods, wombats and stock in privately owned areas), which is likely to result in extensive changes. Through step-wise change a substantial loss of aquatic and amphibious plants, frogs and aquatic invertebrates is possible, along with complete transformation of the ecosystem. This would be irreversible if the peat layer were lost in the erosion process or consumed by fire. Loss of water from these wetlands has consequences for systems farther downstream, as water is released from the wetlands slowly over time. If the upland wetlands dry out, there could be compositional change in the riverine ecosystem downstream. Those species that rely on a regular flow regime would be most affected.

Bog and fen wetlands often have a drier transitional grassland ecotone ringing their edges between the wet areas and the surrounding sclerophyll communities. The wetness of the soils discourages species invasion, as does frost, which is also likely to be playing some role in preventing sclerophyll communities from invading grasslands. With a decrease in frost and/or an increase in dry conditions across the region, these ecotones may be at risk of shrub and tree invasion. Drier conditions and increased CO₂ levels are also likely to favour the growth and spread of woody plants. Dry conditions in drought years, causing an increase in flammability, increase the chance that these communities will be burned. Over time the wetland communities may start to change in composition and structure as woody and more drought-tolerant species start to invade (quite a lot of wetland plants are quite fire tolerant). There may also be a loss of hydrophilic species if conditions dry. A number of fauna and flora species restricted to these ecosystems are at risk of being outcompeted (e.g. rare plants in or around bogs found along the South Coast escarpment, including Eucalyptus parvula, Grevillea acanthifolia ssp. paludosa, Boronia deanei, Pultenaea parrisiae, Prasophyllum canaliculatum, Euphrasia scabra and Xerochrysum palustre). If montane wetland communities dry out, weeds such as blackberry can start to invade and become more of a problem.

The endangered giant dragonfly Petalura gigantea, which breeds in upland wetlands, will be further disadvantaged if these habitats contain water for shorter and less frequent periods.

Upland wetlands are typically isolated in the landscape, as they are usually surrounded by dry forest. These wetlands are located at the upper end of the
catchment, and there are no higher altitude areas to retreat to. Thus, there is limited
capacity for wetland specialists to retreat to other suitable habitat in response to
environmental change. Warmer temperatures may cause some shifts in species
composition over time. Change may be related to competition with species moving
up from lower altitudes, as well as to physiological requirements for cool
temperatures. The southern swamps have a number of species in common with the
subalpine areas of the Snowy Mountains, and these species may be at greatest risk.

**Coastal freshwater lagoons**

Freshwater lagoons on coastal floodplains are currently listed as an Endangered
Ecological Community. Lagoons located on sand plains form where swales intersect
with the watertable. Those located on floodplains often form when river bends
become isolated from the main channel by deposition of alluvial material.

Those in proximity to the coast or estuarine waters are likely to be adversely affected
by sea-level rise through inundation, coastal recession, and/or saline intrusion
through the ground water. The severity of the impact will depend on the lagoon’s
distance from the coastline, the presence of impermeable barriers to groundwater
flow (bedrock, clay or coffee rock), and the frequency and strength of storm or tidal
surges. The Moruya, Bega and Shoalhaven rivers have extensive floodplain
wetlands, albeit often degraded by agricultural activities. These are important refuges
for fauna such as the green and golden bell frog, coastal waterbirds such as
Australasian bittern, crakes and rails, and species from western NSW that use
coastal wetlands as a drought refuge. Saltwater intrusion will result in the loss of a
suite of species that regularly feed and breed in these wetlands. Saltwater intrusion
may kill off trees fringing the wetlands; these trees are important for frogs, hollow-
users and roosting waterbirds.

These systems typically have dry and wet phases, but warmer temperatures in El
Niño periods may increase the frequency or length of periods in which these
wetlands are dry. Human activity is likely to exacerbate impacts as people extract
groundwater through spear points during dry spells. Damming or water extraction
upstream would also reduce inflow into these systems. An increase in fire activity in
the catchments could cause more sediment and nutrients to enter the lagoon
systems, resulting in changes in water quality.

Floodplain wetlands have already been altered significantly by farming. For example,
many of the wetlands in the Bega Valley are only wetlands after floods; the rest of the
time they are pasture. Climate change factors are likely to exacerbate the existing
threats to these communities. If the dry phase increases, these ecosystems will
become more vulnerable to grazing and invasion by weeds. Increased storminess
may result in the placement of additional infrastructure to prevent local flooding. This
would further shift the balance towards the dry phase. Additional flood mitigation
infrastructure and diversion of water for agriculture will further reduce the incidence of
large flooding events, which are already rare in these communities.

Lagoons on the coast are refuges for waterbird species from farther west. With dry
spells associated with more seasonal rainfall likely to occur in western NSW, the
presence of these species in the coastal ecosystems is likely to be more common.
This may affect resources and interactions with coastal species.

In wet years, storm and flooding events will also bring about changes to these
communities. For example, frog-breeding events are likely to respond to summer
storms, which will be beneficial for these species and their predators as long as
enough individuals can survive through the drier years. Flooding could change
sediment dynamics and the quantities of nutrients entering these systems; these
changes in turn would change water quality. With the possible exception of the
hottest time of the year, wetter, warmer years are likely to promote the spread of the chytrid fungus. The fungus may be inhibited in summer because it is intolerant of high temperatures and dies at 30°C.

Pest species such as the mosquito fish (*Gambusia holbrooki*) and carp may become a greater problem in this region if water temperatures increase. The abundance of aquatic weeds such as water hyacinth and salvinia may also increase if water temperatures increase.

**Coastal heath swamps**

These communities exist in a subtle mosaic of wet and dry heaths across the landscape. They generally occur in poorly drained swales on coastal sand sheets or in the headwaters of creeks on sandstone plateaus where a perched watertable is associated with an impermeable layer in the bedrock.

In drier years the heath swamps will dry out and become more fire prone. If fire becomes more prevalent because of increased temperatures in drier years, then the plant assemblage will gradually change over time. Greater numbers of sedges and species that regenerate from resprouting, rather than from seed, would be expected. Species from the drier heaths may be favoured in these communities.

Changes in structure and species composition could adversely affect some fauna (ground mammals, honeyeaters). Animals such as the long-nosed potoroo, eastern bristle bird and ground parrot, which have low mobility and/or depend on thick cover for protection from feral predators, would be disadvantaged by more regular fire. An increase in fire frequency is likely to cause direct mortality and lead to a more open vegetation structure, both of which may make these species more vulnerable.

These communities are already subject to natural disturbances that cause expansion and contraction of the heathland–sclerophyll forest mosaic. Given this, they are likely to be more resilient than other communities to change.

These communities typically occur on infertile soil, which makes them less prone to weed invasion. One exception is pampas grass, which is starting to become established near human habitation. This weed persists after fire, and monitoring of its expansion is warranted even though it is currently only a localised problem.

Existing stresses such as *Phytophthora* may be exacerbated by climate change through increased frequency of fire or changes in the seasonality of wet and dry conditions. If changed climatic conditions favour the chytrid fungus, frogs in this ecosystem, such as Littlejohn’s tree frog, that live in the same moist habitat all year round could be affected.

**Forested wetlands**

The forested wetlands of the South Coast include the tall forests of the fertile floodplains, the swamp forests on low-lying sands, and the alluvial forests of the major rivers.

**Floodplain wetlands**

These tall eucalypt ecosystems were found on the moist and nutrient-rich alluvial soils located on the floodplains of the major rivers. These tall forests were mostly cleared from the floodplains in this region early in the period of European colonisation. Hence, they are listed as an Endangered Ecological Community. There are small isolated fragments along some coastal creeks at the northern end of the Moruya floodplain and near Milton, where they are reduced to scattered trees in pasture. They are already threatened by a multitude of other factors (e.g. weeds and
fragmentation). These communities will be completely lost from areas affected by increased salinity.

*Casuarina glauca* communities are also listed as an Endangered Ecological Community and fall into two categories: those containing only freshwater understorey species and those more tolerant of brackish conditions. Changes to inundation regimes and ground water associated with sea-level rise will affect these communities. Some freshwater areas will become brackish and brackish areas will become saline. The likely outcome will be that the more saline areas will no longer support these communities and the salt-tolerant species will move back into the area previously occupied by the freshwater communities. The freshwater communities are likely to decrease in extent, as landward retreat will be blocked by urban development (on the edges of some coastal lakes) and the limited amounts of suitable flat, low-lying land in this region. The end result would mean an overall decrease in its extent and a change in species composition.

These communities around fresh water are already prone to invasion by weeds, such as morning glory, bridal creeper, Lord Howe Island hibiscus, African box thorn, blackberry, privets and asparagus ferns. It is expected that any additional disturbance to these communities from climate change will exacerbate this problem. Although increasing salinity could remove a lot of these weeds at freshwater sites, there is one highly invasive species—sharp rush—that is tolerant of salinity and would be likely to increase in abundance.

Loss of these communities located on Intermittently Closed and Open Lakes and Lagoons (ICOLLS) may have additional impacts on coastal land stability. These communities are likely to provide some salt buffering to neighbouring communities. This capacity may be lost if these communities are subject to substantial change.

*Coastal swamp forests*

These communities are found on deep sandy soils with a high watertable on low-lying swales, flats and lakeshores of the coastal sand sheets. They include forests dominated by *Eucalyptus robusta* and the wetter forests dominated by *Eucalyptus botryoides*. They are listed as an Endangered Ecological Community.

Changes to ground water associated with saline intrusion are likely to kill some of the eucalypts and change the community’s understorey species, with melaleucas and *Casuarina glauca* potentially becoming more dominant. Communities located on sand spits or in dune swales will be vulnerable to coastal recession. They are also limited in their capacity to colonise areas farther inland owing the occurrence of urban infrastructure barriers and limitation of the amount of suitable substrate.

An increased fire frequency may have a small impact on these communities’ ability to regenerate. Increased fire frequency is likely to promote a change in the ground cover towards sedges rather than shrubs.

*Eastern riverine forests*

This community occurs on mobile alluvial sediments along the major rivers of the eastern ranges. This is a moist, dynamic environment, with sediments being mobilised and redeposited among river boulders and cobblestones during major floods. Bega is the southern limit of this community. It is likely that episodic flooding events will favour this community, as floods stimulate germination. This increase may be negated slightly if large flows occur before seedlings are big enough. This community could be affected by an increase in sediment or nutrient loads from upstream as a result of more extensive fire or increased erosion associated with heavier rainfall pulses. However, the quantity of sediment is unlikely to be sufficient...
to greatly affect the community. It is more likely to have negative impacts on stream fauna such as fish, invertebrates and platypus.

This community is highly weed prone because of the reliability of moisture levels and the relatively high nutrient status of the loamy riverbank soils. In this region weeds are already a problem around agricultural land, so it would be expected that weeds will continue to be problem with climate change.

The community is not very fire tolerant, so there would be compositional change at sites exposed to fires at increased frequency. However, much of this community should continue to be sheltered from fire, so this should not be a widespread concern. Overall, this is quite an adaptable community.

Aquatic assemblages in rivers within this community are likely to be affected by a decline in winter flows and possibly an increase in summer flows, together with rising water temperatures. These changes are likely to produce shifts in species composition, with warm-adapted species expanding their ranges to higher altitudes and cool-adapted species contracting from lower altitudes. Because river systems in this region generally run east–west rather than north–south, opportunities for latitudinal adjustment of distributions are limited, except in the case of those fish species with a marine phase in their life cycles. Reduced river flows and increased siltation as a result of fires and erosion could affect the threatened Macquarie perch, *Macquaria australasica*, which requires unsilted gravel beds for spawning. Such changes could also adversely affect the Australian grayling, *Prototroctes maraena*, which is confined to this region within NSW and is listed nationally as vulnerable.

**Saline wetlands**

The saline wetlands of the South Coast include mangroves, salt marsh, and seagrass beds.

*Mangroves*

Mangroves occur around the margins of coastal estuaries, on mudflats that are exposed to regular tidal inundation.

An increase in sea level and coastal erosion will cause a loss to the extent of these communities in some locations because of inundation and the removal of the soft sediments on which they occur, particularly where the communities abut infrastructure or steep slopes (e.g. around Batemans Bay). They do have the capacity to re-establish themselves and may move farther upstream or into lakes if soft sediment is present. In this region the availability of new substrates would be restricted to some extent by urban development. Re-establishment of the river mangrove might be restricted by the generally steeper terrain adjoining the mudflats in the upper reaches of estuarine streams.

These communities could also expand into new areas such as ICOLLs where these lakes become permanently open, upstream along estuaries where the topography is suitable, and into areas of soft sediments that currently support salt marsh communities. The spread of mangroves out into mudflats and salt marsh communities will also affect shorebird foraging sites.

In summary, these communities are quite robust and are well able to colonise new locations because of very efficient dispersal mechanisms. There will be changes to their distribution, but the end result will depend on coastal sediment erosion and mangrove re-establishment.
Salt marsh

Salt marsh is listed as an Endangered Ecological Community and occurs on estuarine mudflats that experience intermittent inundation and on small soaks occurring on coastal headlands that experience abundant sea spray. In estuaries they generally occur in the zone between the regular high-tide mark and the spring tide mark.

With an increase in sea level, these communities are likely to be inundated more frequently and will become vulnerable to invasion by mangroves. In turn, these communities could expand back on to the floodplain adjoining estuaries (currently often covered by kikuyu pasture), where the terrain is flat. In this region the opportunities for retreat are limited because of the large number of lakes and estuaries with predominantly steep shorelines, so there is likely to be a net decline in their extent.

Seagrass

Seagrasses typically grow in estuaries in shallow waters on soft sediments such as sand and mud.

With climate change there is likely to be a decline in the extent or compositional change of seagrass beds because of the increase in water depth and the possibility of an increase in the amounts of sediment in the water with more frequent storm events. With warmer water, algae growth on seagrass may become more prevalent. The amounts of sediments and nutrients entering the seagrass beds and the amount of flushing will also affect algal growth. With warmer water, weeds such as Caulerpa taxifolia may start to move farther south, putting additional pressure on these communities.

Seagrass beds are important nursery areas for fish and good foraging areas for fish-eating birds. Any loss of these communities will reduce fish habitat and have flow-on impacts up the estuarine food chain.

Rocky platforms and mudflats

These habitats include intertidal mudflats, sand spits and rock platforms. They are typically exposed at low tide and inundated at high tide.

Rocky platforms

These habitats which are abundant—at least in Eurobodalla Local Government Area (LGA)—are likely to be lost because of inundation through sea-level rise or adversely affected by increased storm activity. Sooty oystercatchers and reef egrets use these platforms for foraging and nesting.

Mudflats

Examples of this habitat are found in the Shoalhaven estuary, as well as in most other estuaries and Lake Conjola. This is an important foraging habitat for local shorebirds and for breeding and non-breeding summer migrants. For example, the little tern, hooded plover and pied oystercatcher, which are already under pressure from other threats, use these areas. They may be affected directly (e.g. loss of nesting sites) or indirectly by increased storm activity and removal of unconsolidated flats.

In some locations inundation and increased erosion will result in the loss of some areas of mudflat habitat. In other locations mudflats may be created by increased sediment deposition and inundation of new areas. Although this habitat is likely to persist as sea level and other coastal processes change, the ability for shorebirds to
use the new habitat depends on whether, and how quickly, the habitat is colonised by
invertebrate species. The effect of a redistribution of mudflats on shorebirds is hard
to predict. In summary, existing habitat is under threat and new habitat is likely to
form, but the rate of loss relative to re-formation and the suitability of new habitat are
uncertain.

**Wet sclerophyll forests**

The more widespread wet sclerophyll forests of the region include South Coast wet
c sclerophyll forest, southern lowland wet sclerophyll forests and southern escarpment
wet sclerophyll forests. Montane wet sclerophyll forests and Southern Tableland wet
c sclerophyll forests are present on the margins of the study area along the higher
parts of the escarpment.

These forests need a moderate amount of soil moisture and moderately fertile soils.
They are often located along moist, sheltered gully lines and shaded slopes. These
communities can tolerate fires, and occasional fire may help in their regeneration. As
the South Coast is fairly fire prone, invasion of wet sclerophyll forests by nearby
rainforests has been kept in check. On the relatively infrequent occasions when they
burn, these forests support intense fires that usually occur during hot dry seasons.
The slight increase in rainfall in the north of the study area may favour these
communities, possibly leading to some expansion. Dry spells are not likely to result in
stress in these communities because of their position in the landscape (i.e. in gullies
and on moist, sheltered slopes). Invasion by rainforest may be kept in check by fires.

In general, these communities are likely to be quite resilient to changes owing to their
position in the landscape and their occurrence in large patches (e.g. at the back of
Wadbilliga, Stokes Creek and Clyde Mountain) that are well protected and have large
catchments. They may experience some subtle floristic changes, especially where
they abut drier forests. An increase in fire frequency around the edges may promote
a change in species composition because of competition with fire- and drought-
tolerant species. Resprouters would be advantaged over plants regenerating from
seed (mostly understorey species) if fire frequency were to increase in these
communities.

Weeds such as lantana, mist flower and Cape ivy may be advantaged by warmer
temperatures and a slight increase in rainfall in the north of the study area. Weeds
are less likely to be a problem to the south, except where the forests abut human
settlements (e.g. in coastal gully forests near coastal towns such as Merimbula). On
the escarpment and tablelands, blackberry may become more widespread where
increased stress associated with fire or dry spells opens up the canopy.

The development of a dense understorey (e.g. of lantana) may promote bell miner–
associated dieback in the overstorey. The reasons for this dynamic are not well
understood, so there is a high degree of uncertainty about this possible impact.

Changes in leaf palatability (e.g. in nutrient composition and toxin concentration) are
highly likely to affect this community. There are a number of arboreal mammals,
insects, and insectivores (altitudinal migrants such as olive whistlers and pink robins)
that could be adversely affected, depending on the severity of the change. Change is
most likely to affect species such as koalas, which have to consume a lot of food to
meet their nutrient and energy requirements, or species occupying marginal habitat.
The science around this issue is still being developed, so the panel was not able to
go into more detail. However, it wanted to flag this issue as one that could have a
substantial impact on these ecosystems.
In summary, in these ecosystems there are likely to be some species composition changes—particularly in the understorey and mainly around the edges—and perhaps greater weed activity.

**Montane and Southern Tableland wet sclerophyll forests**

There are only a few isolated occurrences of montane wet sclerophyll forests, in the colder parts of the coastal mountains and escarpments (e.g. in the upper Shoalhaven and on Mt Imlay). Southern Tableland wet sclerophyll forests have a limited occurrence in the upper Deua River district.

These communities are not as topographically protected by the landscape from fires as those located in gullies and on sheltered slopes. They are still reasonably robust in low-intensity fires and can survive hot burns. Small patches and narrow ribbons along gullies and on the edges of larger examples are most vulnerable to intense or extensive fire. The affected parts of this ecosystem may experience some changes in species composition and structure, such as a simplification of the understorey. The severity of impacts to these communities after fire depends on the climatic conditions afterwards. If drought or subsequent fires occur in close succession, regenerating species will be greatly affected, especially in areas with less geographic protection. These communities are important to fauna that uses hollows (e.g. bats, owls, arboreal mammals and parrots). More intense fire is likely to result in a decline in the abundance of large, old, hollow-bearing trees. A decline in the abundance of gliders from these forests would have a flow-on effect on predators such as quolls and forest owls. These communities are favoured for logging, because they occur in the more productive parts of the landscape. Because of fire or dry spells there could be increased occurrences of failure of regeneration after logging.

**Coastal communities**

Southern lowland wet sclerophyll forests occur on moderately fertile loamy soils on coastal hills and lowlands below 300 m. South Coast wet sclerophyll forest generally occurs in small pockets on reasonably fertile soils among a greater expanse of dry forests. It typically occurs as ribbons along steep gullies and on sheltered slopes below 500 m elevation. Southern escarpment wet sclerophyll forests occur mostly on the higher parts of the escarpment, but they also continue down moist, sheltered gullies to lower elevations.

Communities occurring closer to the coast in small patches and fragmented across the landscape will be more at risk from impacts such as increased fire frequency and weeds.

This ecosystem supports a relatively high density of foliovores, and any changes to leaf palatability would be important. Populations of foliovores may be reduced, with flow-on impacts for their predators. There is uncertainty as to whether increased CO₂ levels will lead to lower nutrient levels. If this does occur, it is likely to reduce the amount of suitable habitat, because areas that are currently of marginal palatability to foliovores may become unsuitable.

**Dry sclerophyll forests**

Dry sclerophyll forests are the most widespread ecosystems in the region. These communities are found on shallow, low-nutrient soils with poor water-holding capacity. These communities are highly flammable, and fire is a reasonably regular event during dry spells.

Southern hinterland dry sclerophyll forests are shrub/grass forest occurring in the southern part of the region. Of the shrubby forests, south east dry sclerophyll forests occur throughout the region and Sydney montane dry sclerophyll forests are found
only in the north of the region. South Coast sands dry sclerophyll forests, coastal dune dry sclerophyll forests and southern wattle dry sclerophyll forests are restricted to specific substrates.

**Coastal communities**

South Coast sands dry sclerophyll forests are found in small patches scattered along the relatively young coastal dunes at locations such as Wreck Bay, Moruya Heads, Tura Beach and Pambula Beach. There is overlap in their distribution of South coast sands and coastal dune dry sclerophyll forests between Narooma and Gerringong, with examples of the latter at Seven Mile Beach and St Georges Basin. Coastal dune dry sclerophyll forests occupy the landward portions of the sand masses, and South Coast sands dry sclerophyll forests occur adjacent to the beaches.

South Coast sands forest, which is an Endangered Ecological Community, is the more extensive community, with a small amount of coastal dune forest around Jervis Bay. These ecosystems are often in narrow strips that have already been extensively cleared for coastal developments (e.g. caravan parks, residential areas).

These forests will be affected by inundation by sea water in low-lying areas (in some instances this may occur from flows wrapping around points and coming in from behind) and by changes to ground water resulting from increased levels of salt water in the permeable substrates. In locations where these communities occur along bars at the front of coastal lakes they will also be affected by recession of the coastline. Urban barriers and lack of suitable substrates will prevent inland retreat in some instances. These communities are already threatened by other factors (weeds, fragmentation, and degradation from visitation), which will be exacerbated by the addition of pressures from climate change. In summary, these communities are likely to decline in their extent and those areas that remain are likely to degrade further. Increased disturbance (by e.g. fire) to these communities and changes in temperature may facilitate the spread of lantana, bitou bush and many other weeds.

A reduction in the extent or productivity of these communities will have a significant impact on migratory nectar feeders (honeyeaters and lorikeets) that utilise the winter-flowering banksias (*Banksia integrifolia, B. serrata*) in these communities as they travel up and down the coast. These resources are particularly important, as they occur in a gap in the coastal heath communities, which provide alternative sources of nectar to the north and south. The loss of these communities would also affect more sedentary species, such as insects, honeyeaters and pygmy possums.

These communities in this region may be less likely to be affected by fires, as they are isolated from other vegetation and often have water bodies behind them.

**Sydney coastal communities**

These heathy open woodlands, extending down to Ulladulla, occur on sandstone and sandy soils in a mosaic with heathlands, notably around Jervis Bay and Conjola. These species-rich communities contain many endemic plants and an abundance of hollows, which provide homes for bats and gliders. They also contain masked owls, pygmy possums and high numbers of honeyeaters. This community is prone to, and well adapted to, fires.

The panel thought that this community would not be affected greatly by climate change. More extensive fire, associated with increased temperatures, may reduce nectar production in species such as *Banksia ericifolia*. As this community is well adapted to fire, many species would cope with some amount of change. There are likely to be some species that will benefit (e.g. orchids) and some that might decline (e.g. banksias) with increased fire frequency. These communities cover a reasonable
area, so it is likely that a mosaic of species assemblages will occur in response to local fire regimes. There may be a few compositional changes within these communities, but in general the communities are not likely to change much.

Species in this community are found farther to the north, indicating that they can withstand increases in temperature.

**Southern wattle forests**

These forests grow in small patches on steep, rocky slopes along the coastal foothills from Buckenbowra to Brogo. There is a lack of understanding as to why these communities occur where they do, but their presence is likely to be substrate driven, given their restricted distribution. These communities are sensitive to drought, because they occur on skeletal soils and the characteristic species do not appear to be highly drought tolerant. Hence, they are likely to be stressed during long dry periods. As their seeds persist for a long time in the soil, they can regenerate opportunistically when conditions become suitable. The communities found in this region will be much better off than those found farther west near Byadbo, which is an area likely to receive less rainfall. They may be sensitive to increased fire frequency, but they are not very flammable, except in extreme conditions.

**Southern hinterland**

Southern hinterland dry sclerophyll forests occur in the undulating hinterland and escarpment foothills of the far South Coast. They usually occur on sandy loams of moderate fertility derived from granitic substrates. These communities are widespread and occur at a variety of altitudes and positions in the landscape.

More frequent dry spells may have some impact on stringybark species in these communities (e.g. white stringybark, *Eucalyptus globoidea*); these trees have been noted to suffer significantly greater mortality than other species over recent droughts. With repeated dry spells over time, numbers of the almost ubiquitous white stringybark may decline in these communities, especially in the more marginal areas along ridges and upper slopes. This would change the canopy composition to a small degree, although the species occurs over a wide extent and will persist in other locations. As stringybarks contribute to the fuel load in these communities, any reduction may change their fire-carrying capacity and fire behaviour, possibly resulting in fewer crown fires.

If fire becomes less prevalent, mesic species may start to move into topographically protected, grassy locations. These communities cover a wide area and a variety of altitudes and topographic positions, so there are plenty of opportunities for ecosystems or individual species to advance and retreat. Weeds are unlikely to be a significant problem. In general, this community is not likely to be greatly affected by changes, but there may be some subtle shifts in species composition with changes in fire frequency or with the impact on stringybarks discussed above.

**Sydney montane**

These forests are found on the quartz-rich sandstone plateaus around the Budawangs and Fitzroy Falls.

These communities are already fire prone and are well adapted for recovery after fire, but they may take longer to recover following fire if growing seasons are shorter. With an increase in fire frequency there may be some decrease in the understorey floristic diversity. Rocky areas are likely to protect fire-sensitive species in some locations.
Weeds are unlikely to be an issue in this community. Changes affecting *Eucalyptus radiata* in these communities on more fertile soils could affect fauna species, as these trees are important to browsers. Impacts are expected to be similar to those in lowland sandstone communities, except that montane communities are less fire tolerant. With an increase in fire, the species composition in these forests may start to resemble those of lowland communities.

**Sydney hinterland**

Changes in fire/rainfall patterns may cause minor changes in species composition, mainly in the understorey. Increased rainfall in the north of the study area may mitigate the effects of higher temperature in these communities. On the South Coast, this community is often located on fingers at the ends of plateaus and below the escarpment. These topographic situations are well protected from fire, so substantial changes in fire regimes are not anticipated.

**South east**

South east dry sclerophyll forests dominate the coastal ranges, lowlands and escarpment from sea level to 1300 m. They occur on shallow, infertile soils on ridges and dry slopes. This grouping is made up of a number of diverse communities that extend over a large portion of the region. They are not as species rich as those communities found on sandstone.

Long dry spells may affect some species in these communities (white stringybark and *Allocasuarina littoralis*), as these have been noted to suffer some losses in recent droughts. This would be more pronounced on the upper slopes and along ridge lines. This may lead to a change in species composition in these locations over time.

Isolated patches of rock scrubs are sparsely scattered within this community. Their occurrence is likely to be a function of soil depth (shallowness) and fire exclusion. These communities are likely to be more drought tolerant than the surrounding forest, but they may be less fire tolerant. A number of rare or threatened endemic species are concentrated in these areas (e.g. on rhyolite outcrops: *Leionema ralstonii*, *Westringia davidii*, *Genoplesium rhyoliticum*, *Zieria parrisiae*, *Zieria formosa*, *Zieria buxijugum*).

Increased occurrence of fire may also slightly change species compositions in other locations. For example, *Allocasuarina littoralis* proliferates from seed after fires, but its abundance would decline if fires were sufficiently intense to fully consume its seed-bearing cones. These environments may be more susceptible to post-fire erosion, with trees falling over and ash washing into streams, given that they often occur on steep slopes. One fauna species that could be adversely affected by a decrease in *Allocasuarina littoralis* abundance is the glossy black cockatoo, which would also (along with many other species) be adversely affected by a reduction in the numbers of tree hollows caused by more frequent fire.

Leaf palatability (nutrition and concentration of toxins) changes may affect this complex of communities. There are a number of arboreal mammals, insects, and insectivores that could be adversely affected, depending on the severity of the change. The science around this issue is still being developed, so the panel was not able to go into more details but wanted to flag this issue as one that could substantially affect these ecosystems.

Establishment of new ecosystem-modifying weeds or the emergence of existing weeds is unlikely to occur in these communities.
Heathlands

Heathlands generally grow on exposed, shallow soils that are especially deficient in phosphorus, nitrogen, potassium and magnesium, which are key nutrients for plant growth. On sandstone plateaus, they often occur where bedrock is very close to the surface. Near the coast, they also occur in areas where tree growth is limited by sea spray. These communities are highly flammable, and fire is a reasonably regular event during dry spells.

Heathlands have a patchy occurrence in the region. South coast heaths generally occur south of Bournda, whereas Sydney coastal heaths occur in the north of the region. Coastal headland heaths occur on many headlands, whereas southern montane heaths are restricted to the higher parts of the escarpment.

Coastal heaths

South coast heaths are found along flat coastal plateaus south of Bournda. They also occur on the elevated range around Mount Nadgee and in a few patches in the Wallagarah River catchment. Sydney coastal heaths are found on coastal sandstone plateaus around Jervis Bay.

These communities are important to a number of threatened fauna species, such as the eastern bristlebird, ground parrot, eastern pygmy-possum, chestnut mouse and New Holland mouse. Changes to the floristics and structure of these communities associated with more intense and/or extensive fire will affect these species. Impacts will vary, depending on the individual species. Some age classes suit some species and are less suitable for others. A mosaic of different age classes and fire intensity regimes would be optimal for maintaining species diversity in these communities, rather than a uniform, intense fire consuming much of the landscape. A similar case can be argued for maintaining the diversity of flora species.

In years with increased summer rain in combination with increases in CO₂ levels, plant growth should also increase, contributing to fuel loads. In dry years following these wetter periods, with hotter temperatures and a greater number of extreme fire danger days, there are likely to be more fires. Arsonists will have more opportunities for lighting fires during extreme conditions. An increase in fire frequency is likely to result in changes in the floristic composition and structure of these communities. Sedge species are likely to become more dominant and fire-sensitive shrubs to decline in abundance. Some species of flora and fauna may be lost.

Coastal headland heaths

Coastal Headland Heaths occur in small patches on exposed headlands or coastal plateaus that are within the sea-spray zone.

On the far South Coast there are large patches of Melaleuca armillaris, with little understorey, on many headlands, such as Tura Head and Long Point and those around Nadgee and Ben Boyd. These communities are difficult to burn, given that they have virtually no understorey and the ground is covered by a moist carpet of decaying leaves, although they will carry a fire under extreme conditions. Given that extreme fire conditions are predicted to increase, it is possible that these communities will burn more frequently than under current conditions. Two fires in relatively quick succession would be likely to affect the species composition and structure of this community. Such changes may affect the populations of common ringtail possums and yellow-tailed black cockatoos, which use this community.

This community is generally not prone to weed infestation, except near urban areas, which constitute only a very small proportion of stands in the region. However, more
frequent disturbance could promote greater weed invasion, particularly by those that can exploit canopy gaps.

**Montane heath**

Southern montane heaths are scattered along the southern ranges of NSW above 600 metres on stony, skeletal, infertile soils. These communities are generally dominated by *Allocasuarina nana*.

They are likely to be fairly resilient to the expected changes in climate. This community is resilient to a range of fire extremes and reasonably tolerant of drought conditions. An exception is the western edge of their range, where some drought-related shrub deaths have been recorded at Coolumbooka. Increased incidence of fire may change the species composition, with some of the rarer plants in these communities (e.g. *Dampiera fusca*, *Westringia kydrensis*, *Haloragodendron monospermum*) benefiting because of the opening up of space between the *Allocasuarina nana*.

**Grasslands**

Grasslands are usually found on fertile heavy clay soils on flat topography in regions with low to moderate rainfall (300 to 750 mm). Establishment of trees in these areas is limited by factors such as seasonally wet soils, cold temperatures or wind shear in coastal areas.

Grasslands occur in limited parts of the region. Maritime grasslands are found on beaches, headlands and islands. Temperate montane grasslands occur only in the higher parts of the escarpment.

**Maritime**

The maritime grassland group is found scattered along the very coastal margin of NSW on headlands, beach strandlines and offshore islands such as Montague Island. Maritime *Themeda* grasslands are a listed Endangered Ecological Community.

Strandline communities at the back of beaches will be substantially affected by coastal erosion and the removal of sandy substrates. They are also likely to be inundated. Some communities are likely to remain in the higher dunes, and areas may be recolonised if sands are redeposited in new locations. Shorebirds such as the hooded plover, little tern and pied oystercatcher that often use these areas for breeding may be detrimentally affected by a reduction in potential habitat. Sea spurge (*Euphorbia paralias*) may become a greater problem in these communities, particularly as increased storm surge carries seed into the hind-dune area more frequently. Although some of its habitat is likely to be removed, this community appears to have high capacity for recolonising new habitat.

*Themeda* grasslands on islands such as Montague Island and headlands are already vulnerable to weed invasion. It is likely that weed invasion will be enhanced by climate change, particularly bitou bush and kikuyu. Expansion of the distribution of these weeds could affect the breeding habitat of seabirds such as shearwaters. With fires restricted because of the isolation of these grasslands, there is the potential for woody weeds to continue to advance into them in response to increased concentrations of CO$_2$. This would alter the composition of the plant species and fauna typical of these habitats. Seabird breeding habitat (e.g. for little penguins and shearwaters) may also be affected by surges associated with storms of increased intensity and sea-level rise on offshore islands.
Temperate grassland (listed as an Endangered Ecological Community under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act))

Small examples of temperate montane grasslands occur between Nerriga and Boggy Plain. They are generally restricted to the lower slopes of broad, open valleys containing fertile soils that are often moist in winter. In this region, these grasslands occur mainly on the fringes of montane bogs and swamps. They are of limited extent and are considered in more detail later. In this region, they are susceptible to changes in water balance. A decrease in soil moisture associated with increased evaporation or greater seasonality of rainfall would allow woody vegetation to move into fringing grasslands. Greater levels of CO₂ may also favour woody species over the grasses.

Grassy woodlands

Grassy woodlands occur in major rain shadow valleys along the NSW coast where the annual rainfall ranges from 700 to 1000 mm. They generally occupy flat to undulating terrain that has fine-textured soils of moderate to high fertility, with good water-holding capacity. They also occurred extensively on the Western Slopes and Plains.

Coastal valley grassy woodland is the predominant grassy woodland in the region. Small patches of tableland clay grassy woodlands and subalpine woodlands occur in the higher parts of the escarpment.

Subalpine woodland

Subalpine woodlands and tableland clay grassy woodlands are localised in the South Coast region, extending into the western edges of Deua, Monga and Wadbilliga national parks. These woodlands are found in frost hollows along the edge of the escarpment, typically around swamp edges. Examples include Badja Swamp, Nunnock Swamp and western Wadbilliga and Tallaganda national parks.

With an increase in temperature and potentially a reduction in the occurrence of frost in these areas, woody tree/shrub species from surrounding communities may start to invade the grassy woodlands. Increased CO₂ levels are likely to favour woody plant species. Over time, this may start to change the species composition. Some plants and animals in these communities largely occur at higher altitudes. Examples include flame robins and reptiles such as Eulepis coventryi, Eulepis entrecasteauxii and Tiliqua nigrolutea. Increase in temperature may cause contraction in the range of these species.

Coastal Valley Woodland

These communities occupy rainshadow areas among hinterland hills with moderately fertile soils. The main examples in this region are found in the Araluen, Moruya and Bega River valleys. They are naturally separated from each other, and existing vegetation is additionally fragmented because of past clearing and land-use practices. They are currently most intact in the more marginal locations in the valleys, with small fragmented remnants, often in poor condition, scattered through the more central parts of the valleys. Consequently, many of these communities are already vulnerable to a number of threats such as weed and pest species invasion. They are also naturally fragmented by the patchy nature of suitable habitat, such as the small fertile flats scattered among rugged hills. These communities include the lowland grassy woodland Endangered Ecological Community in the Bega Valley and Eurobodalla Local Government Areas, red gum grassy woodland near Milton, and some spotted gum woodlands on the low rises on the Shoalhaven floodplain.
Current threats to these communities are likely to be exacerbated by climate change. Warmer conditions during dry spells may increase the mortality of remnant trees—particularly the older, hollow-bearing ones that are likely to be important habitat for wildlife. Loss of hollows from this habitat may in turn affect the numbers of bats, birds and arboreal mammals, which have already been severely reduced by loss of habitat and competition with exotic species such as European starling and feral honey bee in these ecosystems.

Given that the soils in these areas are relatively fertile, weeds such as kikuyu and African olive, or new tropical grass weeds such as Coolatai grass, may be favoured by warmer winter conditions and may spread where already present, or may start moving into the area. Some native species such as blady grass may be favoured by warmer temperatures. Additionally, an increase in rainfall in wetter years may exacerbate problems with existing weeds (e.g. fireweed, serrated tussock, African lovegrass) that are able to respond quickly to changed conditions. However, these weeds have already demonstrated the ability to spread to new locations and become more prolific following recent disturbance by drought, so uncertainty remains as to how they will repond in a changing climate.

With increased CO₂ levels, woody shrubs and kangaroo grass may be favoured over other grasses and small herbs, resulting in a gradual change in species composition and the loss of some species. As these communities are restricted to coastal valleys, some of the species within them occur only in a few locations in the region. Hence, loss from a single valley may mean these species are lost from the entire region.

Not as many threatened woodland bird species occur on the South Coast as on the Tablelands and Slopes. However, there are resident populations of diamond firetail, which could be affected by changes such as an increase in weed invasion or increased shrubbiness in the understorey.

**Comments applicable to more than one ecosystem**

The panel felt that monitoring of key predictions should take place to determine whether changes are occurring in the predicted direction. It would not be reasonable to repeat this sort of exercise in the future without some testing of the current set of predictions. The monitoring should be targeted to specific questions. There was no attempt to draw up a comprehensive set of monitoring proposals, but discussions touched upon examples such as mapping of fire extent and intensity or monitoring of populations of species whose range is believed to be shifting and/or contracting.

Reptile species in which sex determination of offspring is temperature dependent may be affected by summer and winter increases in temperature. This has potential consequences at both the species and ecosystem level. The magnitude of the potential repercussions will be dependent on factors such as the ability of reptiles to place nests in a variety of microclimates or to modify basking behaviour.

Species that can have multiple clutches/offspring, such as some birds and insects, may be favoured by a longer breeding season associated with warmer temperatures.

Many species of birds in Australia move across the landscape to take advantage of resources as they become available. Similarly, changes to the timing of migration have already been noted for some species and greater shifts to arrival and departure dates will occur as temperatures increase. The timing of resource availability events, such as flowering and high insect activity, will be affected by climatic changes. There is some potential for these events to change in an asynchronous manner, because cues such as day length or temperature may experience differential change. This is an area with a number of unknowns, but the impacts on a number of ecosystem processes could be substantial.
Phytophthora is a possible sleeper problem in some ecosystems, such as montane heaths. However, there is considerable uncertainty as to whether the potential threat from Phytophthora is likely to increase under the predicted scenario and which ecosystems are likely to be more susceptible.
3 Sydney region

3.1 Description of the region

The Sydney basin (Figure 2) comprises an elevated sandstone plateau surrounding a lowland coastal plain. The coastal lowlands and the sandstone plateau are separated by the great escarpment, which is often the most prominent landscape feature. This region includes greater Sydney, the Central Coast, the Illawarra, the Blue Mountains and Morton National Park. The elevation ranges from sea level up to 1000 metres in the Blue Mountains. Over four million people live in the area, mostly on the coastal plateaus north and south of Sydney, and on the Cumberland Plain and in the Illawarra, the Central Coast and the Blue Mountains. Much of the coastline is flanked by cliffs associated with the sandstone plateaus. Low-lying coastal areas are relatively restricted and usually associated with estuaries or lagoons such as Botany Bay, Narrabeen Lagoon and the Tuggerah Lakes system. The main agricultural area is the Cumberland Plain, where there are a large number of reasonably small market gardens. The main river system is the Hawkesbury–Nepean and the smaller Wyong, Georges and Hacking Rivers. The estuaries associated with these rivers support commercial fishing operations.

The sandstone plateau is largely covered in dry sclerophyll forest, although warm temperate rainforest and tall eucalypt forest occur along the great escarpment and in sheltered gorges. Smaller patches of heath and upland swamps are interspersed among the dry forests. Saline wetlands are found in all of the major estuaries, including Broken Bay, Sydney Harbour, Botany Bay and Port Hacking. Freshwater wetlands are not extensive and occur in swales on coastal sandplains or as floodplain wetlands along the major rivers. The eucalypt forests of the Blue Mountains have been recognised as globally significant and are included on the world heritage list. The more fertile soils of the Cumberland Plain support grassy woodlands that have been listed as endangered ecological communities. Internationally recognised wetlands include Towra Point in Botany Bay and Homebush Bay.

Figure 2 The Sydney region
3.2 Climate projections presented to the expert panel

The projections suggest that there will be an increase in temperature across the study area. The projected increase in mean daily minimum and maximum temperature is 1.5 to 2.6 °C. The projected increase is largest in winter and smallest in summer for both maximum and minimum temperature. The increases in maximum and minimum appear to be reasonably uniform across the study area. The projected increases in temperature largely appear to be outside the 30-year monthly means observed in the last 90 to 120 years. However, it is worth noting that the 30-year mean maximum temperatures for Katoomba (1911–1940) and Bowral (1941–1970) were 0.5 to 1.8 °C above the 1970–2000 mean maximum temperatures in the summer months.

The rainfall projections are closer to the observed data, but there are some seasonal differences. Rainfall in summer is projected to increase across the study area by 25% to 32%. A smaller increase in autumn and spring rainfall is predicted for the study area. Winter rainfall is predicted to decrease in the hinterland and on the Central Coast by 2% to 18%. Winter rainfall appears to be close to recorded variations around Sydney and Point Perpendicular. The trend in annual rainfall is that the study area may be between 1% and 10% wetter than the next-wettest 30-year period.

A number of climatic parameters in addition to rainfall and temperature will affect biodiversity. The likely changes in the following parameters have largely been drawn from reviews by Dunlop and Brown (2008) and Hughes (2003).

<table>
<thead>
<tr>
<th>Minimum Temperature</th>
<th>Maximum Temperature</th>
<th>Precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5–2.6 °C warmer (larger increase in winter, smaller increase in summer).</td>
<td>1.5–2.6 °C warmer (larger increase in winter, smaller increase in summer).</td>
<td>25–32% increase in summer rainfall. 2–18% decrease in winter rainfall in hinterland and on Central Coast. Overall 1–10% wetter.</td>
</tr>
</tbody>
</table>

Sea-level rise

The expert panel was asked to consider a sea-level rise of 0.5 metres by 2050 and the combined effects of sea-level rise and storm surges resulting in recession of 30 to 50 metres where unconsolidated sediments are present along the coastline. Subsequent to the expert panel’s consideration of climate change impacts on biodiversity, the NSW Government has released a policy statement advising that a sea-level rise of 0.4 metres by 2050 be considered for planning. Because of the qualitative nature of this assessment, the difference between these two figures does not affect the regional impact statements made in this report.

El Niño Southern Oscillation

Since the 1970s, El Niño events have increased and La Niña events have decreased. There is debate about whether this is associated with climate change or natural decadal-scale variability. However, it is clear that it will be warmer during both El Niño and La Niña events.

Evaporation

Some initial modelling of net water balance (i.e. rainfall minus evaporation) for NSW has been undertaken for this project. Modelling evaporation is more difficult than
modelling rainfall or temperature, because it depends on a number of factors such as temperature, wind speed and humidity. A decrease in net water balance of 15 to 160 mm has been predicted for much of Australia by 2030. The initial modelled results for this region are at the lower end of this range.

If there is a decrease in the net water balance, soil moisture and runoff to streams and stream flow are also likely to decrease. Predictions of annual runoff suggest a decrease of between 0% and 20% for south-eastern Australia. The initial results for net water balance suggest that any change may likewise be towards the lower end of the predicted range for this study area.

**Fire risk**

Models considering temperature, relative humidity, days since rain and fuel load predict an increase in the number of days with very high or extreme fire danger over much of Australia. Typical predictions for the increased frequency of high fire risk days are between 4% and 25% by 2030.

**Extreme events**

The return times for heavy rainfall events and flooding are projected to decrease in south-eastern NSW. For temperate regions, the number of days per year greater than 35°C is expected by increase by 4 to 18 by 2030.

### 3.3 Overall impacts on the ecosystems of the region

An overview of the main impacts identified by the panel for each ecosystem appears in Table 4. These impacts are discussed in more detail in the next section.

**Table 4 Summary of impacts by ecosystem: Sydney region**

<table>
<thead>
<tr>
<th>Ecosystem</th>
<th>Community</th>
<th>Main reasons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainforest</td>
<td>Warm temperate/sub</td>
<td>Prone to structural and compositional change or change to a different ecosystem due to the incursion of fire and weed invasion</td>
</tr>
<tr>
<td></td>
<td>tropical/dry</td>
<td></td>
</tr>
<tr>
<td>Littoral</td>
<td></td>
<td>Prone to structural and compositional change or change to a different ecosystem due to inundation, erosion and higher watertables</td>
</tr>
<tr>
<td>Freshwater wetlands</td>
<td>Montane bogs and fens</td>
<td>Prone to composition change in response to fire in dry periods, erosion in heavy rain, temperature rise</td>
</tr>
<tr>
<td>Coastal and floodplain</td>
<td></td>
<td>Low-lying examples prone to change to a different ecosystem due to coastal erosion and saline intrusion. Other examples prone to composition change due to changed flooding regimes and weed invasion</td>
</tr>
<tr>
<td>lagoons</td>
<td>Swamp Heaths</td>
<td>Prone to loss of fire-sensitive fauna and changes in plant composition and structure in response to fire</td>
</tr>
<tr>
<td>Ecosystem</td>
<td>Community</td>
<td>Main reasons</td>
</tr>
<tr>
<td>---------------------</td>
<td>----------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Forested wetlands</strong></td>
<td>Floodplain tall forest</td>
<td>Low-lying examples prone to change to a different ecosystem due to saltwater intrusion; otherwise composition change due to increased flooding and weed invasion</td>
</tr>
<tr>
<td></td>
<td>Coastal swamp forest</td>
<td>Prone to structural and compositional change or change to a different ecosystem due to saltwater intrusion</td>
</tr>
<tr>
<td></td>
<td>Eastern riverine forest</td>
<td>Possible compositional change due to changed sedimentation regimes</td>
</tr>
<tr>
<td><strong>Saline wetlands</strong></td>
<td>Mangroves</td>
<td>Prone to loss through inundation and re-establishment in new areas</td>
</tr>
<tr>
<td></td>
<td>Salt marsh</td>
<td>Prone to invasion by mangroves; re-establishment restricted by infrastructure</td>
</tr>
<tr>
<td></td>
<td>Sand spits</td>
<td>Loss from erosion and creation through sedimentation; species composition in re-created spits may be simplified</td>
</tr>
<tr>
<td></td>
<td>Rock platforms</td>
<td>Substantial loss from inundation</td>
</tr>
<tr>
<td><strong>Wet sclerophyll</strong></td>
<td>Illawarra, Watagans</td>
<td>Composition change due to incursion of fire</td>
</tr>
<tr>
<td></td>
<td>Blue Mountains</td>
<td>Prone to structural and compositional change due to fire in the surrounding, drier matrix.</td>
</tr>
<tr>
<td><strong>Dry sclerophyll</strong></td>
<td>Coastal sand communities</td>
<td>Prone to change to a different ecosystem if close to high-tide mark. Otherwise compositional change due to weed invasion and wind erosion</td>
</tr>
<tr>
<td></td>
<td>Communities of the gravels and sands – Cumberland Plain</td>
<td>More intense fire due to increased temperatures, prone to invasion by new weed species</td>
</tr>
<tr>
<td></td>
<td>Shrub-grass communities of gorges and Central Coast</td>
<td>Loss of old trees due to stress associated with increased temperatures in dry spells</td>
</tr>
<tr>
<td></td>
<td>Sydney sandstone communities</td>
<td>Compositional changes associated with more intense fires</td>
</tr>
<tr>
<td><strong>Canyons, caves and rock faces</strong></td>
<td></td>
<td>Microclimatic change – drying out in dry spells, increased temperatures. May be buffered from changes depending on their size and depth.</td>
</tr>
<tr>
<td><strong>Heathlands</strong></td>
<td>Sandstone/headland</td>
<td>Changes in plant composition, loss of fire-sensitive fauna, disrupted nectar production in hotter dry spells</td>
</tr>
<tr>
<td></td>
<td>Wallum</td>
<td>Compositional change due to invasion by new weeds</td>
</tr>
<tr>
<td>Ecosystem</td>
<td>Community</td>
<td>Main reasons</td>
</tr>
<tr>
<td>-------------------</td>
<td>-----------------</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Grassland</td>
<td>Maritime</td>
<td>Substantial loss of strand line due to coastal erosion</td>
</tr>
<tr>
<td>Grassland Maritime</td>
<td>Subalpine</td>
<td>Contraction of high-altitude specialists and invasion by wet shrubby forest</td>
</tr>
<tr>
<td>Coasal valley and western slopes</td>
<td>More intense fire, weed invasion, loss of old trees from stress associated with increased temperatures in dry spells</td>
<td></td>
</tr>
</tbody>
</table>

3.4 Assessment of impacts on each ecosystem

A brief description of each ecosystem precedes the discussion of the likely impacts of climate change. A more detailed description of each ecosystem of the region, including the subformations under each ecosystem, is presented by Keith (2004).

Rainforests

Rainforests are generally found in reliably moist and fertile locations that offer topographic protection from fire and wind. As they adjoin an extensive matrix of flammable dry forests, rainforests occur only in situations protected from fire by a combination of topographic features, such as escarpments or gorges, and moist conditions provided by a combination of high rainfall (often orographic) and sheltered aspects. Many canopy species produce fruit that is dispersed by vertebrates, particularly in subtropical rainforest. Littoral rainforest is likely to experience a suite of impacts different from those in the other rainforests of the region (subtropical, warm temperate and dry).

**Subtropical, warm temperate, dry rainforest**

Northern warm temperate rainforest is the most extensive rainforest community in the Sydney area. It is found on sedimentary substrates that yield acid soils in the gorges of the Blue Mountains and along the Illawarra escarpment. Dry rainforests typically occur on moderately fertile rocky substrates in landscapes dominated by dry forests. Major occurrences include the Kowmung River gorge and drier sandstone gorges. Dry rainforest is generally restricted to small patches reflecting the marginal conditions in which it exists. Subtropical rainforest is restricted to localised fertile soils on the Illawarra escarpment and around Kiama.

Existing threats include fragmentation, which may create unsuitable edge conditions and disrupt dispersal by animals (particularly arboreal and ground mammals). Fragmentation may limit pollination and dispersal of subtropical rainforest plants. Some components of the insect assemblage associated with rainforest may have poor dispersal ability. Most plant taxa can resprout to some extent; hence rainforest can recover from infrequent fire.

The main impacts of climate change relate to fire and drought. A change in species composition and structure would occur if these areas were to burn at a frequency of every two decades or less. Fires of this frequency are likely to cause disturbance at the edges, and communities may be whittled back, with more fire-tolerant species or weeds moving in. While fire would be a rare event in the Illawarra rainforest owing to its topographic position, Blue Mountains rainforest occurs in relatively small patches in a matrix of more flammable eucalypt forest (often in linear ribbons along gully lines), and the fire regimes typical of the dry eucalypt forest would be detrimental to these rainforests. However, even though Blue Mountain rainforest patches are small, their topographic position buffers them to some extent (e.g. deep gorges, bases of
escarpments). Rainforest patches embedded in large tracts of dry sclerophyll forests are potentially at increased risk of large wildfires, which are likely to gain momentum and continue on through these communities. Similarly, rainforests with a eucalypt overstorey may also be at increased risk because of intense wildfires.

Weed invasion often follows fire, with the Illawarra and Watagans rainforests being more susceptible than the Blue Mountains. Lantana would be the main weed, along with African olive and tropical grasses capable of invading dry rainforest. Regular drought could contribute to changes in the availability of fruit (e.g. production of smaller fruit). This would have flow-on effects to frugivores.

Salinity and erosion will directly affect the lowland subtropical rainforest on the coast—especially gallery rainforest, where salt and waves will extend up creeks. There may also be an increased exposure to salt spray if storm events are more frequent. Examples include the rainforest at Bass Point.

Heat stress is not likely to greatly affect the species composition of rainforests. Some change in species composition is likely if hotter, dry periods become more frequent. This is more likely to affect the understorey. No substantial tree deaths have been observed in recent droughts. Locations where ground water contributes to soil moisture are likely to be more resilient in dry spells.

The food supply for birds and bats would be disrupted if heat or drought stress were to lead to lower fruiting levels. Trees that are stressed in this way may produce smaller fruit. Another unknown is whether high levels of CO₂ would have any impact on the palatability of fruits in these communities.

Increased frequency of high-intensity rain pulses will accelerate erosion on the Illawarra escarpment, including landslides. This unstable area is susceptible to stream scouring, resulting in loss of canopy and dense weed infestations following disturbance. Gallery rainforest along streams in the Illawarra is most at risk. Storm damage is a lesser issue away from streams, although mud and rock slides are also more frequent in heavy rainfall events.

Amphibians need good rainfall in some years for successful breeding and survival of juveniles. They can tolerate extremes provided there are some good seasons. This is probably not a substantial impact because amphibians have a long life cycle and wet periods are still expected.

Rainforest communities are fairly resilient and have the capacity to disperse over long distances. If good years are still interspersed with dry periods they will be able to regenerate and recover. Given the predicted changes, rainforest communities of some type will continue to persist, but species composition may change and adapt to the new circumstances.

**Littoral rainforest**

These communities are patchy in occurrence and are located on low-lying sandy substrates behind coastal dunes or on rocky headlands. They gain a substantial input of nutrients from sea spray. In the Sydney region, examples can be found at Jibbon Beach, on the Garrawarra escarpment and at Minnamurra Point. They occur where rainfall is high and reliable and where there is some topographic shelter from fire and direct sea spray. With the exception of invertebrates, there is no unique fauna associated with littoral rainforest, which is currently listed as an Endangered Ecological Community.

The existing threats include fragmentation impacts and weeds (principally bitou bush and lantana and, on the Central Coast, North Coast lily). Many of the taxa can resprout after fire, but frequent fire opens up the canopy and dense weed infestations
frequently follow. Littoral rainforest has less topographic protection from fire, and its close proximity to population centres means that it is vulnerable to deliberately lit fires, especially on severe fire risk days. Most littoral rainforest occurs in small patches, and the levels of change of some of the predicted climatic changes, such as increased temperature, may be magnified along the edges of remnant vegetation.

As littoral rainforest occurs on sandy substrates near the sea, it is threatened by coastal erosion associated with sea-level rise and increased storm events. It is also threatened by rising groundwater levels, as it frequently occurs in low, sheltered spots behind the taller dunes. Existing threats such as fire, weeds and edge effects will continue to have a substantial impact and may be exacerbated by the projected changes to the climate.

**Freshwater wetlands**

The wetlands of the region include montane bogs and fens, coastal freshwater lagoons and coastal heath swamps.

**Bogs and fens**

Bogs and fens occur where soils are permanently or seasonally wet. They are usually found at the upper ends of streams where runoff is limited by low gradients and rainfall exceeds evaporation. They are dynamic ecosystems, contracting in long, dry periods and expanding again in wetter times. The soils are sufficiently waterlogged to prevent trees from establishing or growing in these areas. The composition of shrubby wetlands is influenced by the fire regime. Most of the shrubs present are resprouters, although exceptions include the rare species *Dillwynia stipulifera*. Smaller shrubs dominate soon after a fire but are eventually outcompeted by taller shrubs such as *Leptospermum*. This sequence starts again after a fire. Examples can be found at Narrow Neck Plateau, Kings Tableland, Newnes Plateau and Bindook Highlands.

The primary impacts are related to drying, fire and erosion. Peat around edges could dry out in long, dry periods associated with El Niño events and/or more seasonal rainfall. Peat is vulnerable to fire once it dries out, with the perimeter of the swamp most vulnerable because it adjoins the more flammable surrounding matrix. Burnt peat is susceptible to erosion if heavy rain follows a fire. This could cause a sudden change to this ecosystem if it leads to channel erosion. Channel erosion could result in drainage of the wetland, with drying out and possibly irreversible change. Existing pressures such as disturbance of the soil profile by pigs could be exacerbated by the abovementioned effects of climate change.

The water balance in these wetlands would also be vulnerable to increased evaporation. The endangered giant dragonfly *Petalura gigantea*, which breeds in upland wetlands, will be further disadvantaged if these habitats contain water for shorter and less frequent periods.

With warmer temperatures or dry conditions there are likely to be some shifts in species composition over time. It was noted that montane species in the Kosciuszko region are being found at higher altitudes. The Blue Mountains water skink (found only above 600 m) and a number of regionally endemic plant species that typically occur above 1000 m elevation would be at risk with increased temperatures. The Blue Mountains water skink may be lost from lower elevation swamps, and high-elevation plants have very few options for retreat. Change may be related to competition with other species in addition to physiological requirements for cool temperatures.
These communities are limited in distribution and occur in small patches that are likely to be vulnerable in drier conditions. Any reduction in, or loss of, these communities is important, because they are naturally isolated and vulnerable under existing conditions.

The following questions about issues with a high degree of uncertainty or requiring further investigation were raised:

- To what extent will the plant composition in tableland ecosystems be influenced by changes in the number of frosts? There is potential for considerable structural and compositional change.

- Is the species composition of comparable sites such as bogs in Kosciuszko National Park changing? Are lowland or dry-tolerant species increasing in abundance? It may be possible to detect some early change here.

**Heath swamps**

These communities exist in a subtle mosaic of wet and dry heaths across the landscape. They generally occur in poorly drained swales on coastal sand sheets or in the headwaters of creeks on sandstone plateaus with perched watertables associated with an impermeable layer in the bedrock. Some examples of coastal heath swamps occur in Ku-ring-gai Chase and Royal national parks, in Dharawal Nature Reserve and at Maddens Plains.

A unique suite of fauna, some of which are poor dispersers, are found in heath swamps and in wet heath. This fauna, which includes the ground parrot, eastern bristlebird and long-nosed potoroo, is prone to local extinction, as has occurred in some areas already. The fauna seems to prefer a mosaic of post-fire age classes in the vegetation, including some thickets that act as refuge from predators.

The main existing threat that is unrelated to climate change is long-wall coal mining. Existing weeds of hanging swamps near urban areas in the Blue Mountains include the buttercup (*Ranunculus repens*), honeysuckle (*Lonicera japonica*) and blackberry. Some of these may benefit from environmental change, and pampas grass is a potential weed that may benefit from regular fire.

One possible impact of climate change is more extensive and/or intense fire in El Niño periods. Swamps have a high proportion of resprouting shrubs. Hence, the plants are probably less sensitive to fire than the surrounding vegetation. However, there would probably be some change in the plant species assemblage if the plants were burned in a hot fire every El Niño cycle. Specialist elements in the fauna, such as the ground parrot, eastern bristle bird, long-nosed potoroo, Blue Mountains water skink and giant dragonfly, would be at greater risk. These components of the fauna all share the characteristics of being relatively immobile, habitat specialists. They require areas of dense vegetation, which provide shelter and carry small populations of feral predators. If repeated fires open up the vegetation, they will be exposed to a greater level of predation and will become more vulnerable. Burning every 7 to 10 years would be too frequent to sustain fire-sensitive plants and animals, particularly if the fires were large, widespread events.

Some specialist plants such as late successional specialists would also be affected by regular fire. For example, the sedge *Chordifex dimorphus* at North Head is found mainly in heathlands that have remained unburned for long periods of up to 50 years.

Plants are more susceptible to *Phytophthora* when they are already under some stress, such as nutrification, drought or defoliation by insects. *Phytophthora* may be advantaged somewhat by the wetter overall conditions. The impact of *Phytophthora* may be greatest under scenarios such as drought stress followed by a wet period.
The yabby, *Cherax destructor*, is native to central and western NSW, but it has been introduced to eastern NSW in farm dams. It can tolerate warm water, low flows and poor water quality better than eastern crayfish species, and it may outcompete them.

The following questions with a high degree of uncertainty or areas for further investigation were raised:

- The balance between infiltration and runoff could be affected by the predicted changes in rainfall intensity patterns. Will heavier rainfall pulses result in more runoff to streams and less infiltration into the soil? The situation is complex, because it also depends on the water content of the soil. Also, this logic may not apply to groundwater systems. Apparently, heavier rainfall results in more infiltration into groundwater than light rain.

- The chytrid fungus may affect some specialists such as the heath frog (*Litoria littlejohni*). This species is highly susceptible to chytrid, and the risk of exposure for taxa breeding in swamps may be increased, because many frogs congregate at the same spot to breed. However, it is unclear whether climate change will exacerbate this problem.

- Mapping fire severity in addition to extent would make a useful contribution towards understanding impacts on ecosystems. The critical interval between fire events and the impact on a number of components of ecosystems is not well understood.

- There is poor information on how quickly many plants recover from fire.

*Coastal lagoons*

Freshwater lagoons on coastal floodplains are currently listed as an Endangered Ecological Community. Lagoons located on sand plains form where swales intersect with the watertable. Those located on floodplains are depressions that are filled during floods, by ground water, or by tributary streams. They often form when river bends become isolated from the main channel by deposition of alluvial material. The floodplains have been so comprehensively drained and cultivated that there are very few intact examples wetlands left. Examples of such wetlands of varying quality include Longneck and Pitt Town lagoons on the Hawkesbury River floodplain, the Botany wetlands (e.g. in Centennial Park and on Southern Cross Drive) and Jibbon and Marley lagoons.

Existing threats to floodplain wetlands include eutrophication, aquatic weeds, alien fish, water regulation, grazing and invasion by a different suite of weeds when the wetlands are in their drier phase. Many have been either converted into farm dams or filled in. The former retain values for taxa adapted to more permanently wet conditions and altered nutrient status (e.g. turtles and some aquatic invertebrates). Loss of individual wetlands may increase the level of isolation of the less mobile components of their fauna. Wetlands have also been fragmented by construction of levee banks (e.g. for flood evacuation routes). These structures change the nature of wetlands by cutting off floodwaters or creating deeper, more permanent impounds.

The main impact of climate change for sandplain lagoons is saline intrusion into ground water or erosion of unconsolidated sands close to the coast. Under either scenario, the existing ecosystem will be lost and will change into a totally different ecosystem. A suite of fauna depend on coastal freshwater wetlands, either as a permanent habitat or as a drought refuge. These drought refuges may be used more regularly if inland wetlands dry out more frequently because of increased seasonality of seasonal rainfall and/or increased levels of evaporation. The impact of the presence of migratory species on the resident species is hard to predict. In dry years,
saltwater intrusion into the ground water may affect wetlands above the usual level of the saline watertable.

Floodplain wetlands—particularly those fed by ground water—will be affected by saltwater intrusion farther up the estuary. Increased dry spells and evaporative losses will result in lower water levels. This will exacerbate the stress on wetlands resulting from insufficient flooding.

Many ICOLLs contain wetland vegetation on their fringes or upper reaches. Examples include Lake Illawarra, Bellambi Lagoon, Coomaditchy Swamp, Narrabeen Lake and Dee Why Lagoon. Crakes, rails and frogs rely on dense fringing vegetation such as grasses and reeds for foraging and shelter. Frogs also need freshwater habitat. The loss of fringing trees will affect the taxa using them for roosting (e.g. some egrets and herons). *Casuarina glauca* and *Phragmites* are likely to replace existing vegetation. These offer poorer habitat for birds than the existing vegetation. ICOLLs are also drought refugia for inland species.

Saltwater intrusion will cause the decline of a whole suite of species that regularly feed and breed in these wetlands, such as invertebrates, frogs, crakes and rails. Examples include the Green and golden bell frog, Baillon’s crake, spotless crake, Lewin’s rail and the Australian bittern. Saline intrusion threatens this suite of fauna to the extent that it could become far rarer in the Sydney region, because there are few freshwater wetlands in this region. More frequent or more intense use of these drought refuges may result in changes because of eutrophication.

Structures such as levee banks may have to be raised, or new ones constructed, if floods are more frequent or intense. This will further fragment and alter flow regimes to wetlands.

Aquatic weeds are already present in many floodplain wetlands. Their growth is likely to be enhanced under low-flow conditions associated with dry spells.

**Forrested wetlands**

The forested wetlands of the region include the tall forests of the fertile floodplains, the swamp forests on low-lying sands, and the alluvial forests of the major rivers.

**Coastal floodplain tall forest**

These tall eucalypt ecosystems were found on moist and nutrient-rich alluvial soils, such as levee banks and alluvial flats on the floodplains of the major rivers. They are dominated by *Casuarina glauca* in the more saline areas. They have been virtually totally cleared for agriculture. Only small patches now remain on the upper margins of floodplains. Examples include the creeks of the Tuggerah Lake system and Georges River.

Existing threats include fragmentation, weed invasion and lack of flooding due to river regulation. Some trees require wet conditions for germination (e.g. *Eucalyptus amplifolia*). However, the predicted rainfall/flood conditions should be sufficient for recruitment events.

The main impacts of climate change are likely to be saline intrusion and changed flooding regimes. Increased saline intrusion is likely in low-lying areas near tidal reaches of rivers. Under this scenario, *Casuarina glauca* is likely to replace the tall open forest. The change from eucalypt-dominated forest to casuarina will substantially affect fauna in these communities. *Casuarina glauca* is likely to die from an increase in salinity where it currently occurs.

Tall forest often occurs in depressions behind levee banks. These sites are vulnerable to more frequent flooding if rain falls in heavier pulses. The trees may be
killed by waterlogging if the duration of flooding increases, particularly on unregulated rivers. Gallery forest within tidal ranges will be susceptible to bank erosion because of the higher tides associated with sea-level rise.

Some fauna are likely to be affected by further loss of this community. Cormorants use *Casuarina glauca* for nesting. Ducks, bats and possums use hollows in *Eucalyptus amplifolia* and *Eucalyptus bauerana* for nesting. Regent honeyeaters and swift parrots use these trees as alternative food sources in years when more regularly used eucalypts do not flower. Remnant trees are important for foraging grey-headed flying-foxes. Some taxa such as black-chinned honeyeaters and koalas use this community as a corridor. These communities are disproportionally important for fauna in the landscape, even if they consist of a few tall forest canopy species.

This community is susceptible to the emergence of some new weeds that benefit from climate change owing to the fact that a wide range of weeds is already established (e.g. tropical weeds). Climate change is likely to exacerbate existing threats such as edge effects.

*Coastal swamp forests*

These communities are found on deep sandy soils with a high watertable on the low-lying swales, flats and lakeshores of the coastal sand sheets. They are listed as an Endangered Ecological Community. These forests are limited to a few small, localised patches in the southern half of NSW. Locations in the region include the eastern side of Sydney, Port Kembla, and between Berry and Nowra.

Typical trees include *Eucalyptus robusta* and *Melaleuca quinquenervia*, which both flower reasonably reliably. The wetter forests dominated by *Eucalyptus botryoides* are also in this group. Their fauna assemblage is characterised by nectivores such as flying-foxes, sugar gliders and insects.

The threats associated with increased groundwater levels are essentially the same as those in the more widespread ecosystems occurring on coastal sands. Any stress-related reduction in flowering could place additional pressure on the locally threatened population of squirrel gliders in the Barrenjoey area. Existing woody weeds such as privet may benefit from increased CO₂ levels.

*Eastern riverine forests*

This community occurs on mobile alluvial sediments along the major rivers of the eastern ranges. This is a moist, dynamic environment, with sediments being mobilised and redeposited among river boulders and cobblestones during major floods. Examples of these communities can be seen along the fringes of watercourses such as the Capertee, Coxs, Kedumba, Nattai, Little, Jenolan and Kowmung rivers, as well as along many smaller creeks.

*Casuarina cunninghamiana* is susceptible to drought in the drier parts of its range (e.g. along the Macquarie River). The community has been reduced to linear remnants, with many weeds in agricultural areas. The possible impacts of climate change include more frequent tree loss during storms in places where the community is a linear remnant. This could affect flying-foxes, as their camps often occur along watercourses. Their loss would place additional pressure on existing sites.

This community is not generally limited by nutrient or water availability. Woody shrubs may gain a competitive advantage over other species under these conditions because of increased CO₂ levels. This would change the community structure and simplify the community by shading out the ground cover.
Increased storms could result in erosion of alluvial flats. Runoff after fires may lead to erosion and an increase in the transport of sediments and nutrients (from ash) into the rivers. This may affect a suite of species sensitive to water quality, including the Booroolong frog, freshwater fish species such as Macquarie perch, and many freshwater invertebrate species.

High levels of genetic diversity have been found among macroinvertebrate species in upland streams within this region, indicating the existence of cryptic species. Short-range endemics with highly restricted distributions may be particularly affected by changes in thermal regimes, particularly when these are coupled with other threats such as stream dewatering caused by longwall mining. Some cold-adapted upland species might face extinction.

One issue with a high degree of uncertainty was raised:

- If intense fire becomes more frequent, this could cause an increase in sediment loads. The panel was uncertain as to whether this would smother the understorey and stress trees, or whether this community is sufficiently well adapted to the regular deposition and removal of sediments.

**Saline wetlands**

The saline wetlands of the region include mangroves, salt marsh and seagrass beds.

**Mangrove swamps**

Mangroves occur around the margins of coastal estuaries, on mudflats that are exposed to regular tidal inundation. The most extensive mangroves in the region are found at Homebush Bay and Towra Point.

Sea-level rise may cause a landward migration of mangroves provided that the rate of sea-level rise is not too fast and the land morphology and sedimentation processes are favourable for the deposition of mudflats. Mangroves may persist on some existing mudflats if the rate of sedimentation can keep pace with sea-level rise. Established mangroves play a role in promoting sedimentation by slowing water flow. _Aegiceras corniculatum_ occurs farther upriver, where the landward gradient is often steeper. There may be fewer opportunities for it to become re-established, especially in sandstone landscapes.

Mangroves are likely to grow larger in response to increased temperature, because they are a tropical species. Also, some mangrove species typical of northern NSW might extend their distributions southward.

Mangroves are strong colonisers and are likely to expand into salt marsh. There may be some expansion of their distribution around river mouths if sediment loads increase in response to heavy rainfall pulses or post-fire sediment loss.

The following issues with a high degree of uncertainty or topics for further investigation were raised:

- Will the relative extent of open mudflats and mangrove-dominated mudflats change with sea-level rise? The majority of shorebirds prefer open mudflats, but some roost in mangroves.
- There are a range of insectivorous birds and bats in mangroves. How will the insects, birds and bats associated with mangroves respond to the redistribution of this community, given the possible lag between loss and recolonisation?
Salt marsh

Salt marsh occurs on estuarine mudflats that experience intermittent inundation and in small soaks occurring on coastal headlands that receive abundant sea spray. In estuaries salt marshes generally occur in the zone between the regular high-tide mark and the spring-tide mark. They include the *Sporobolus* grassland found on their fringes, which is similarly threatened. The southern emu-wren and white-fronted chat nest in this grassland. Shorebirds use salt marsh as secondary habitat if their normal roosts are disturbed by king tides or strong winds. A range of waterbirds, such as herons and teals, use salt marshes for breeding.

Salt marsh is highly threatened by sea-level rise, because there are often barriers behind it. Re-establishment (where the gradient is suitable) will be slower than for mangrove communities, because there are a wider range of species in this community. Salt marsh is at risk of invasion by mangrove communities. The morphology of the landforms at locations such as Lake Illawarra, the Shoalhaven estuary, Homebush Bay and Towra Point should allow salt marsh to become re-established, but the resulting community may well have a simpler species composition.

Birds such as southern emu-wrens and white-fronted chats are likely disappear if fire becomes more regular in the adjoining grasslands.

Seagrass

Seagrasses typically grow in estuaries in shallow waters on soft sediments such as sand and mud. They need reasonably clear water. Seagrass provides shelter for fish and invertebrates that are prey for seabirds, shorebirds, other waterbirds and larger fish. Most estuaries in NSW have some cover of seagrass, with examples from the region including Botany Bay and Port Hacking.

Climate change will affect these communities through increased water depth, increased sedimentation and increased storm activity. Severe storms uproot seagrasses and deposit them in deep water. Increased erosion from larger rainfall pulses will result in increased turbidity of the water in estuaries. This is likely to favour algae over seagrasses. Warmer sea temperatures may also favour algal growth, which can smother seagrasses. Tropical algae may move farther south if water temperatures increase.

The following issues with a high degree of uncertainty or topics for further investigation were raised:

- New tropical species from ballast water may be introduced and may outcompete seagrasses.
- More permanent incursion of sea water into former ICOLLs may favour those species adapted to consistent salinity levels and water temperatures over those that proliferate in shallow lagoons, where salinity and temperature fluctuates dramatically. For example, the abundance of *Ruppia* species may decline, whereas that of *Heterozostera* and *Posidonia* may increase.

Rocky platforms and mudflats

These are intertidal mudflats, sand spits and rock platforms. They are typically exposed at low tide and inundated at high tide.

Little terns and other shorebirds nest at, or just above, the top of the high-tide zone in a few locations in the study area, such as on Towra Island. Little terns feed on small fish associated with seagrass beds in the nearby estuary. They also roost in low-lying locations, such as on Long Island Point and Merries Reef. Pied oystercatchers and
red-capped plovers both roost and nest on shingle within the storm-tide zone. The populations of many of these shorebirds are already in decline. They are further threatened by climate change due to more regular disturbance of nests and roosts by big storm events and high tides and increased erosion of sand spits by storms and sea-level rise. A reduction in fish populations due to loss of seagrass beds would also affect shorebirds.

Rock platform communities are also vulnerable to inundation. The impact on many species typical of this zone, such as invertebrates, is likely to be substantial. The impact on other species, such as sooty oystercatchers, is less certain.

**Wet sclerophyll forests**

The more widespread wet sclerophyll forests of the region occur along the Illawarra escarpment and the eastern fall of the Watagans. The wet forests of the Blue Mountains occur as smaller patches within an extensive matrix of drier forest. The shrubby wet forests of the Blue Mountains, Watagans and Illawarra escarpment belong to the North Coast wet sclerophyll forests group. Southern escarpment wet sclerophyll forests are found along the coastal escarpment between Macquarie Pass and Cambewarran Mountain and on the basaltic rocks of the Robertson Plateau. Grassy wet forests are more limited in distribution, with Northern hinterland wet sclerophyll forests occurring in the Watagan Mountains and on the eastern fringe of Sydney’s Cumberland Plain. Southern Tableland wet sclerophyll forests have isolated occurrences in the Moss Vale district, around Lithgow, and on limestone at Jenolan.

All types of wet sclerophyll forests need a moderate amount of soil moisture and moderately fertile soils. They are often located on alluvial soils along sheltered gully lines and shaded slopes. These communities can tolerate fires, provided that they are not intense. They mostly will not extend into the drier forest types because of the shallow, infertile soils.

Many patches of wet sclerophyll in the Blue Mountains and on the Woronora Plateau occur as relatively small patches within a matrix of drier forest. They are vulnerable to regular fire (e.g. each El Niño cycle), especially where their topographic position does not offer protection from fire. The shale-cap forests of the Blue Mountains are especially vulnerable because they occur on hilltops. The wet forests occurring as narrow bands along watercourses in the gorges of the Blue Mountains are similarly vulnerable. Loss of limbs and foliage in dry periods may contribute to fire risk. Some canopy dominants are weak resprouters (e.g. *Eucalyptus deanei*). They would be vulnerable to regular, intense fire. *Eucalyptus deanei* also has a transient seed bank. It sheds its seed once mature. Germination seems to take place only where bare ground has been exposed from a low-intensity fire or other disturbance. The capsules are not very woody and would be consumed in an intense crown fire.

The canopy dominants in the wet forests of the Woronora Plateau, such as *Eucalyptus smithii* and *Eucalyptus elata*, have regenerated as even-aged stands following the last fire, suggesting regeneration from seed. There are a reasonable proportion of seeders in the understorey. These may not germinate well if a dry winter follows a fire. More regular fire in these wet forests may cause a shift from a diverse shrubby understorey to a simpler one with fire-tolerant species such as bracken and blady grass. If fire occurs regularly, there is potential for structural and compositional change in both the over- and understorey in these wet sclerophyll forests. This impact of these changes will also flow on to fauna. The wet sclerophyll forests of the Watagans and Illawarra are less threatened than in other regions, because they occur in wetter, more fire-sheltered situations.

Regular fire could contribute to a net loss of hollows by weakening large, old trees, which are then likely to fall over during windstorms. Even low-intensity fire weakens
old trees at their bases. These forests are very important to arboreal mammals, bats and birds. Loss of hollows would have flow-on effects on predators, such as owls and quolls, because hollow-dependent species such as greater gliders are important components of the food web. Changes to leaf palatability in response to increased CO₂ levels would have similar effects. Hollows in fallen timber on the ground are also vulnerable to frequent fire.

Weeds—particularly shrubby weeds such as lantana—could become a greater problem with increased fire and disturbance. If temperatures become warmer, tropical weed species will be more likely to proliferate in these communities following disturbances such as fire.

A shift from a diverse, shrubby understorey to a simpler, grassy one would result in changes to the fauna assemblage (e.g. understorey birds). Increased fire in the narrow ribbons of wet sclerophyll could affect fauna dependent on wet conditions such as stuttering frogs. This group of species will be affected by factors such as reduced litter cover, opening of the canopy and understorey, and increased turbidity. Increased erosion of alluvial deposits because of heavier rainfall events would also affect the wet sclerophyll commonly occurring on alluvial flats in the Blue Mountains.

There is some potential for rainforest to invade wet sclerophyll and for shrubby, mesic understorey species to expand in wet sclerophyll in the Watagans and Illawarra because of the warm, moist climate and topographic protection from fire. Impacts on edge species such as pademelons and the green-thighed frog may not be significant in the shorter term, as these species may simply move with the ecotone. However, a longer term reduction is the availability of wet forest with a grassy understorey would disadvantage these species.

Climate may be a factor in exacerbating bell miner–associated dieback. More frequent dry periods may cause stress of trees, making them more susceptible to insect attack. Under this scenario, wet sclerophyll forest in diatremes with small catchments would be most at risk. Warmer temperatures may also favour the buildup of folivorous insects by promoting multiple clutching.

The following issues with a high degree of uncertainty or topics for further investigation were raised:

- Leaf palatability is likely to depend on soil fertility and climatic conditions as well as on CO₂ levels. Some groups of insects are likely to be disadvantaged, whereas others may be winners. It is difficult to make detailed predictions. Arboreal mammals are at risk from these impacts, and this risk would have flow-on effects on their predators. There are very high densities of arboreal mammals in the Blue Mountains.

- Some invertebrates (e.g. dragonflies, cicadas) have long-lived juvenile stages. They may be vulnerable if their post-emergent period coincides with long dry periods or intense fire. They may be buffered from these impacts to some extent because the numbers emerging each year are variable (e.g. as occurs in the giant dragonfly).

**Dry sclerophyll forests**

Dry sclerophyll forests are the most widespread ecosystems in the region. These communities are found on shallow, low-nutrient soils with poor water-holding capacity. These communities are highly flammable, and fire is a reasonably regular event during dry spells.

Dry shrubby forests are found on siliceous sandstones, whereas dry shrub/grass forests occur on marginally better soils. Of the shrub/grass forests, central gorge dry
sclerophyll forest occurs in the dissected gorges of the Blue Mountains. Cumberland dry sclerophyll forest is restricted to patches of Tertiary alluvium within the extensive shales of the Cumberland Plain. Small amounts of Hunter-Macleay dry sclerophyll forest occur in rainshadow areas within the Wyong, Hawkesbury and Gosford Local Government Areas. Dry shrubby forests occur across the sandstone plateaus and in other dry rocky soils. Sydney coastal dry sclerophyll forests are found in higher rainfall areas near the sea. Sydney hinterland dry sclerophyll forest occupies the lower rainfall band behind the coastal forests, and Sydney montane dry sclerophyll forest occurs on the elevated plateaus of the upper Blue Mountains and the Woronora Plateau and around Fitzroy Falls.

More localised dry forests, such as coastal dune dry sclerophyll forest, occur at North Entrance and Seven Mile Beach. Sydney sand flats dry sclerophyll forest occurs on older, nutrient-poor sands in the Castlereagh district and at Kemps Creek, Elderslie and Holsworthy.

**Coastal dune dry sclerophyll forest**

This community occurs on sand dunes or plains behind beaches or perched sands on coastal plateaus (e.g. Royal and Kurnell National Parks). The community is already highly fragmented and threatened by a number of factors. Its fauna is relatively diminished because of disturbance. Reptiles are an important component of dry forest, generally because the canopy is fairly open.

The primary impact of climate change is coastal erosion where these forests are located between the ocean and a water body. Impacts from rising groundwater levels are likely where this community occurs on subtle rises on sandplains.

Weed invasion will be exacerbated if the canopy is opened up by increased fire or storm damage. Bitou bush and boneseed are major weeds. Increased temperatures may advantage bitou bush relative to boneseed. Wind erosion following storm damage is also possible, particularly where the topography enhances wind speeds. For example, katabatic winds coming down the escarpment have exacerbated erosion in locations such as Windang.

**Sydney sand flats / Cumberland dry sclerophyll forest**

This community is close to settlements in the Castlereagh and Agnes Banks area and is already affected by frequent burning, much of which is arson. This is likely to be exacerbated, given the predicted increase in the number of severe fire danger days. This will lead to simplification of the understorey through loss of fire-sensitive shrubs such as acacias.

African lovegrass is a tropical species that is already a weed in Cumberland Dry Sclerophyll Forest. It may be advantaged by increased temperatures and CO$_2$ concentrations. Otherwise, no major weed threats have been identified, particularly in the case of Sydney Sand Flats forest, which occurs on infertile soils.

This community has been fragmented by clearing, but it is also naturally fragmented because it restricted to specific soils. Increased temperature is likely to exacerbate these edge effects because of the harsher microclimate occurring at the edges.

**Hunter Macleay / central gorge dry sclerophyll forest**

The Hunter forests, which are limited in extent and occur within a matrix of flammable forest, could be more prone to large, intense fires. Regular fire, such as occurs in each El Niño cycle, could simplify the understorey by favouring grasses over shrubs. In contrast, the topographic variability and low fuel loads in the central gorge forests seem to mitigate against extensive fires in this landscape.
The central gorge forests have plenty of hollows and good populations of yellow-bellied gliders and owls. Weakening of old trees in dry, hotter periods would make them susceptible to falling over in storms, especially on steep slopes. There was some recent evidence of drought stress in this community in the Wollondilly Valley, where many trees shed their leaves but resprouted once the drought broke. Attrition of older trees will lead to loss of hollows. Although extensive fires are uncommon in this landscape, any increase in the extent of fires, including low-intensity burns, would also contribute to the attrition of older trees.

**All dry shrubby forest on sandstone**

These forests are found on the quartz-rich sandstone plateaus of the region. They occur in situations where the soil is reasonably shallow or dry, such as on the plateau tops or on the north- and west-facing slopes. The sandstone forests are important secondary habitat for fauna associated with heath, such as Rosenberg’s goanna, the rock warbler and the broad-headed snake. Most of the region’s endemic fauna occurs in dry forest or heaths. A number of species in dry forest or heaths are also important for nectivores such as the eastern pygmy possum.

The coastal forests have the highest proportion of taxa regenerating from seed, followed by the high-elevation plateaus. The hinterland forests have the fewest seeders. Hence, there is a gradient of susceptibility to fire in El Niño periods. If fire frequency were to increase to one each ENSO cycle, then these communities would start to lose species. Impacts on fauna could be extensive, because large areas will be burned under extreme conditions because of the extensive, contiguous nature of the dry forests. Impacts will be greatest where there are few incised gullies or rocky outcrops.

The timing of fire could also affect fauna. Early in a dry period would be worse for fauna than later, because ongoing dry conditions delay recovery. Increased temperatures may bring forward the start of the fire season. This may cause the fire season to coincide with the breeding season for some taxa—in particular those that breed in winter. Those taxa that start breeding earlier in response to rising temperatures may be less affected. Winter breeders such as powerful owls are less likely to start earlier and may not successfully fledge their young before an earlier fire season. Loss of hollows due to weakening of old trees is also an issue. All of these fire impacts could be exacerbated by additional pressure for hazard reduction burning if there were a perceived greater risk to property due to temperature increase.

Some plants have germination cues related to seasonal patterns. The cues for *Leucopogon*, for example, include fire and a period of colder temperatures. Germination in taxa with cold-dependent cues could be disrupted by increased temperatures over winter.

A suite of vertebrates typical of dry forests occurs only above 600 metres. These include the highland copperhead, three-lined skink, *Litoria ewingi* (brown tree frog), blotched blue tongue, gang gang cockatoo, flame robin and eastern false pipistrelle. The lower elevation limit for this group of taxa may increase to approximately 750 to 800 metres because of temperature increases (based on temperature decreasing with elevation at a rate of 1 °C per 100 metres). There are few higher elevation sites rising above the general height of the plateaus in this region, so there is little potential for these species to compensate for loss of lower elevation habitat by migrating to higher altitude sites.

There are also some plants restricted to higher elevations. However, it is not certain whether their physiological responses to higher temperature are somewhat plastic. Even so, their germination cues may be disrupted or they could be outcompeted by...
lower elevation plants. There may even be some positive effects on their growth (e.g. because of an increase in the length of the growing season).

The following issues with a high degree of uncertainty or topics for further investigation were raised:

- The rock warbler and other widespread species such as the broad-tailed gecko or the Sydney form of Cunningham’s skink are endemic to the Sydney sandstone. The impacts of fire on these taxa are poorly understood.

- Grey-headed flying-foxes are important pollinators for a range of species in dry eucalypt forests and coastal dune forests—particularly those with white flowers. There is conflicting evidence on whether the range of the grey-headed flying fox has contracted southwards. However, the most recent evidence (Roberts et al. 2011) suggests that their range has not changed over time. Evidence does suggest that their numbers have declined within the area of distributional change since the arrival of the black flying-fox. This may be due to the capacity of the black flying-fox to tolerate higher temperatures than the grey-headed flying-fox which it appears to outcompete at roosting sites. This may have implications for the pollination of some dry forest species, especially where forests are fragmented, because the black flying-fox favours fruit as a food source to a greater extent than the grey-headed flying-fox. The black flying-fox has experienced a range shift poleward. However, the pace of its southern range shift is much quicker than temperature latitudinal shift, suggesting that its movement is not related to a warming climate (Roberts et al. 2011). The little red flying-fox occurs mainly in drier areas such as on the Goulburn River, and less frequently in the lower Hunter. It plays a similar role in pollination as the grey-headed flying-fox. It is under pressure from fragmentation and loss and degradation of remnants, but there is less evidence of expansion of the black flying-fox into its habitat.

Canyons, rock faces and caves

This is a permanently moist, relatively fire-free environment with relatively stable temperatures. A number of plants and animals (such as the red-crowned toadlet, the Sydney form of Cunningham’s skink and cave crickets) that are either endemic and/or have a restricted distribution occur in this environment.

A combination of factors could lead to higher sediment loads being deposited in canyons. More frequent high-rainfall pulses and more extensive wildfire associated with hotter, dry periods could both favour increased erosion. However, it is uncertain whether these sediments will be deposited in canyons or in higher order streams.

There is a risk that these environments will sometimes be drier because of increased seasonality of rainfall and/or increased evaporation. There is also the risk that fire will extend farther into these environments during hotter dry periods.

Weathering patterns in overhangs are important for some species. Honeycomb-type weathering produces suitable roosting sites for bats and, to some extent, the broad-tailed gecko. A change in weathering patterns, such as more frequent wind-driven rain, would be detrimental. Intense fires can cause the collapse of overhangs, and blackening of the rock by the fire makes them less favourable to fauna. Heavy rainfall events after drought may contribute to the collapse of cliffs and overhangs and increase erosion.

Some bats in cave systems are sensitive to temperature change. However, underground caves may be reasonably well buffered, as evidenced by the considerable latitudinal range of cave-roosting bats. Some species, such as the eastern horseshoe-bat, are very particular about their breeding locations, and
changes in temperature may have a sufficient impact to affect the suitability of these sites. Breeding locations are very limited within this region.

Rock outcrops also support a suite of species, such as the broad-headed snake, geckos and others that seem to be sensitive to microclimatic changes. They could be susceptible to the hotter conditions predicted during dry spells. Also, fire in rocky refuges could create less suitable microclimatic conditions by opening the canopy and baking or splitting rock shelters. Increased storm events could affect some cliff-nesting birds that are already uncommon, such as peregrine falcons.

The following issue with a high degree of uncertainty was raised:

- The balance between infiltration and runoff could be affected by an increase in the proportion of rainfall occurring in intense pulses. A possible outcome of heavier rainfall pulses is higher runoff and a less even availability of water across the year. Less moisture at certain times could affect a number of species that are dependent on permanently moist conditions.

**Heathlands**

Heathlands generally grow on exposed shallow soils that are especially deficient in phosphorus, nitrogen, potassium and magnesium, which are the key nutrients for plant growth. On sandstone plateaus heathlands often occur where bedrock is very close to the surface, and they are more extensive in the high rainfall zones (i.e. coastal and montane areas). Near the coast, they also occur in areas where tree growth is limited by sea spray. These communities are highly flammable, and fire is a reasonably regular event during dry spells.

Sydney coastal heaths are mostly found on exposed coastal sandstone plateaus from Gosford to Garie in Royal National Park, with disjunct patches at Jervis Bay and the Barren Grounds and on the Budderoo Plateau. Sydney montane heaths extend from western parts of the Wollemi Wilderness to the southern Blue Mountains and the Morton–Budawang region. Examples of coastal headland heath can be seen on headlands around Garie Beach in the southern part of Royal National Park. Wallum Sand Heaths occur only in a few locations in the Sydney area, such as at Botany Bay, in Royal National Park and Centennial Park, and at Windang.

**Dry heath on sandstone**

More regular fire in this ecosystem would disadvantage seeders relative to resprouters. The proportion of seeders in heath is reasonable high. The end result is likely to be species simplification, with an increased proportion of small shrubs and sedges. Pagoda heath also has a reasonable proportion of fire-sensitive plants, as it typically occurs in fire-protected locations. Some structural change is also likely if fire becomes more extensive. There would be less long-unburned heath dominated by tall shrubs such as *Banksia ericifolia*. These changes will be gradual, as some of these species have large seed banks. Heath patches are isolated, and the poor dispersal capacity of the plants and some animals suggests that dispersal between patches is unlikely.

Drought-sensitive species include old *Banksia ericifolia* and a number of seeders in their juvenile stages. As germination tends to occur after fires, which are more likely in summer, lower autumn or winter rainfall could reduce seedling survival.

There is a high risk of *Phytophthora* infection in areas below 800 metres elevation with a mean annual rainfall greater than 600 mm and with infertile soils with high levels of organic matter and poor drainage. High soil moisture levels and warm soil temperatures are necessary for infection to occur. These conditions are likely to be more common, given the rainfall and temperature predictions, particularly in La Niña
periods. Plants in the Proteaceae, Ericaceae, Fabaceae and Dilleniaceae families, and *Xanthorrhoea* species, are particularly susceptible.

The greatest impacts on fauna are likely to be those on relatively immobile habitat specialists such as ground parrots. These impacts have already been described in the section dealing with heath swamps. In addition, a reduction in the abundance of *Banksia ericifolia* due to factors such as increased fire or drought would disadvantage the eastern pygmy possum and a suite of birds, such as the tawny-crowned honeyeater, that rely on nectar from this species.

*Headland heath*

Coastal headland heaths occur in small patches on exposed headlands or coastal plateaus that are within the sea-spray zone.

*Banksia integrifolia* may be vulnerable to long, dry periods, given that some losses have been noted in recent droughts. Its nectar is an important food source for the grey-headed flying-fox and eastern pygmy possum and for a suite of birds, including the tawny-crowned honeyeater.

Headland heaths are burned infrequently because of their relatively low fuel levels and their isolation because of coastal development. Change in fire regimes is therefore unlikely to be a factor. No weeds were identified that were likely to benefit from climate change. Bitou bush does occur in this community, but to a lesser extent than in heaths on sand.

There may be some minor losses from very low elevation sites affected by saltwater incursion, but this may be offset by limited expansion in response to an increase in the extent of the zone affected by salt spray.

*Wallum heath*

This has a limited extent in the study area and it is already fragmented and highly disturbed. Climate change is likely to exacerbate the threats already affecting this community.

Wallum health is situated very close to the coast at Bouddi, Wyrrabalong and Botany Bay and at North Head, where it is threatened by weeds such as lantana or bitou bush that are likely to be favoured by climate change. Regular fire leading to structural change and species simplification is a threat at the Bouddi site and at other sites where the heath is not isolated by coastal development. This is not likely to be an issue at sites such as North Head.

*Maritime grasslands*

Maritime grasslands are usually found on headlands or off shore islands or behind beaches, where the establishment of tress is limited by factors such as wind shear. Examples can be found at most beaches and at Cape Banks, in Royal National Park and on the northern Illawarra coast and the Five Islands.

Coastal recession is an obvious threat, but the *Spinifex sericeus* community is likely to become re-established on coastal sands that re-form further inland. There will be considerable loss of this community along urbanised sections of the coastline where the re-deposition of sands will be impeded by infrastructure. During the re-establishment phase, *Spinifex sericeus* and the other native taxa will have to compete with sea spurge and other cosmopolitan weeds that have become established along the coast.

Grasslands on headlands are usually less exposed to the direct impacts of sea-level rise and storm surges. Low-lying islands, such as the Five Islands near Wollongong,
would be an exception. Headland grasslands generally occur on friable soils and often on steep slopes. This combination makes them prone to accelerated erosion if an increased proportion of rainfall occurs in heavier pulses.

The main weeds are bitou bush/boneseed and myrtle-leaf milkwort. Both are from South Africa and could be advantaged by higher temperatures. Maritime grasslands are important breeding sites for seabirds, especially on islands. Important sites include the Five Islands, Lion Island and Bowen Island. Birds cannot land if these sites are invaded by shrubs. Species that could be affected include shearwaters, little penguins and sooty oystercatchers. Kikuyu could also be favoured by increased temperatures and could become a greater threat to seabird species nesting in burrows.

The following issue with a high degree of uncertainty was raised:

- The distributions of some species appear to be expanding at the expense of others. For example, the distribution of the wedge-tailed shearwater may be expanding and those of sooty shearwaters and little penguins declining. It is hard to predict whether this will be exacerbated by climate change.

Grassy woodlands

Grassy woodlands occur in major rainshadow valleys along the NSW coast where the annual rainfall ranges from 700 to 1000 mm. They generally occupy flat to undulating terrain that has fine-textured soils of moderate to high fertility, with good water-holding capacity. They also occurred extensively on the Western Slopes and Plains.

Coastal valley grassy woodland is the predominant grassy woodland in the region; it formerly occupied much of the Cumberland Plain and parts of the Illawarra, where it is now heavily cleared and fragmented. Western Slopes grassy woodlands occur in dry areas such as the Capertee Valley and the Burragorang. Subalpine woodlands are restricted to the western part of the region.

Coastal valley and Western Slopes grassy woodlands

Coastal woodlands occur on moderately fertile soils in rainshadow coastal valleys (e.g. on the Cumberland and Illawarra plains), whereas the Western Slopes woodlands occur in drier valleys farther from the coast (e.g. Burragorang, Capertee). Frogs such as the spotted grass frog that are associated with grassy, shallow depressions are not common in other ecosystems around Sydney. Woodland birds inhabit these communities, particularly in Western Slopes woodlands in the Capertee and Burragorang valleys.

On the Cumberland Plain and around Lake Illawarra, fragmentation, edge effects, arson, weeds and lack of recruitment due to grazing are the main factors threatening this community. Climate change is likely to be of secondary importance, unless conditions become more suitable for some new tropical weeds.

Drought stress will contribute to the loss of some old, hollow-bearing trees. Increased hot, dry spells could lead to more arson. An increase in fire frequency would weaken old, hollow-bearing trees and remove logs from ground cover, with associated loss of birds and reptiles (e.g. bush stone curlew, speckled warbler). Drought stress leading to reduced flowering could substantially affect nectar feeders such as flying-foxes, the swift parrot and the regent honeyeater. In the Western Slopes woodlands in the Capertee Valley, climate stress to old trees could be exacerbated by heavy occurrences of mistletoe as a secondary impact.

Warmer, wetter conditions could favour rabbits and hares. This would increase grazing pressure on the understorey and possibly simplify its species assemblage.
However, rabbits and hares are not currently in high densities on the Cumberland Plain.

Some characteristics of this ecosystem may help to buffer it from the changes associated with climate change. Germination of the plants in this ecosystem is primarily episodic in nature and occurs following good rainfall. Most plants re-sprout after fire, but few require fire for germination. Germination is not related to fire as closely as it is in dry forests and heaths. The rainfall predictions provide for episodes of good rainfall that should promote germination.

African olive, which is the main weed in this ecosystem, has a Mediterranean distribution. Hence, it may not be advantaged by warmer, wetter summers. African lovegrass is a flammable weed, but it does not seem to invade remnants with an established over- and understorey. The Western Slopes woodlands are affected by agricultural weeds, many of which are annuals. Their persistence is associated with soil changes associated with the use of fertiliser, rather than with climatic factors.

No shrubs were identified that are likely to be favoured over grasses under increased CO₂ concentrations, particularly given that one of the major grasses in this ecosystem (Themeda australis) is a C4 species.

The following issues with a high degree of uncertainty or topics for further investigation were raised:

- The impact of reduced leaf palatability on folivores may be offset to some extent by the reasonable fertility of the soils.
- Flowering is affected by drought, but phenology is complex in many Australian ecosystems. What is the role of other climatic factors in flowering, and will the projected changes result in less flowering?

Subalpine woodlands

Subalpine Woodlands are localised in the region, occurring on the western edge of the Blue Mountains and in the Gardens of Stone National Park. These woodlands are found mostly in high-altitude frost hollows above 1000 metres.

The most likely impacts of climate change relate to increased temperature and fewer frosts. Competition from plants from lower elevations and increased competition for high-altitude species such as flame robins and a suite of reptiles are possible impacts. The community may progressively develop a taller overstorey and moister, shrubbier understorey. There may be a gradual contraction of range and simplification of species present.

This is not a fire-prone community, but it may become slightly more fire prone as a result of temperature increases.

Comments applicable to more than one ecosystem

Climate change is likely to increase the intensity of fires and the size of the burned area, particularly in El Niño periods. Those parts of the landscape that are rarely burned under existing conditions are likely to experience more frequent fire. These changes result from the predicted warmer temperatures in dry periods and an increase in the number of extreme weather days each year. A combination of dry spells and warmer temperatures will lead to periods when the landscape as a whole is more flammable, enabling fires to encroach on otherwise moist riparian and gully communities. Extreme fire days during these dry spells will lead to fire spread-rates and intensities that are essentially uncontrollable. Hence, large areas are burned, as occurred in the summers of 2001–02 and 2002–03.
The consequences for vegetation are likely to be an increased abundance of resprouting herbs and grasses such as bracken and a reduction in the abundance of non-resprouting shrubs and trees. This would include iconic seeder trees such as Blue Mountains ash (Eucalyptus oreades) and possibly the weakly resprouting Deane's blue gum (Eucalyptus deanei). Iconic habitats such as blue gum forest and diatremes are likely to be put under pressure from these large fires, particularly in the drier, non-coastal parts of the region. These effects could compound over time and lead to dramatic structural change in both the widespread dry forests as well as moist gully habitats. The result may be a loss of important nesting and food resources. In addition, fire can favour resprouting grasses, adding another possible pressure on these ecosystems.

Increased fire intensity would negatively affect fauna dependent on hollows, fissures or a dense, mesic understorey. Intense fire is likely to increase mortality and fall of old trees with hollows. Hollow formation in younger trees may be initiated, but the development time for new hollows is very long. Hence, the loss of hollows is likely to exceed gain. Taxa such as sooty owls disappear if there is structural change in the understorey after intense fire, because they require well protected roost sites, particularly when using rock overhangs. The disappearance of sooty owls from the Hacking River after fire illustrates this point.

Grey-headed flying-foxes have high mortality rates during hot spells. Because they roost in the canopy, they are vulnerable to injury due to buffeting by wind. They control their body temperature by fanning their wings, but above about 40°C this is ineffective, and they either drop their young or succumb to heat stress and fall out of trees. They are a mobile animal and there is already evidence that their distribution is shrinking, although the evidence is not conclusive. There is also evidence that the distribution of the black flying-fox is moving southwards. This species is considered more of a generalist than the grey-headed flying-fox, which feeds on nectar to a greater extent. If the black flying-fox were to displace the grey headed flying-fox in this region, then there could be negative consequences for pollination of trees and shrubs throughout the forests. Little red flying-foxes are currently sporadic visitors to the Sydney area, but it is possible that they will also become more regular visitors. There is considerable potential for ecosystem processes such as pollination to be affected by changes in the distribution of the various flying-fox species. Changes to community compositions or assemblages of nectar-feeding insects could also have substantial implications for pollination.

Warmer temperatures may also favour insects, reptiles, frogs and birds by promoting multiple clutching. Not all species will be able to respond to higher temperatures by multiclutching. Some species already attempt to raise a second clutch, which often does not survive.

An increase in temperature of 0.5 to 1.0 °C could cause a sex bias in reptiles. Reptiles may be able to mitigate this impact to some extent by placing nests in a variety of microclimates or by modifying basking behaviour. Egg incubation at increased temperatures also leads to more abnormalities due to faster development.

Ecosystems in fragmented landscapes are likely to be affected by climate change due to an increase in the magnitude of edge effects. A low level of habitat depletion at the landscape scale maximises opportunities for taxa to survive in climatic refugia and to expand if more favourable conditions return. Also, many of the impacts of climate change (e.g. fire regimes, drought) will not be uniform across the landscape. In extensive ecosystems, there is a greater chance that species affected in one locality may be less severely affected elsewhere.

As flowering in some taxa is triggered by temperature, it is likely to occur earlier. Events such as flowering could get out of synchronisation with events cued by day
length, such as bird migration. There is also evidence that migratory birds are arriving earlier in the Sydney region, and remaining in their breeding grounds for longer periods.

Drier, warmer winters may mitigate against the chytrid fungus in parts of the region. Symptoms seem most prevalent in the foggy, moist conditions of the cooler months in locations such as Richmond.

An increased frequency of high-intensity rain pulses may cause increased scouring of watercourses. Impacts on stream frogs include eggs and tadpoles being washed away and simplification of habitat for the surviving tadpoles. Scoured watercourses are likely to provide fewer food resources and less shelter, making tadpoles more susceptible to predation. Slow-maturing tadpoles may be more vulnerable to these impacts.

Seasonal dry spells in western NSW could result in increased movement of species to coastal areas. Such increased movements may result in competition and displacement of resident fauna species. The consequences of such movements are poorly understood. Examples of species likely to show increased movement are long-billed corellas, which feed primarily on seeds from grasses, and sulfur-crested cockatoos, which feed on seeds and berries. They also target immature cones of banksias. Both species nest in hollows. The cattle egret, which feeds on invertebrates and small vertebrates, may be moving south.

Some artificial habitats are important around Sydney. For example, bats often roost in stormwater drains. They could be affected by flooding associated with heavier rainfall pulses.

There is considerable potential for new introduced species to emerge as the climate changes. Pest species by their nature are well adapted to rapidly exploit favourable conditions. Pest species that are problematic to the north of Sydney may well expand into the region. Weeds are dealt with mostly under the relevant ecosystem. Some with potential to benefit from climate change include tropical grasses (warmer temperatures) and succulents (survive dry spells, expand in wetter times). Some native plants such as Pittosporum may also benefit.

Tropical fish, marine species transported in bilge water, and aquarium weeds were identified as an increased problem if water temperatures increase. The mosquito fish Gambusia holbrooki is already common around Sydney, but it may increase in abundance farther south if water temperatures increase.

Cane toads were considered the terrestrial vertebrate most likely to reach the Sydney region if temperatures rise by about 2 °C. Similar concerns were raised about the possibility of fire ants or crazy ants moving south in response to higher temperatures.
4 North Coast, Hunter and New England Tablelands regions

4.1 Description of the region

This study area comprises the North Coast region, the New England Tablelands Region and much of the Hunter Region (with the exclusion of Yengo and Wollemi national parks—see the Sydney basin section for a discussion of these areas (Figure 3).

Figure 3 North Coast, Hunter and New England Tablelands regions

North Coast

The North Coast State Plan region covers 35,800 km² of northern NSW from the coast to the escarpment of the Great Dividing Range, from Taree north of the Hunter Valley to the Tweed lowlands and the Queensland border in the north. It incorporates a number of major river valleys: the Manning, Macleay, Hastings, Clarence, Richmond and Tweed.

Major landforms follow a gradient from the coast to the escarpment, from coastal sand dunes, ridges and strandplains, to major estuarine basins and alluvial floodplains through low foothills and ranges, to the escarpment, mountains and the headwaters of the major rivers.
Coastal vegetation includes swamp oak forests, mangroves and salt marsh fringing the estuaries; freshwater wetlands and coastal swamp forests on the alluvial plains of major watercourses; woodland; headland and strandline grasslands; and littoral rainforest. Dune swales and backbarrier flats and the fringes of coastal lagoons support freshwater wetlands, paperbark swamps, wet heaths and sedgelands.

Although the major river floodplains are predominantly cleared, they still support important wetland complexes and remnants of the original lowland vegetation. Beyond the floodplains, low foothills and ranges are dominated by wet and dry sclerophyll forest, with rainforest occurring in sheltered slopes and gullies. In the far north of the State (Tweed, Brunswick and Richmond catchments), basalt, meta-sedimentary and alluvial soils support diverse lowland subtropical rainforests. Warm temperate rainforests occur on the steeper escarpment slopes, associated with the 20- to 24-million-year-old Tweed volcano and Mount Warning caldera (a collapsed landscape resulting from volcanic eruption). Immediately south of this area, in the Clarence Valley, dry sclerophyll dominates on coarse-grained sandstone-derived sediments. Patches of cool temperate rainforest occur on higher plateaus such as the Barrington Tops, New England escarpment and Border Ranges.

**New England Tablelands**

This region incorporates the Northern Tablelands of the Great Dividing Range, the majority of which falls within the New England Bioregion. The southern boundary of the region is the Liverpool Ranges, and to the north is the Queensland border.

Vegetation in the Tablelands is dominated by dry forests and woodlands on granite and acid volcanic soils and by shrubby woodlands, acacia shrublands and dry rainforests on stony soils on sedimentary geology. On the flatter, more agriculturally productive basalt and sedimentary soils are grassy box woodlands and forested riparian areas and basalt plateau lagoons. High-rainfall areas, particularly along the escarpment, support wet sclerophyll forests and patches of cool temperate rainforest.

Clearing of native vegetation has been extensive on much of the Tablelands.

**Hunter**

The Hunter State Plan region covers an area of 29 300 km². It incorporates the far north of the Sydney Basin, including the northern parts of Wollemi and Yengo national parks, and stretches west past Goulburn River National Park approximately 260 km inland. To the north it incorporates the southern end of the Manning catchment and includes Forster on the coast, and incorporates the escarpment national parks of Curracabundi, Woko and Barrington Tops.

For a discussion of ecosystems that occur on the sandstone plateau of Wollemi and Yengo national parks refer to the Sydney basin section.

The region supports a number of large lake systems, including Wallis Lake, Myall Lakes and Lake Macquarie. Listed as a Ramsar site is the Hunter Estuary Wetlands (Koorangang Nature Reserve and Shortland Wetland). Wallis Lake supports the largest area of seagrasses in NSW (33 km²) as well as extensive salt marsh areas (6 km²). These lake systems provide habitat for a suite of migratory shorebirds.

The Hunter region contains highly developed coastal dune systems, a consequence of a retreat in the sea level over the past 18 000 years.

This region forms a convergence zone for vegetation characteristic of the North Coast, Western Slopes and Sydney Basin. The southern part of the region captures Hawkesbury and Narrabeen sandstone: its upland plateaus and deep gorges contain many dry sclerophyll communities representative of the Blue Mountains area. In the north of the region, the escarpment national parks contain wet sclerophyll forests and
rainforests on basalt, floristically typical of the New England Tablelands region. The Great Dividing Range is at its lowest point in the western part of the Hunter region. The northern and central western slopes of the Great Dividing Range support Grassy Woodlands. Many species in the west of the Hunter region are at the easternmost limit of their distribution. The Liverpool Range includes the reserves of Ben Halls Gap, Towarrri and Coolah Tops. Erosion of northern and western ranges has resulted in sediment being deposited over much of the valley floor, which is dominated by wet and dry sclerophyll forests and woodlands. Much of the valley floor in the Lower Hunter has undergone substantial clearing. Significant areas of saline, freshwater and forested wetlands can be found in the lake areas, major floodplains and estuaries and dunes of the coast.

The region incorporates the IBRA (Interim Biogeographic Regionalisation for Australia; Thackway and Cresswell, 1995) bioregions of Sydney Basin, Brigalow Belt South and North Coast.

4.2 Climate projections presented to the expert panel

Temperature and rainfall
For the projected climate in 2050, this study used a subset of global climate models developed for the Intergovernmental Panel on Climate Change (IPCC; 2007a). These models were selected as outlined in DECCW 2010 for their reliability for NSW. These models used the A2 climate change scenario.

The projected climate models cover monthly/seasonal mean data for temperature and rainfall. The projections include the following:

- The weather will be hotter, with average maximum temperatures increasing in all seasons.
  Maximum temperatures are predicted to increase most in winter and spring; by approximately 2 to 3°C over most of the region. Spring warming may be slightly less on the North Coast, and winter warming may be slightly greater in the west of the Hunter area. Summer and autumn are predicted to increase by approximately 1 to 1.5°C over most of the region.

- Average minimum temperatures will also increase.
  Warming in winter is predicted to be more extreme than summer warming, with winter minimums increasing by up to 2.5°C, and summer maximums increasing by ~1.5°C across the region.

- In the North Coast and Tablelands, rainfall will be close to current levels.
  No discernable change in rainfall is predicted for the North Coast and Tablelands.

- In the Hunter, summers will be wetter and winters will be drier.
  In the Hunter region, annual rainfall is predicted to remain similar to current levels, but seasonal rainfall is predicted to change. Summer rainfall is predicted to increase by 12% to 20% and winter rainfalls are predicted to decrease by approximately 12% to 20%.
Table 5  Temperature and rainfall summary for the North Coast, Hunter and New England Tablelands Regions of NSW (2050 A2 Scenario)

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<thead>
<tr>
<th>Minimum Temperature</th>
<th>Maximum Temperature</th>
<th>Precipitation</th>
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<tbody>
<tr>
<td>Up to 2.5°C warmer (larger increase in winter, smaller increase in summer).</td>
<td>Spring: 2–3°C warmer (slightly less on the North Coast) Summer: 1–1.5°C warmer. Autumn: 1–1.5°C warmer. Winter: 2–3°C warmer (slightly greater in west of Hunter).</td>
<td>12–20% increase in summer rainfall in Hunter. 12–20% decrease in winter rainfall in Hunter. Other regions no discernable change.</td>
</tr>
</tbody>
</table>

**Sea-level rise**

Predictions of sea-level rise vary widely. Ranges for the NSW coast fall between 23 and 91 cm by 2100 using the SRES A2 scenario (relative to 1990 levels) (IPCC 2007a, McInnes et al. 2007). For the purposes of these workshops, DECC adopted a projected increase in sea level of 50 cm by 2050. Taking into account coastal erosion and inundation, this could cause a recession of 30 to 50 m inland of the existing coastline.

**Extreme events**

The length of hot spells (number of days with a daily maximum >35°C) is likely to increase. For example, by 2030 the annual average number of days over 35°C in Sydney could grow from the current 3 days to 4–7, in Canberra from 5 to 6–12, and in Cobar from 41 to 45–65 (Hennessy et al. 2005). There is potential for significant increases in coastal inundation (storm surges) due to increased mean sea levels and more intense weather systems. An increase in the number of high-category cyclones is possible; however, a decrease in total number of cyclones is likely (IPCC 2007b). Hail risk may increase on the NSW coast. Interannual variability in rainfall is likely to increase, causing more extreme droughts during El Niño periods.

**Fire**

Fire regimes are likely to change. Although fire risk is highly variable between localities that are very close to each other, an increase in fire weather risk has been predicted by 2050 for all 10 NSW localities modelled by Hennessy et al. (2005). Using the Forest Fire Danger Index as an indicator of fire risk, Hennessy et al. (2005) predicted an increase in very high and extreme risk days by 12% to 15% in Coffs Harbour and by 13% to 18% in Williamtown by 2050. This equates to an increase from the current average of 4.4 days a year to up to a possible 7.6 days a year for Coffs Harbour, and an increase from the current 16.4 days a year in Williamtown to up to 23.6 days.

During the workshop it was assumed that fire frequency and intensity could increase. Research on the impacts of climate change on fire behaviour is ongoing.
<table>
<thead>
<tr>
<th>Ecosystem</th>
<th>Community</th>
<th>Main reasons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saline wetlands</td>
<td>Mangroves</td>
<td>Rising temperatures and sea level will affect the structure, composition and species abundances.</td>
</tr>
<tr>
<td></td>
<td>Salt marshes</td>
<td>Risk of community extinction due to sea level rise.</td>
</tr>
<tr>
<td></td>
<td>Seagrass meadows</td>
<td>Vulnerable to sea level rise and changes in rates of siltation and erosion.</td>
</tr>
<tr>
<td>Freshwater wetlands</td>
<td>Coastal wetlands</td>
<td>Vulnerable to sea level rise, and changes in salinity gradients.</td>
</tr>
<tr>
<td></td>
<td>Montane wetlands</td>
<td>Rising temperatures and increased fire frequency will affect species composition.</td>
</tr>
<tr>
<td>Forested wetlands</td>
<td>Coastal communities</td>
<td>Sea level rise and saline intrusion will change species composition and structure.</td>
</tr>
<tr>
<td></td>
<td>Tableland riverine forest</td>
<td>May be affected by drought, fire and storm damage.</td>
</tr>
<tr>
<td>Grassy woodlands</td>
<td></td>
<td>Impacts will vary among communities. Major impacts are likely to be from increased temperature and sea level rise.</td>
</tr>
<tr>
<td>Heathlands</td>
<td>Wallum sand heath</td>
<td>Vulnerable to inundation and saline intrusion.</td>
</tr>
<tr>
<td></td>
<td>Northern montane heath</td>
<td>Contraction of geographic range and changes in species composition are likely in changing climate.</td>
</tr>
<tr>
<td>Rainforests</td>
<td>Subtropical rainforest</td>
<td>Vulnerable to sea level rise and weed invasion.</td>
</tr>
<tr>
<td></td>
<td>Northern warm temperate</td>
<td>Major impacts are likely to be from temperature rise, evaporation and changes to the fire regime.</td>
</tr>
<tr>
<td></td>
<td>Northern cool temperate</td>
<td>Short term risks may be relatively moderate.</td>
</tr>
<tr>
<td></td>
<td>Littoral rainforest</td>
<td>Vulnerable to sea level rise, erosion, saline intrusion and changes in the fire regime.</td>
</tr>
<tr>
<td>Ecosystem</td>
<td>Risk from changes in fire regime.</td>
<td></td>
</tr>
<tr>
<td>----------------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Wet sclerophyll</td>
<td>Risk of community composition changes due to changing fire regimes.</td>
<td></td>
</tr>
<tr>
<td>Wet sclerophyll forest</td>
<td>May somewhat resilient to changing climatic conditions. Subtle shift in community composition may occur.</td>
<td></td>
</tr>
<tr>
<td>Dry sclerophyll forest</td>
<td>May somewhat resilient to changing climatic conditions.</td>
<td></td>
</tr>
<tr>
<td>Dry sclerophyll shrub</td>
<td>Vulnerable to fire regime changes.</td>
<td></td>
</tr>
<tr>
<td>Grasslands</td>
<td>Vulnerable to sea level rise, storm events and temperature rise.</td>
<td></td>
</tr>
</tbody>
</table>

### 4.3 Assessment of impacts on each ecosystem

**Saline wetlands**

*North Coast and Hunter regions*

*Mangrove wetlands, salt marshes, seagrass meadows*

The major impacts of climate change on this ecosystem are likely to be from direct inundation from sea-level rise; erosion from inland migration of the coastline, an increase in flood frequency and intensity and subsequent increased silt and nutrient loads; and an increase in storm intensity. Increased temperatures may also have an effect. The impact of climate change could be catastrophic on salt marshes and is likely to cause major changes to the geographic range of mangroves and seagrass communities.

The sea-level rise is predicted to be rapid: 50 cm in 42 years, or 1.2 mm per year. This rate is likely to outstrip recolonisation by mangroves and salt marshes in the newly forming intertidal and king-tide zones. Salt marshes are slow to colonise and are likely to be worst affected. Disturbance in these coastal zones will be exacerbated by an increase in siltation and nutrient levels, as rates of erosion increase in the upper catchments and increase sediment loads in major rivers. Flooding events are predicted to increase in both frequency and intensity in the lower catchments as a consequence of increased sea-level rise coupled with higher downpours, and this is likely to further raise siltation and nutrient levels in the intertidal and king-tide zones.

Mudflats that currently provide important habitat for a suite of shorebirds will be permanently inundated or eroded. Although new mudflats are likely to form, it is not possible to quantify the extent to which this will occur.

Existing and projected drainage, seawall, and other infrastructure works are likely to limit the creation of new habitat suitable for the colonisation of saline wetlands in some localities.
Habitat loss and movement and compositional changes in saline wetlands will severely affect a suite of shorebird species, including resident and migratory populations that are already in decline owing to habitat loss and degradation across their ranges. Two examples are Fullerton Cove and the Hunter Estuary wetlands.

Fullerton Cove is a shallow estuarine embayment in the Hunter Estuary fringed with mangroves, with extensive mudflats exposed at low tide. It is the most important foraging area for the majority of migratory and non-migratory shorebirds in the Hunter Estuary. Most of the mudflats elsewhere in the estuary have been destroyed by reclamation for industrial development; hence Fullerton Cove provides a critical resource for shorebirds.

Fullerton Cove mudflats would be prone to sea-level rise and mangrove encroachment. Because of the abundance of development and ‘hard edges’ such as roads and other infrastructure there is unlikely to be any new mudflat habitat created elsewhere in the estuary.

The Hunter Estuary wetlands are internationally significant as waterbird habitat. At least 45 migratory species presently listed under the Japan–Australia Migratory Bird Agreement (JAMBA) and/or the China–Australia Migratory Bird Agreement (CAMBA) are recorded. This site supports at least 1% of the total international populations of 13 species of shorebirds and is nationally significant as both a feeding and roosting site for a large seasonal population of Palearctic shorebirds and as a way-lay site for transient migratory birds. This site also supports a significant number of birds that overwinter and is ranked fifth in Australia in terms of the total numbers of shorebird species present. The size of refuges such as this is being reduced globally along migratory routes by human coastal modification, and climate change is likely to exacerbate this trend.

Mangrove wetlands

The structure and species composition of mangrove wetlands are defined narrowly by tidal range and salinity gradients and more broadly by latitudinal temperature ranges. The ability of mangroves to colonise newly available habitats, inland and south, may be limited by human infrastructure, drainage works, future sea-rise protection measures and increased flooding and storm surges.

In the North Coast region, some mangrove species have been observed south of their previous range, possibly because of increases in air and sea temperatures (e.g. *Rhizophora stylosa* has been observed at Moonee Beach, although it is not known whether such southerly populations have reproduced and established populations). There are some indications that mangrove-associated bird species are also occurring farther south; they include the mangrove warbler, shining flycatcher and mangrove kingfisher. These trends may continue with climate change and could affect both the Hunter and North Coast regions.

Temperature and sea-level rise will affect the structure, composition, and species abundances of mangrove wetlands across their current geographic extent. Most of their existing habitat will become unsuitable with the projected sea-level rise of 50 cm. New habitat will form within estuaries and floodplains. Mangroves have the ability to colonise new areas rapidly, and many of the fauna dependent on them are highly mobile; therefore, new communities may be able to form. The saltwater tidal limit within estuaries will migrate farther upstream, potentially opening up new habitats. However, colonisation may be hampered by the rapidly changing tidal zone, which will be influenced by not only by rapid sea-level rise but also other coastal processes, such as flooding and erosion. Development including new infrastructure in this coastal zone is likely to continue and may accelerate as the need for flood controls rise. An increase in storm intensity may also slow colonisation. Given the complexity

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and degree of uncertainty regarding these coastal processes, the overall degree of threat that climate change poses to mangrove wetlands is difficult to quantify.

**Salt marshes**

Salt marsh communities are very narrowly restricted to suitable substrate in the king-tide zone. Species diversity within the community is very low, and salt marsh species are considered very slow to colonise. The projected sea-level rise is likely to exclude salt marsh from most or all of its current geographic extent, and the speed of the predicted rise is likely to prevent recolonisation. The suite of coastal processes that could hamper mangrove colonisation will also affect salt marshes.

The impact of climate change on salt marshes could be extreme, with the potential for a major reduction or total loss of this community in these regions. The impact of climate change on salt marsh-dependent fauna could be catastrophic.

**Seagrass meadows**

Seagrass species distributions are graded by latitude and by narrow limits of water depth and turbidity (affecting light availability) and by salinity. Seagrasses are of limited diversity and are slow to colonise, as most successful reproduction is by vegetative means.

Sea-level rise will make deeper water unsuitable for the species that currently occupy these areas, as light levels will be insufficient. A distributional shift may occur, with the landward community boundaries expanding inland in response to inundation while seaward boundaries may contract, providing that the rate of colonisation can keep pace with the rate of sea-level rise. Species assemblages are likely to change in response to changing environmental conditions, including water depth, turbidity, nutrient levels and salinity. Shallow-water seagrasses such as *Posidonia australis*, *Zostera* sp. and *Ruppia* sp. may be worst affected, as most of their current habitat is likely to become unsuitable.

Changes to coastal processes that will affect other saline wetlands (increased rates of siltation and erosion, increased storm intensity and increased nutrient levels) are all likely to affect existing seagrass communities and their ability to colonise new habitats. Other factors that may limit recolonisation may include availability of suitable substrate, the spread of introduced species such as *Caulerpa taxifolia*, and CO₂ fertilisation, which may increase algal smothering.

Additional pressures on seagrasses may be changing marine conditions. Sea acidity is predicted to increase as concentrations of atmospheric CO₂ rise. Sea temperature is also predicted to increase, which may in turn increase the level of plankton and the turbidity in coastal waters. Planktonic algae and epiphytes could increase in abundance with these changes to environmental conditions, altering light availability and affecting colonization and species composition.

Major areas of seagrass meadows occur in ICOLLS. Permanent inundation of sea water into these lakes and lagoons is likely to influence species composition, favouring those species adapted to constant salinity levels and water temperatures over those that proliferate in shallow lagoons, where salinity and temperature fluctuate dramatically. Possible changes to species abundances may be a decline in the abundance of *Ruppia* species and an increase in the abundance of *Heterozostera* and *Posidonia* species.

This community could lose some component species and is likely to be lost from most of its current range. Seagrass Meadows may recolonise new areas if coastal and marine conditions permit. The overall impact of climate change on this community is likely to be major.
### Freshwater wetlands

<table>
<thead>
<tr>
<th>Region</th>
<th>Ecosystem Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>North Coast region</strong></td>
<td>Coastal heath swamps, coastal freshwater lagoons</td>
</tr>
<tr>
<td><strong>New England Tablelands region</strong></td>
<td>Montane bogs and fens, montane lakes</td>
</tr>
<tr>
<td><strong>Hunter region</strong></td>
<td>Coastal heath swamps, coastal freshwater lagoons</td>
</tr>
</tbody>
</table>

This ecosystem is dominated by shrubs, sedges, grasses or non-succulent herbs that tolerate permanent or periodic inundation or waterlogging with fresh water, often with highly variable water regimes.

This ecosystem is likely to be affected by increases in temperature, changes to the fire regime, and sea-level rise (inundation of surface water and watertables).

Current and potential human activities, such as alteration of surface drainage, consequent changes to siltation and nutrient loads, and increased water extraction are likely to exacerbate the direct impacts of an altered climate.

Both coastal and montane communities have limited opportunities to colonise alternative habitat and are likely to contract in range. Most montane communities could be lost from the Tablelands.

Coastal and montane wetlands provide important habitat for western ducks when droughts reduce the availability of inland wetlands. These refugia are likely to be reduced in area during El Niño periods. Climate models also predict a substantial decrease in rainfall in western NSW, which would further reduce available habitat for these species across south-eastern Australia.

The ability of species and communities to move (e.g. south to cooler latitudes) in response to temperature increase is severely limited by a lack of connectivity between isolated patches of this highly fragmented ecosystem. Species with limited mobility will be most affected and may contract in range.

A suite of specialist fauna will be affected by habitat loss and alteration; they include frogs such as *Crinia tinula*, small mammals, waterbirds, and ground parrots.

### All coastal wetlands

Coastal wetlands may be affected by sea-level rise, saline intrusion, temperature increase, increased intensity of flooding events and altered fire regimes.

Sea-level rise will affect water levels, salinity gradients and watertables, affecting many coastal wetlands over much of their current extent.

Sea-level rises are likely to cause the coast to retreat inland, particularly into Pleistocene sand masses, resulting in an interruption of existing dunal sequences and erosion of existing coastal wetlands.

Changes to hydrology on the coastal lowlands are likely to alter species composition. In permeable substrates such as sand plains, salt water intrusion into watertables is likely to raise groundwater levels. The salt watertable is likely to rise and push fresh water towards the surface, increasing freshwater water availability at or near the surface. In lower parts of the landscape, salt water may approach or reach the surface. These physical changes to the watertable will almost certainly alter ecosystems as species adapted to the new conditions become established and others die off.

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Communities exposed to an increase in salinity will change their species compositions toward the more-salt-tolerant species such as *Phragmites australis*. Communities exposed to higher watertables and greater freshwater availability are also likely to undergo compositional changes. A simplification of species composition is likely, particularly in the more isolated or fragmented patches.

The ability of many coastal communities to colonise new areas will be limited by a lack of suitable substrate or nutrient profile, and by existing and future infrastructure. Heath species that require low-nutrient soils may be particularly constrained. Colonisation may also be hampered by the current distribution of coastal wetlands, which are disjunct.

The contraction of coastal wetlands will affect specialised fauna such as Oxleyan pigmy perch (*Nannoperca oxleyana*), which may contract in range.

If fire encroaches into freshwater wetlands during more severe droughts, this could alter the abundance and composition of species that regenerate by seed or by resprouting and could cause a shift in boundaries with neighbouring communities, allowing encroachment of better-fire-adapted communities.

Warmer temperatures may create conditions suitable for new pest and weed species, including the cane toad, which may increase its rate of southerly migration. Warmer conditions might favour the spread of *Typha domingensis* and other reeds and rushes on lagoon edges.

**All montane wetlands**

Climate change is likely to have a major impact on montane wetlands. These communities have very restricted distributions and may be affected by an increase in temperature and altered fire regimes.

Many flora species in montane wetlands are likely to be intolerant of the projected increases in temperature, which will cause changes in species composition. Opportunities for these species to colonise new areas at higher altitudes to compensate for the temperature increase will be limited by a lack of suitable substrate, including soils with suitable nutrient content. Species that require low-nutrient soils with specific drainage or moisture gradients may be particularly constrained. They are likely to become more shrubby (as the northernmost ones currently are) or to become dominated by grasses such as *Themeda* (again as is seen in the northernmost bogs and fens).

If fire frequency increases, this may increase the occurrence of peat fires in fens. Fens will also be vulnerable to desiccation during hotter and drier El Niño years. Many fens may be reduced in area, and some may be lost altogether.

Remaining bogs and fens may be further degraded by colonisation by weed species that are now common in grasslands and that are likely to be favoured by the warmer conditions.

Some cold-adapted, narrow-range, endemic aquatic invertebrates found in montane wetlands, such as amphipods, isopods and micro-caddis flies of the Barrington Tops (Adlem and Timms 2000; Wells 2002), might undergo a range contraction because of rising temperatures. Heat-sensitive Bassian montane fauna such as the copperhead snake and some montane skink species may contract in range southward or to higher altitudes.

Montane wetlands could be affected by changes to frost frequency, although the effects of warmer average temperatures coupled with drier conditions on frost frequency are difficult to quantify. The effect of increased temperatures on diseases, particularly *Phytophthora*, is also unknown but warrants further consideration.
Forested wetlands

<table>
<thead>
<tr>
<th>North Coast region</th>
<th>Coastal swamp forest, coastal floodplain wetlands, coast and Tablelands riverine forest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tablelands region</td>
<td>Coast and Tablelands riverine forest</td>
</tr>
<tr>
<td>Hunter region</td>
<td>Coast and Tablelands riverine forest, coastal swamp forest, coastal floodplain forest</td>
</tr>
</tbody>
</table>

These communities are characterised by periodic inundation, soil water retention and (on the coast and estuaries within tidal limits) an ecotone along a salinity gradient. Forested wetlands are reliant on periodic inundation to maintain species and habitat diversity and regeneration.

All coastal communities

Climate change could have a major effect on coastal forested wetland communities, causing substantial changes to species composition over most of their range. Impacts are likely to include sea-level and temperature rises, altered fire regime and changes in storm behaviour. The ability of these communities to colonise higher elevations may be constrained by infrastructure and agricultural clearing, and an overall contraction range is likely.

Sea-level rise and saline intrusion will change species composition and structure.

As discussed for freshwater wetlands above, on permeable substrates such as sand plains sea-level rise is likely to cause saltwater intrusion into watertables, thereby raising groundwater levels. The salt watertable is likely to rise and push fresh water towards the surface, increasing freshwater water availability at or near the surface. In the lower parts of the landscape, salt water may approach or reach the surface.

The ways in which species assemblages will be affected are likely to be complex, but non-saline adapted species are likely to be selected against in places where changes to salinity are most extreme. Some changes may occur along micro-relief gradients, reflecting different salinity concentrations. For example, some low-lying communities may be replaced by saline wetlands and shrublands, with swamp oak – paperbark and swamp mahogany–dominated communities moving to slightly higher altitudes along a saline gradient. An expansion of mangrove- and swamp oak–dominated wetlands has already been observed in the North Coast and Hunter regions, possibly because of increased salinity levels.

As well as affecting native species, saline intrusion may disadvantage some current invasive weed species such as lantana (*Lantana camara*) and bitou bush (*Chrysanthemoides monilifera*), although some weeds, such as groundsel (*Baccharis halimifolia*) may be more salt tolerant.

Drainage works on the Hunter floodplain have reduced surface and groundwater retention, and some river red gum (*Eucalyptus camaldulensis*) forests (an Endangered Ecological Community) are already under water stress. Similar effects could result from hotter and drier El Niño years. Many swamp mahogany (*Eucalyptus robusta*) forests around estuaries in the Hunter have hard-surfaced infrastructure and other development on three sides, allowing little scope for retreat from salinity.

Reductions in the area and habitat quality of coastal swamp-forest communities could affect populations of nomadic and migratory nectarivorous birds and flying-foxes that depend on the nectar and pollen resource provided by these communities in autumn and winter. At this time, species from the Tablelands and both southern
and northern latitudes congregate along the Hunter and North Coast regions, and a reduction in the seasonal food resource provided by the prolifically flowering broad-leaved paperbark (*Melaleuca quinquenervia*) and the swamp mahogany could adversely affect populations of these species. Vertebrates likely to be affected include lorikeets (*Trichoglossus* spp.), honeyeaters such as the eastern spinebill (*Acanthorhynchus tenuirostris*), yellow-faced honeyeater (*Lichenostomus chrysops*) and scarlet honeyeater (*Myzomela sanguinolenta*), the noisy friarbird (*Philemon corniculatus*), and the threatened eastern blossom-bat (*Syconycteris australis*) and grey-headed flying-fox (*Pteropus poliocephalus*).

Other vertebrate fauna likely to be adversely affected by losses of, and changes to, swamp forests due to sea-level rise and increased salinity and temperature are the threatened common planigale (*Planigale maculata*), the koala (*Phascolarctos cinereus*), and the eastern long-eared bat (*Nyctophilus bifax*). The loss of mesic elements and the thinning of dense stands are likely to detrimentally affect the koala, which is sensitive to heat stress, and also the eastern blossom-bat and eastern long-eared bat, which require a shaded, cooler understory for roost sites.

In the North Coast region the threatened black grass-dart butterfly (*Ocybadistes knightorum*) is likely to be placed at risk because its host plant, the threatened Floyd’s grass (*Alexfloydia repens*), will be displaced from its restricted range in the king-tide zone of estuarine swamp forests.

**Tableland riverine forest**

Tableland Riverine Forest may be affected by drought, fire and storm damage. If fire frequency increases, this may produce a simplified structure with fewer hollow-bearing trees. Peat fires during severe droughts may reduce the community’s range. Structural change and higher temperatures may favour some weed species.

An increase in fire frequency may simplify forest structure to the detriment of hollow-dependent species, reflecting a loss of older stems and a change in stand dynamics reflecting faster turnover of stems. These impacts could be exacerbated if storm intensity were to also increase. Such dynamics may be to the advantage of some weed species by increasing recruitment opportunities.

Some restricted-range, endemic, aquatic invertebrates of upland streams might undergo range contractions because of rising temperatures or reduced flows. These include amphipods of *Austrocrangonyx* sp. (Brown and Timms 2002), the snail *Glacidorbis isolatus* (Ponder and Avern 2000) and various crayfish in the genus *Euastacus* (e.g. Coughran 2005). The ranges of coldwater fishes, including the introduced trout, are also likely to shrink.

Tablelands riverine forests are often the only native vegetation in an agricultural landscape and provide important refuges and movement corridors for many bird and mammal species, including the common wombat *Vombatus ursinus* and the threatened spotted-tailed quoll *Dasyurus maculatus*. Consequently, losses or constriction of these forests could result in declines of local populations, particularly of mammals.
Grassy woodlands

<table>
<thead>
<tr>
<th>North Coast region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coastal valley grassy woodland, Tableland clay grassy woodland, New England grassy woodland, subalpine grassy woodland.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>New England Tablelands region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coastal valley grassy woodland, Tableland clay grassy woodland, New England grassy woodland, subalpine grassy woodland.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hunter region</th>
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</thead>
<tbody>
<tr>
<td>Western Slopes grassy woodland, coastal valley grassy woodlands.</td>
</tr>
</tbody>
</table>

The impact of climate change on grassy woodlands will vary markedly among communities but is likely to have a major impact overall, as these already highly fragmented and degraded communities will come under increasing pressures. Major impacts are likely to be increased temperatures and, for coastal and lowland communities, sea-level rise. Although hotter and drier El Niño periods may have some impact, this community is better adapted to dry conditions than are many other communities. Other potential impacts include changes to the fire regime and potentially increased atmospheric CO₂.

Subalpine and New England grassy woodland communities, in particular, are likely to be intolerant of higher temperatures and contract to the higher altitude parts of their current distribution, whereas Tableland clay grassy woodland has a wider climatic envelope and could potentially undergo some slight expansion in range. Coastal valley grassy woodlands on lowlands are likely to suffer from sea-level rise and inundation, coastal erosion and saline incursion into watertables.

Fires may become more frequent and intense under drier conditions with increased hot spells. Intense crown-scorching fires may promote tree hollow development but are also very likely to increase tree mortality rates and cause an overall decline in hollow-bearing trees. A gradual change in species composition is likely, particularly in the understorey, as fire-tolerant species are advantaged. Grasses are likely to decrease in diversity; this in turn would affect seed-eating birds. Fire-induced disturbance may provide opportunities for weed colonisation.

Changes in the timing and frequency of flowering events (phenological patterns) could have major impacts on nectivorous birds and mammals. A number of species have local abundance fluctuations in response to varying but important flowering patterns. Seed-dependent species such as finches can have population fluctuations associated with mass flowering of grasses. Changes in phenology patterns could be catastrophic for such species, reducing population size and causing a contraction in range.

Regent honeyeaters are particularly vulnerable to changes in flowering patterns, as their breeding opportunities are closely tied to flowering events. This species has recently bred for the first time in a number of years in the lower Hunter at a time when flowering was poor on the Western Slopes, the species’ usual breeding grounds. This extended period without breeding may have been influenced by the drought and consequent lack of major flowering events. Other migratory or nomadic nectar feeders could be similarly vulnerable.

The Hunter, with its coastal rainfall influence, can provide a refuge for western species when drought reduces resource abundance farther west. This makes grassy woodlands a highly significant habitat for the region.
Many grassy woodland communities are already included within a number of threatened ecological communities and survive only in highly fragmented and degraded remnants, leaving them vulnerable to edge effects and making it far more difficult for species to respond to climate change by shifting their distribution. Affected communities include Western Slopes grassy woodland, Tableland clay grassy woodland, New England grassy woodland, subalpine grassy woodland, and coastal valley grassy woodlands (Hunter Valley occurrence).

There are other impacts that could be an issue for this ecosystem but they are poorly understood at this time. The likelihood of adverse impact from increased atmospheric CO2 is not known. If shrubs were advantaged over grasses in the understorey, this could lead to a major structural change for this ecosystem. The replacement of grasses by shrubs may also lead to an increase in fire intensity. Alternatively, an increase in fire frequency may select against many shrub species and maintain a grass-dominated understorey.

It was speculated that changes in the ratio of grassy to woody species in the understorey structure may induce hydrological changes, for example, by changing evapotranspiration levels or as a consequence of woody species being potentially deeper rooted and therefore drawing water from deeper in the soil profile. Such changes could affect water infiltration into the subsoil and ultimately streams, or change surface water flow and soil permeability, affecting stream flows. Foliage and nectar-feeding invertebrates are important in this ecosystem and could be affected by changes to foliage chemistry and by a reduced nectar resource if flowering were less frequent. This would have a flow-on effect for insectivorous birds and bats.

Heathlands

<table>
<thead>
<tr>
<th>North Coast region</th>
<th>Northern montane heath, wallum sand heath, coastal headland heath</th>
</tr>
</thead>
<tbody>
<tr>
<td>New England Tablelands region</td>
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</tbody>
</table>

The major impacts of climate change on heathlands include more intense droughts during El Niño periods, changes to the fire regime and, for coastal heaths, sea-level rise, increased storm intensity and coastal development in response to rising sea levels. Climate change could have a major effect on both coastal and montane heaths, and many communities are likely to undergo simplification of species composition and structure. An overall contraction of heathlands is likely.

Long and hot dry spells are likely to cause water and heat stress for many plants and animals and could alter fire frequency and intensity. The dependence of coastal wet heaths on inundation makes them particularly vulnerable to drying. Similarly, montane heaths on shallow skeletal soils such as those on rocky outcrops are at risk. These heaths are likely to undergo changes in species abundances and potentially species loss due to drier conditions.

If fire frequency and intensity increases, fires may influence community structure and cause a gradual reduction in species diversity over time, as plants that regenerate by resprouting are advantaged over obligate seeders. Whereas all heaths may be affected, the drier Tablelands and headland heaths are likely to be most vulnerable. A potential advantage of increased fire frequency is that invasive weeds may be selected against.
Some heathland shrub species, such as *Homoranthus* sp. in northern montane heath, are highly restricted in range and could be under serious threat from the combined impacts of drier conditions and changes to the fire regime.

**Wallum sand heath and coastal headland heath**

Inundation, watertable rise and saline intrusion are likely to exclude wallum sand heath from low-lying areas. Storm events of increased intensity are likely to increase the degree of storm damage to all coastal heaths and provide greater opportunities for weed infestation.

Many coastal headland heath communities are isolated by geography and infrastructure. There is a high degree of variability in species composition among patches and a high level of endemism among flora species (e.g. *Pultenaea maritima*). This leaves coastal headland heath vulnerable to species extinction if individual patches are lost. For larger patches, the degree of change for this community may not be as great as for wallum sand heaths, but the impacts are likely to be widespread.

As a consequence of loss of habitat, specialised fauna in coastal wet heaths may contract from its current range: examples include wallum frogs [e.g. wallum rocket frog *Litoria freycineti*, Olongburra frog *Litoria olongburensis* and wallum froglet *Crinia tinnula* (vulnerable)].

Changes to the fire regime, as well as winter warming, may affect flowering events. Coastal heaths are important habitat for a suite of migratory bats and birds that show seasonal migration patterns linked to flowering events. Coastal heaths are winter flowering and provide an important resource at times when feeding resources are scarce in other habitats. Drier conditions will probably affect the duration and volume of nectar production, potentially affecting species such as blossom bats, flying foxes and migratory honeyeaters.

As well as the direct loss and displacement of low-lying heath, fauna may also suffer from a reduction of food resources in remaining heath owing to changed flowering, fruiting and seeding. Specifically, a shift in dominance towards resprouters at the expense of seeders would reduce the abundance of a food resource significant to species such as the emu. These impacts may be exacerbated by the existing fragmented character of these habitats and the potential inability of fauna to recolonise isolated patches. Specialised fauna such as wallum frogs, heathland small mammals and the ground parrot may have their ranges altered.

Increased summer rainfall and temperature rises may increase weed invasions into isolated communities and exacerbate existing weed problems, particularly in those wetter communities that are likely to have a lower frequency of fire than drier communities. This effect may be compounded where these communities are subject to nutrient runoff from adjacent development, as in the case of Byron Bay dwarf graminoid clay heath (an Endangered Ecological Community under the TSC Act).

Wallum sand heath is likely to be affected across most of its range, and many changes to the structure and composition of the community are likely. Some refugia may persist where the watertable remains sufficiently high.

**Northern montane heath**

This generally occurs on low-fertility sites on granite or acid volcanic substrates, and on higher nutrient sites on basalt or sedimentary substrate with deeper soils.
A contraction of geographic range and changes to species composition are likely for this community. Climate change is likely to have a relatively major effect on montane heathlands.

Montane heaths are often isolated and edaphically limited; they have high levels of endemism and limited seed dispersal mechanisms and are currently under pressure from goats and rabbits. Major flowering events occur in spring.

Montane heaths on low-fertility soils are particularly vulnerable to increases in drought severity and changes to the fire regime. Isolated communities on rock outcrops, such as Howell shrublands, could disappear completely.

Similar communities overseas have been shown to support species that require frost periods to help break seed dormancies. Reductions in numbers of frosts (if this occurs) could affect some species in this community.

Spring-flowering geophytes such as ground orchids and other herbs and forbs could be adversely affected by drier winters, particularly if spring rains were to occur later. Weed invasions are more likely on higher nutrient sites.

Fauna dependent on montane heath tends to consist of restricted specialists. As these communities are often relatively isolated it is possible that there are high levels of within-species genetic diversity relative to geographic distance, particularly in poor mobility fauna (such as the eastern chestnut mouse and some frogs), and in isolated habitat patches. Loss of habitat patches may therefore lead to a loss of genetic diversity.

Drier conditions may adversely affect the Booroolong frog, for example, in the upper catchment of the Isis River in the Hunter region.

**Rainforests**

<table>
<thead>
<tr>
<th>North Coast region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subtropical rainforest, northern warm temperate rainforest, northern cool temperate rainforest, dry rainforest, littoral rainforests</td>
</tr>
<tr>
<td>Oceanic rainforest and cloud forest (Lord Howe Island only)</td>
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</tbody>
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<tr>
<th>New England Tablelands region</th>
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</thead>
<tbody>
<tr>
<td>Subtropical rainforest, northern warm temperate rainforest, northern cool temperate rainforest, dry rainforest</td>
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<tr>
<th>Hunter region</th>
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<tbody>
<tr>
<td>Subtropical rainforest, northern warm temperate rainforest, northern cool temperate rainforest, dry rainforest, littoral rainforest, subtropical rainforest</td>
</tr>
</tbody>
</table>

The impact of climate change on rainforest is likely to vary widely among vegetation classes depending on factors such as the current extent and condition of the community and the likely climatic tolerance of the community. Low-lying subtropical rainforest is likely to be worst affected, as a rise in sea level is likely to inundate most of its remaining habitat. For other rainforest communities, an increase in temperature, increased intensity of droughts during El Niño periods and changes to the fire regime are likely to pose the major risks.

**Subtropical rainforest**

Subtropical rainforest on lowlands has suffered a massive range reduction from clearing and exists only in small isolated pockets on the true lowlands, on the foothills of the main ranges, and on riverine alluvial floodplains and islands.
The impact of climate change is likely to be extreme. Many components of the community will be affected across its entire range.

Sea-level rise, flooding and erosion are likely to have a major impact on low-lying examples of subtropical rainforest, removing almost all of the sea-level occurrences and further reducing the total area of this community. Examples of low-lying subtropical rainforest remnants include those on Susan Island in the Clarence River, Bellingen Island on the Bellinger River and Stotts Island on the Tweed River. In areas that are not inundated, warmer temperatures and CO₂ fertilisation are likely to make already catastrophic weed infestation even worse, leading to further structural change, functional disruption, and reduced species diversity.

Weeds are currently a substantial problem for this community. Climate change will improve conditions for a number of current weeds, and colonisation by new weeds is likely. Weeds have the capacity to replace native species as major food sources for seed dispersers such as fruit-eating birds. Active management may be required to prevent weeds from causing substantial compositional and structural change.

Populations of specialised fauna such as Mitchell’s rainforest snail may be further reduced.

Upland subtropical rainforest exists over broad latitudinal, altitudinal and precipitation ranges. This suggests it may be more resilient than other classes. Changes in temperature and precipitation are likely to have the greatest impact, and there are likely to be many changes to this community over much of its range.

There is a huge variation in species composition and abundance within this community, although some species are present across this community’s range and others are shared with the lowland foothill forests. Climate change is more likely to affect species abundances than species composition, with the overall effect being shifts in the mosaic of species at a local scale.

There may be an altitudinal shift upward into neighbouring warm temperate rainforest habitat, depending on the strength of the influence of edaphic factors and gradients.

Fauna impacts are likely to be similar to those listed for warm temperate rainforest (below), although upland subtropical rainforests and dry rainforests provide a more diverse range of resources and are more important habitat for frugivores than other rainforest types, notably in terms of key species such as those of the genus *Ficus* (figs) and the diversity of soft/fleshy fruiting families and genera present (e.g. Myrtaceae, Rubiaceae, Sapotaceae, Sapindaceae, Rutaceae).

**Northern warm temperate rainforests**

Climate change may affect many of this community’s characteristics over much of its range.

Northern warm temperate rainforest is adapted for relatively constant conditions. Some species have relatively low dispersal distances, and there is a high level of endemism in the Tweed Volcano caldera. The community mostly lacks a distinct suite of successional species, and mature trees are often replaced by the same species following disturbances. Some sub-communities are edaphically determined (e.g. the simple notophyll- and coachwood-dominated vine forest); this restricts their ability to migrate altitudinally in response to warmer temperatures.

This community exists across a range of climates. Temperature rise, evaporation and changes to the fire regime may cause contraction of this community at the lower altitudinal boundary. For those rainforest patches abutting more pyrophytic forest, there is a risk of range contraction if fire incursion increases. The dominant species that maintain the structure of this rainforest community probably have a wide climatic
envelope and are likely to persist in refugia. Where warm temperate rainforest supports endemic species with very limited ranges there is some risk of extinction due to stochastic events.

Some specialised fauna from warm temperate subtropical transition rainforest and notophyll vine forest may experience range shifts or contractions from seasonal drying, changes to the fire regime and an overall contraction in area of habitat. Such species include Albert's lyrebird, which may be affected by an increase in seasonal drying of leaf litter, and the long-nosed potoroo. Periods of extreme hot temperatures coupled with drier conditions and changes to the fire regime are likely to affect a range of rainforest fauna during El Niño periods. Affected species may include Tumbunana fauna (relict mesic montane and submontane species of the Great Dividing Range) such as Stephen's banded snake, the leaf-tailed gecko and the angle-headed dragon.

Fruiting events can occur as masting events and are often tightly keyed to climatic cues. If these change because of climate change some frugivores such as the top-knot pigeon and wompoo fruit dove may be affected.

Hotter El Niño periods and fire intrusion may affect fauna microhabitats such as stream edges and sedge and heath patches within rainforests that are important for rufous scrub-bird, *Mixophyes* sp., *Philoria* sp. and other frogs and fossorial skinks.

There are, as in the subtropical rainforests, high levels of species diversity among invertebrates in this community. Microclimate changes could change invertebrate composition.

**Northern cool temperate rainforest**

Northern cool temperate rainforest occurs above 900 m above sea level, often on or near mountain tops where there is no opportunity for upward migration. It occurs in areas of high (>1750 mm) rainfall on moderate to high nutrient soils, and has characteristically simple structural and floristic composition. Patches are usually less than 100 ha.

The short-term risks to northern cool temperate rainforests (that is, changes likely to occur by 2050) may be relatively moderate. Although a range contraction of this community is likely at its lower limits, changes to higher altitude patches may not be great if local weather patterns at high altitudes maintain climatic refugia for this community.

However, there is a risk that climate change may affect the frequency of cloud cover or the altitude of the cloud base and mist blanketing. If this occurs, there may be some potential for altitudinal contraction of cool temperate rainforest, as ‘cloud stripping’ is a substantial and important contributor to maintenance of the water budget in this ecosystem. Changes to the cloud base would also have implications for the oceanic cloud forest on Lord Howe Island.

An overall drying may influence the relative abundance of floristic elements such as *Nothofagus* and *Doryphora* and possibly *Sloanea* as potential canopy dominants in different circumstances, in which case *Nothofagus* would be most at risk of contraction. The Mt Hyland community is an example of a cool temperate forest that contains a higher proportion of species typically found in somewhat drier rainforest. This could be indicative of how other cool temperate rainforest communities could change or develop under an altered climate regime.

There is likely to be some contraction of range for this community at the lower boundary of its occurrence, where warmer temperatures may be outside the tolerance limits of some cool temperate rainforest species. Warm temperate
rainforest may replace cool temperate rainforest at these lower altitudes. Fire intrusion may cause the contraction of rainforest boundaries where drier and more fire-prone communities abut the rainforest. However, in many cases, northern cool temperate rainforest is surrounded by other rainforest communities, and these will buffer cool temperate rainforest from fire intrusion.

More intense droughts could cause changes to species composition. For example, the litter layer may undergo more extreme drying during winter, leading to lower soil moisture levels and poorer conditions for seed germination. This could favour species that regenerate from resprouting over obligate seeders.

Most vertebrates that utilise northern cool temperate rainforest also utilise other rainforest types. Therefore, a major contraction in habitat area is unlikely for these species. However, at least one species, Tyron’s skink *Eulamprus tryoni*, occurs only in northern cool temperate rainforest. This species is known from only a few sites in the Border Ranges. Its habitat requirements and climatic tolerances are poorly understood, but its restricted distribution suggests that it could be highly specialised and at risk of extinction from climate change.

**Littoral rainforest**

Littoral rainforest is adjacent to the coast, often on unstable wind-blown substrates, and is generally bounded by drier pyrophytic vegetation communities.

This community is vulnerable to sea-level rise and associated erosion and saline intrusion, increased storm intensity, heat stress, drier seasonal conditions, drought and changes to the fire regime. Large shifts in assemblage composition and abundances are likely, and this community is likely to be lost from most of its (already highly limited) geographic extent. Some remnants may persist in limited refugia such as bedrock headlands.

Most littoral rainforest species are represented elsewhere in subtropical and dry types, except for a small suite of littoral specialists (such as *Sophora tomentosa*). Therefore, a reduction in the extent of this community is likely to cause few, if any, species extinctions.

Littoral rainforest provides important resources for fauna that also utilise neighbouring coastal banksia scrub. A reduction in the extent of littoral rainforest will affect blossom-eating and microchiropteran bats, frugivorous birds, pittas, and altitudinal and latitudinal migrant birds and bats that currently use this habitat on a seasonal basis.

**Dry rainforest**

Dry rainforests (drier vine forests) are often edaphically limited. Changes to the fire regime could cause many changes to this community. Although some dry rainforest occurs in sites protected by rock outcrops or scree, those more exposed communities may be more vulnerable to fire than other rainforest types, particularly where these abut more pyrophytic forests. If fire incursion into dry rainforest increases, this is likely to cause a gradual contraction from the existing boundaries, as the less fire-tolerant dry rainforest species are killed by fire and replaced by more fire-tolerant eucalypt species.

Fire incursion into dry rainforest could affect litter depth and structure, with impacts on invertebrates and on plant species recruitment and regeneration. Weeds—particularly lantana—can gain a stronghold following fire events. Any opening of the understorey may increase predatory pressure on species such as the black-striped wallaby and the brush-tailed rock wallaby.
Soils are highly erodible in dry rainforest, and an increased summer rainfall, particularly following fires, is likely to increase soil erosion. Increased summer rainfall may also advantage weeds such as lantana, and when combined with warmer conditions it could provide suitable conditions for cane toads to become established in some areas. One potential advantage of an increase in summer rainfall is that it may create conditions more suitable for seed-based regeneration of rainforest species.

Vine thickets in rainshadow areas in the Upper Hunter are already at their distributional limit and may be vulnerable to even small climatic fluctuations. These communities are likely to contract in range.

**Wet sclerophyll (shubby)**

| North Coast, New England Tablelands and Hunter regions |
| North Coast wet sclerophyll forest, northern escarpment wet sclerophyll forest |

Wet sclerophyll forests may be affected by increased CO₂, temperature rise and changes to the fire regime. In the Hunter, where summer rainfall is predicted to increase, this could cause biomass accumulation and increased fire intensity.

Like the upland subtropical and warm temperate rainforest assemblages, the shrubby wet sclerophyll forest subformation occupies a broad habitat niche with regard to variables such as altitude, substrate, rainfall and temperature, and it may therefore be considered more flexible and resilient in its response to changes in some of these variables due to climate change. With changes to the fire regime, wet sclerophyll could expand into rainforest edges, whereas drier grassier elements may invade at the drier edges. This may cause a shift in range while maintaining the same total area of coverage. The response of this subformation to climate change may be a subtle shift in community composition and structure across its geographic range.

Wet sclerophyll shrubby forests are representative of a tension zone between more mesic (i.e. in this case rainforest) elements and the more sclerophyllous fire-based regenerators. Changes in the abundances of mesic and sclerophyllous components depend on the scale and frequency of ‘fire events’ over mostly long time scales. A moderate increase in fire frequency and intensity could cause a gradual transition of species assemblages to less mesic and more sclerophyllous species on the more exposed sites. However, the extent of changes that occur within a 40-year time frame are likely to be minor and may not be apparent until more time has passed. Conversely, if fire frequency and intensity are dramatically increased, there is an increased risk of catastrophic crown fires, and this could cause more rapid and widespread structural and compositional changes.

In the North Coast region, fires are unlikely to be substantial enough to alter the overstorey. If fires become more frequent, the understorey may gradually become more sclerophyllous, and some species may change their altitudinal limits in response to the increase in temperature. In the Hunter, the changes could be more magnified. Summer rainfall is predicted to increase the most in this region, and an increase in productivity and growth rates may influence the intensity of fires, causing a more rapid ‘drying’ of the understorey and, in the case of severe fires, altering the age class of trees.

The effect of climate change on the fire regime may be complicated by changes to anthropogenic fire management. As fire risk is likely to increase, the frequency and extent of control burning may also increase in many areas. This may increase the proportion of sclerophyllous species. It is also likely to increase the rate of turnover of
larger trees, including those with hollows. A reduction in the number of hollows could affect arboreal mammals, tree-roosting microchiropteran bats and forest owls.

Opening and drying of understorey vegetation during more severe droughts may cause localised losses of species such as tiger quoll, parma wallaby, pademelons and potoroos through reductions in shelter, food availability and modification of habitat patch characteristics and distribution. Understorey microclimate changes may affect invertebrate populations. CO₂ fertilisation and drying may affect changes to leaf chemistry, folivorous insects, koalas and greater gliders.

**Wet sclerophyll forest (grassy)**

| North Coast, Tablelands and Hunter regions |
| Northern hinterland wet sclerophyll forest, Northern Tableland wet sclerophyll forest, northern escarpment wet sclerophyll forest, North Coast wet sclerophyll forest |

Like the shrubby wet sclerophyll forest subformation, the grassy wet sclerophyll subformation occupies a broad habitat niche with regard to variables such as altitude, substrate, rainfall and temperature, and it has extensive coverage. This ecosystem may therefore be more flexible and resilient in its response to climate change. Overall, the impact of climate change may be a subtle shift in community composition and structure across this ecosystem’s geographic range.

Higher temperatures, hotter and drier El Niño periods and changes to the fire regime could increase the area of grassy understorey communities at the expense of adjacent shrubby communities. Changes to the fire regime may cause subtle changes to species composition. For example, if fire frequency were to increase, the less fire-tolerant *Poa* spp. and *Themeda* spp. may decline and species such as *Imperata cylindrica* may increase in abundance. Plants that regenerate by resprouting may increase in abundance, whereas obligate seeders may decrease.

If fire frequency is maintained or increased, this is likely to maintain the grassy understorey structure on less fertile sites, particularly if these areas are also grazed. However, on the more fertile soils, high-quality grassy understoreys may be at risk of becoming weed affected (e.g. *Lantana, Ageratina*).

Predicting the impacts of climate change on this ecosystem is complicated by the continuing debate about whether and to what extent these are ‘natural’ or ‘derived’ landscapes influenced by logging, grazing and anthropogenic fire.

Grassy wet sclerophyll forests provide habitat for the Hastings River mouse and rufous bettong, and the populations of these species at Mt Royal and Barrington are regionally important in the Hunter. An increase in the frequency of major fire events may put populations of these and other species at risk at a local scale. Tree hollows may also be reduced in number, affecting resource availability for hollow-dependent fauna. Shifts in the timing of seasons may cause disruption to flowering events, which in turn may affect nectarivorous fauna such as the grey-headed flying-fox and yellow-bellied glider.
Dry sclerophyll forest (shrubby)

<table>
<thead>
<tr>
<th>North Coast region</th>
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<tbody>
<tr>
<td>North Coast dry sclerophyll forest (DSF), northern escarpment DSF, coastal dune DSF</td>
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<table>
<thead>
<tr>
<th>New England Tablelands region</th>
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<tbody>
<tr>
<td>Northern Tablelands DSF, northern escarpment DSF</td>
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<table>
<thead>
<tr>
<th>Hunter region</th>
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</thead>
<tbody>
<tr>
<td>Northern Tablelands DSF, northern escarpment DSF, Sydney sandflats DSF</td>
</tr>
<tr>
<td>Sydney montane DSF, Sydney hinterland DSF, Sydney coastal DSF, Western Slopes DSF, coastal dune DSF</td>
</tr>
</tbody>
</table>

The boundaries of this ecosystem are determined by fire history and soil types; the ecosystem occurs on low-fertility soils derived largely from granites, coastal sands and coarse sediments. This habitat is likely to be affected by higher temperatures, drought stress and changes to the fire regime. Coastal and low-lying communities may be threatened by sea-level rise, coastal erosion and storm events.

Although the response is difficult to predict, a number of factors may make this ecosystem relatively resilient to climate change: it is pre-adapted to extreme drought stress, more frequent fire and some edaphic extremes (shallow to skeletal soils on rocky sites; poorer soils). As many dry sclerophyll communities are relatively widespread, there is a greater availability of refuge areas. If fire frequency increases, dry sclerophyll communities may expand into adjacent areas occupied by communities that are more sensitive to fire, such as wet sclerophyll forest. Overall, the response of this ecosystem may be a subtle shift in community composition and structure across its geographic range.

Dry sclerophyll forests are adapted to frequent fire, but increased frequency may simplify the structure by removing woody and fire-sensitive understorey species. Increased occurrence of fire in neighbouring communities might also allow some extensions in the range of dry sclerophyll communities into those areas, although edaphic factors may limit that spread.

Drought stress may affect communities that occur on particularly coarse, shallow soils, such as the community on Jurassic sandstones of the southern Richmond Range (e.g. at Gibberagee) in the Northern Rivers area. Some loss of species diversity is possible, with the less drought-tolerant species being lost, particularly in communities that occur on skeletal soils.

Warmer winter nights in high, cold areas such as Timbarra, Spirabo, and Gibraltar Range may allow the more frost-sensitive species to become established.

Drought stress and changes to the fire regime in Northern Tablelands forests on granite may allow spread into adjacent sedgelands (fens) and taller forested areas. An increase in fire intensity may affect the availability of tree hollows, affecting hollow-dependent species. Intense fires may also kill mature casuarinas, which are a food source for glossy black cockatoos.

Shifts in the timing of seasons may alter flowering sequences. This, in turn, may affect nectarivorous fauna—particularly those sedentary species that require regular nectar sources throughout the year, such as the pygmy possum and squirrel glider. Migratory nectarivores that may be affected include honeyeaters, blossom bats and flying foxes. A reduction in nectar availability may affect invertebrates; this in turn may affect microchiropteran bats that congregate in large numbers in highland areas over winter.
Additional threats for coastal dune DSF include sea-level rise, coastal erosion and storm events. Drought stress and increased evaporation could be a major problem for coastal dune DSF communities on well-drained substrates. An example is the Tomago sand beds, which could be under additional pressure if there is an increased demand for water from neighbouring population centres and a subsequent increase in water extraction from the aquifer in this area.

Those communities that have more confined distributions and are currently under threat may be further disadvantaged under climate change. For example, Kurri sand swamp woodland (a Sydney sand flat dry sclerophyll forest that is an Endangered Ecological Community) is currently under intense development pressure and would be further affected under climate change by drought stress, evaporation and alterations to the fire regime.

**Dry sclerophyll (shrub/grass)**

<table>
<thead>
<tr>
<th>North Coast region</th>
<th>Hunter Macleay DSF, Clarence DSF, northern gorge DSF, North West Slopes DSF.</th>
</tr>
</thead>
<tbody>
<tr>
<td>New England Tablelands region</td>
<td>New England DSF, northern gorge DSF, Hunter Macleay DSF, Clarence DSF</td>
</tr>
<tr>
<td>Hunter region</td>
<td>Hunter Macleay DSF, North West Slopes DSF, New England DSF, northern gorge DSF</td>
</tr>
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</table>

This ecosystem’s geographical distribution is influenced by edaphic conditions and fire regime. The understorey species mix and structure may often be a result of management of grazing intensity, the deliberate promotion or exclusion of fire, and the invasion of exotic pasture species.

This ecosystem is likely to be affected by fire regime changes, and warmer, wetter summers may affect the mix of native and exotic grasses. CO₂ fertilisation may promote the growth of woody understorey species.

Although the response is difficult to predict, a number of factors may make this ecosystem relatively resilient to climate change, i.e. it is pre-adapted to extreme drought stress, more frequent fire, and some edaphic extremes (shallow to skeletal soils on rocky sites; poorer soils). As many dry sclerophyll communities are relatively widespread, there is a greater availability of refuge areas. If fire frequency increases, dry sclerophyll communities may expand into adjacent areas occupied by communities that are more sensitive to fire, such as wet sclerophyll forest. Human management practices (which are also likely to change as the climate changes) such as hazard reduction burns may be a stronger determinant of change for this ecosystem than the direct impacts of climate change. Overall, the response of this ecosystem may be a subtle shift in community composition and structure across its geographic range.

Warmer, wetter conditions in summer may promote existing exotic perennial grasses such as Coolatai grass and some summer-growing annual weeds. Blady grass may expand in distribution and displace tussock species, with a consequent impact on the rufous bettong.

At Camira and Royal Camp, and in parts of the Lower Clarence and Richmond highlands, red ash (*Alphitonia excelsa*) has been observed to outcompete other understorey species and become a dominant shrub. This may be a function of fire and grazing exclusion. Where red ash displaces grass there may be a detrimental effect on species such as the bush stone curlew. This issue could be exacerbated in these locations under climate change.
Fire regime changes may allow some DSF communities on gorge slopes to expand and displace neighbouring dry rainforest.

If dry sclerophyll communities on serpentine are adversely affected by climate change, the extreme edaphic specialisation of this community will limit any range movement.

Changes to understorey structure and food sources may affect the North Coast emu population and species such as bettongs, masked and barking owls, the grey-crowned babbler and the hoary wattled bat.

**Grasslands**

<table>
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<tr>
<th>North Coast and Hunter</th>
<th>Maritime grasslands</th>
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<tbody>
<tr>
<td>New England Tablelands</td>
<td>Temperate montane grasslands</td>
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</table>

This ecosystem is a loose association based on dominant structure alone. Both montane and maritime grasslands may be under major threat from climate change, albeit from very different climatic factors.

Maritime grasslands are at risk from rising sea levels, storm events, temperature rise and the CO₂ fertilisation effect, which might benefit weeds and invasive tropical species.

Climate change impacts could be extreme for strand-line spinifex communities, as sea-level rise and coastal dune erosion are likely to remove most or all of this community from its current range. The ability of the strand line spinifex community to recolonise the retreating coastline will depend on the rate of change, the impact of storm events, and geomorphologic dune-building processes.

Sea-level rise, storms and weed expansion may threaten important sea bird rookeries on grassy offshore islands such as Muttonbird Island and the Solitary Islands, as well as Gould’s Petrel on Cabbage Tree Island.

Temperate montane grasslands may be the most heavily affected by temperature rise, as the more tropical grass species may outcompete temperate species under warmer temperatures, and this could be exacerbated if higher levels of CO₂ give C3 species a physiological advantage over C4 species. Woody species may be at an advantage and may colonise existing grasslands: CO₂ fertilisation may promote the growth of woody species, and frost-sensitive woody species may expand into grassy frost hollows.

Climate change could bring about a dramatic reduction in the range of montane grasslands, with the possibility of a total loss of this community from the Tablelands region. This community has persisted because cooler temperatures at higher altitudes, therefore higher temperatures are likely to be beyond the tolerance limits of many flora and fauna species.

**Comments applicable to more than one ecosystem**

*Potential impacts across the Hunter region*

The lower winter rainfall may affect vegetation communities to a greater extent than the higher summer rainfall.
The east–west transition of biodiversity in the Hunter differs from that in the North Coast and Tableland regions. The lower topography of the Great Dividing Range west of the Hunter allows more vegetation communities typical of the Western Slopes to spill over and adjoin with more typically coastal communities. Many species have the easternmost part of their distributions in the Hunter. Western species in the Hunter include river red gum, myall, tiger orchid, and an endangered population of the emu. The Hunter serves as an important refuge for many of these western flora and fauna species.

Climate change is likely to add an additional pressure to those vegetation communities on the valley floor that have already been extensively cleared and fragmented, and that are often highly degraded or in fragments so small that their habitat value is dramatically reduced and their viability is under threat. If fire frequency increases, this may simplify the structure and species composition of these communities and promote weeds. Communities that may be most at risk are the more fragmented or confined dry forests and woodlands, many of which have affinities with Western Slopes communities. A number of these—river-flat eucalypt forest on coastal floodplains, Hunter lowland red gum forest, Lower Hunter spotted gum – ironbark forest and Quorrobolong scribbly gum woodland—have been listed as Endangered Ecological Communities.

Inherent uncertainties

The process of identifying potential impacts of climate change on biodiversity is fraught with uncertainties. Some environmental conditions will have clear implications for biodiversity, such as the impact of sea-level rise on low-lying shore communities, whereas for others, such as increased atmospheric CO₂ concentrations, the implications are much more difficult to predict.

The panel identified some of the major areas of uncertainty in the climate projections and in ecosystem responses. Many of these issues have been included as potential impacts for particular vegetation ecosystems or vegetation classes, but the likelihood and extent of these impacts are not known. These issues, and the limitations on the panel’s consideration of these issues, are outlined below.

Evapotranspiration. No data from climate models were provided to the panel regarding evapotranspiration. Better information on evapotranspiration, water balance and related issues, such as effects on runoff and stream flow, may allow more specific predictions of impacts.

Fire. Fire is a major ecological driver in many vegetation communities.

Only the most general statement was provided regarding climate change impacts on the fire regime: that fire risk would increase. For the purposes of the workshop it was assumed that fire frequency was likely to increase in many areas and that fire intensity may also increase in areas where shrub layers become more developed as a consequence of higher atmospheric CO₂. More accurate predictions regarding the effects of climate change on the fire regime were beyond the scope of the panel.

Extreme events. It is difficult to judge the cumulative ecological effects of extreme events without projections as to their frequency and severity. Whether taking hot spells, drought, flood, fire or storm events as examples, and assuming the past and current vegetation reactions were perfectly known, it would still be difficult to predict impacts in the future.

The panel identified some potential impacts caused by long hot spells, increased frequency and severity of drought and increased intensity of storms. However, these factors could not be quantified.
**CO₂ fertilisation.** Current literature indicates that increased levels of CO₂ may have the effect of increasing the growth of woody species, including shrubs. A number of confounding factors, such as soil nutrients and water availability, may influence this effect.

It was beyond the scope of the panel to determine the likelihood of this occurring and the degree to which this may occur. However, the issue was flagged for those communities where an increase in shrub abundance would cause a major structural change.

**Weeds.** The response of existing weeds to climate change and the potential for new weeds to colonise was beyond the scope of the workshop. However, as a general rule, weeds were identified as a potential problem for those ecosystems where conditions would remain relatively moist but temperatures would increase, or where existing weeds were thought to be favoured by the projected climate conditions.

**Phenology.** Climate changes could have major implications for the timing and frequency of flowering events. There is currently no estimation of the likelihood and extent to which these effects will occur in NSW ecosystems. What is highly uncertain is any asynchrony across trophic guilds with regards to phenological changes.

Ecosystems that produce abundant nectar and that provide a major resource for fauna include swamp forest, dry sclerophyll, wet sclerophyll, heath and some rainforest types.

Phenological changes to nectar availability may affect nomadic/migratory species that migrate in anticipation or response to flowering and sedentary species that require a local continuity of nectar sources. Examples of migratory species that rely on wet and dry sclerophyll include grey-headed flying-fox, and resident species include the yellow-bellied glider. Dry sclerophyll and heath species that may be affected include the less mobile species such as pygmy possum and squirrel glider and the more mobile megachiropteran bats.

**Current and future land uses.** The potential impacts of climate change need to be considered in the context of human land use, both current and future, although the impacts are often difficult to define and predict. For example, all lowland coastal and floodplain communities are at high risk from sea-level rise, saline flooding and saline incursion into coastal aquifers. Ecosystems at risk include coastal swamp forest, mangroves, salt marshes, coastal floodplain wetlands. In the Hunter region, agricultural, industrial, mining and domestic demand have led to extensive water extraction and diversion and drainage works, altering surface water flows and freshwater availability in aquifers. Land modification and structure will also restrict the ability of these lowland ecosystems to expand upward. Consequently, current and future works will alter the locations affected and the extent of the impacts.
5 North West region

5.1 Description of the region

This study area is comprised of the Nandewar bioregion and parts of Brigalow Belt South and Darling Riverine Plains bioregions (IBRA version 6.1; Thackway and Cresswell 1995) (Figure 4). The study area comprises the western section of the New England North West State Plan region.

This region contains an unusually high number of species at their distributional limits. For example, the wetter forests typical of the Great Dividing Range extend west along the Liverpool Ranges and many temperate ‘Bassian’ fauna species have their western and northern limits on the Nandewar and Liverpool Ranges or at Mount Kaputar. Coolah Tops at the south-western corner of the region lies at the junction of the Liverpool Range and the Warrumbungle Range and forms an important link between eastern and western communities. In the far north-west of the region are the riverine plains, which support dry sclerophyll communities typical of tropical conditions in Queensland or grasslands typical of drier conditions farther west. Clearing of native vegetation has been extensive in the far north-west and on the Western Slopes of the Great Dividing Range.
5.2 Climate projections presented to the expert panel

Temperature and rainfall

- The weather will be hotter.
  Maximum temperatures are predicted to increase by 1.5 to 2.5°C, with spring and winter daytime maximums increasing the most.
  Minimum temperatures are predicted to increase by between 1 and 2°C. The northern and eastern parts of the region will experience a greater rise than the southern parts.
- Rainfall will increase in summer and decrease in winter.
  Rainfall is expected to increase in all seasons except winter, when rainfall may decrease.

<table>
<thead>
<tr>
<th>Minimum Temperature</th>
<th>Maximum Temperature</th>
<th>Precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1–2°C warmer (larger increase in northern and eastern parts of the region).</td>
<td>1.5–2.5°C warmer (spring and winter daytime maximums increase most).</td>
<td>Overall increase in rainfall in spring, summer, autumn. Decrease in rainfall in winter.</td>
</tr>
</tbody>
</table>

Extreme events

The IPCC (2007a) states that the number of days above 35°C will increase.
The length of hot spells (number of days with a daily maximum >35°C) will increase.
Interannual variability in rainfall will increase, causing more extreme droughts.

Fire

Fire regimes are likely to change.
Although fire risk is highly variable between even very close localities, an increase in fire weather risk has been predicted by 2050 for all 10 NSW localities modelled by Hennessy et al. (2005). Using the Forest Fire Danger Index (FFDI) as an indicator of fire risk, Hennessy et al. (2005) predicted the increase in fire risk to be most dramatic inland, with Bourke and Cobar in western NSW predicted to have increases in FFDIs of very high and extreme risk days of 25% and 26%, respectively (Hennessy et al. 2005).

During the workshop it was assumed that drier winters and warmer springs would increase fire frequency and intensity. Research on the impacts of climate change on fire behaviour is ongoing.
Table 8  Summary of impacts by ecosystem: North West Region

<table>
<thead>
<tr>
<th>Ecosystem</th>
<th>Community</th>
<th>Main reasons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grasslands</td>
<td></td>
<td>Major impacts likely to be temperature</td>
</tr>
<tr>
<td>Grassy woodlands</td>
<td>Floodplain transition</td>
<td>Major impacts likely due to seasonal changes in rainfall.</td>
</tr>
<tr>
<td></td>
<td>Tableland clay</td>
<td>Vulnerable to impacts from increased temperatures.</td>
</tr>
<tr>
<td></td>
<td>New England</td>
<td>Risk of species composition changes due to changes in fire regime.</td>
</tr>
<tr>
<td>Freshwater wetlands</td>
<td>Inland floodplain swamps and shrublands</td>
<td>Extremely vulnerable to increased temperatures and reduced flood frequency.</td>
</tr>
<tr>
<td></td>
<td>Low altitude fens</td>
<td>Vulnerable to increased temperatures and changes to inundation.</td>
</tr>
<tr>
<td>Forested wetlands</td>
<td>Inland riverine forest</td>
<td>Considerable uncertainty exists as to how climate change will affect this community. If flooding decreases salinity and feral animals could increase.</td>
</tr>
<tr>
<td></td>
<td>Eastern riverine forest</td>
<td>Change in seasonal patterns could alter phenological characteristics.</td>
</tr>
<tr>
<td>Dry sclerophyll forest</td>
<td>Yetman</td>
<td>May somewhat resilient to changing climatic conditions.</td>
</tr>
<tr>
<td></td>
<td>North West slopes</td>
<td>May somewhat resilient to changing climatic conditions.</td>
</tr>
<tr>
<td></td>
<td>Western slopes</td>
<td>Vulnerable to increased fire frequency.</td>
</tr>
<tr>
<td></td>
<td>Northern Tablelands</td>
<td>Warming may cause the loss of this community from some locations.</td>
</tr>
<tr>
<td>Dry sclerophyll-shrubby/grassy subformation</td>
<td></td>
<td>Substantial impacts are possible if fire frequency increases.</td>
</tr>
<tr>
<td>Rainforest</td>
<td></td>
<td>May somewhat resilient to changing climatic conditions.</td>
</tr>
<tr>
<td>Heathlands</td>
<td></td>
<td>Vulnerable to extended dry periods, resulting in substantial structural and compositional change.</td>
</tr>
<tr>
<td>Ecosystem</td>
<td>Community</td>
<td>Main reasons</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>-----------------------------</td>
<td>----------------------------------------------------------------</td>
</tr>
<tr>
<td>Wet sclerophyll forest</td>
<td></td>
<td>Vulnerable to increased droughts, temperatures and fire frequency.</td>
</tr>
<tr>
<td>Semi-arid woodlands: grassy subformation</td>
<td>Clay plains brigalow</td>
<td>May be slightly advanced from projected climate change.</td>
</tr>
<tr>
<td></td>
<td>Subtropical semi-arid</td>
<td>May be slightly advanced from projected climate change.</td>
</tr>
<tr>
<td></td>
<td>Riverine plains woodlands</td>
<td>Vulnerable to increased stresses due to already fragmented nature.</td>
</tr>
<tr>
<td></td>
<td>North-west floodplains</td>
<td>May be affected temperature changes, drought and increases in flooding.</td>
</tr>
<tr>
<td>Semi-arid woodlands: shrubby subformation</td>
<td>North-west alluvial sands</td>
<td>Weed infestation is likely to be substantial.</td>
</tr>
<tr>
<td></td>
<td>Inland rocky hill</td>
<td>Major impacts are likely from increased weeds and changes to fire regime.</td>
</tr>
<tr>
<td></td>
<td>Western peneplain</td>
<td>May be slightly advanced from projected climate change.</td>
</tr>
</tbody>
</table>

5.3 **Assessment of impacts on each ecosystem**

A list of regionally significant fauna was prepared subsequent to the workshop by panel member Phil Spark (Appendix 2). This list outlines significant species in each ecological community. A second list shows significant and common species at the southern, eastern or western limits of their ranges in this region (Appendix 3). This list can be cross-referenced with the text on each ecosystem to identify species that are potentially at risk from habitat change or loss.

**Grasslands**

**Vegetation classes**

*Semi-arid floodplain grasslands, Western Slopes grasslands*

Grasslands are currently limited by seasonal differences in temperature and rainfall. The major climate change impacts for this ecosystem may be temperature—particularly the effect on weed growth—and increased atmospheric CO₂. The predicted impacts of climate change on the vegetation classes in this ecological community vary markedly, reflecting differences in patterns of clearing and climate envelopes.

Semi-arid floodplain grasslands, which occur on the black soil plains west of Moree, are suited to a more tropical climate than Western Slopes grasslands, and the
predicted changes to temperature and rainfall are likely to be within the tolerance limits of this community. Semi-arid floodplain grasslands may be relatively resilient to climate change, provided that the potential threats from increased atmospheric CO\textsubscript{2} are not significant.

There are major uncertainties surrounding the potential impact of increased atmospheric CO\textsubscript{2} on grasslands. The effects are likely to be varied and complex. One potential effect is that an increase in CO\textsubscript{2} will provide more favourable conditions for the growth of shrub species than for grasses. This could lead shrubby weeds such as mimosa (\textit{Vachellia farnesiana}) to increase in extent and abundance within existing grasslands, particularly where fire is excluded. Another potential impact is the selection of C3 grasses (typical of more tropical climates) over C4 grasses (typical of more temperate climates). If this occurs, some northern grass species typical of semi-arid floodplain grassland may move southward. The likelihood of these impacts occurring cannot be quantified at this time.

Western Slopes grasslands may be severely affected by climate change. This community is suited to more temperate conditions than semi-arid floodplain grassland, and a decline in winter rainfall and increase in summer rainfall are likely to add additional stress to this already highly threatened community.

There are no examples of Western Slopes grasslands secured within reserves, and most occurrences are remnants in Travelling Stock Reserves (e.g. on the western Liverpool Plains and in the Boggabri and Bellata areas). Western Slopes grassland remnants are usually surrounded by agricultural land.

Endangered Ecological Communities and flora within Western Slopes grasslands that may be at further risk because of climate change include plains grass grasslands; the Liverpool Plains, myall and fuzzy box Endangered Ecological Communities; and finger panic grass (\textit{Digitaria porrecta}).

Fauna adversely affected by the decline of \textit{Western Slopes Grasslands} may include the little button quail (one of a number of species at the eastern edge of their range in this region), the narrow-nosed planigale, brolga and bustard.

The fragmented occurrence of these grasslands, coupled with warmer and wetter conditions, is likely to exacerbate existing weed problems and favour the establishment of new weed species. Western Slopes grasslands may therefore be under substantial risk from structural and compositional change across their range within this region.

**Grassy woodlands**

<table>
<thead>
<tr>
<th>Vegetation classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Western Slopes grassy woodland, floodplain transition woodland, tablelands clay grassy woodlands, New England grassy woodlands</td>
</tr>
</tbody>
</table>

The major impacts of climate change on this ecosystem are likely to be increased temperatures, altered fire regimes and increased weed growth (due to higher temperatures and summer rainfall). Those higher altitude communities (Tablelands clay and New England grassy woodlands) are likely to be intolerant of the predicted temperature increases and could undergo substantial range contractions.

Higher atmospheric CO\textsubscript{2} levels may increase the abundance of shrubs, but this potential risk cannot currently be quantified. The relative abundances of C3 and C4 grasses could also be affected, (see discussion under grasslands above). If shrubs are advantaged by an increase in CO\textsubscript{2} levels, any increase in the abundance of
shrubs in the understorey may be negated by an increase in fire frequency, which would select for grasses over shrubs.

Warmer conditions and increased seasonal extremes in rainfall are likely to exacerbate existing weed problems for this ecosystem. An increase in fire frequency could advantage the weed Coolatai grass.

For Western Slopes grassy woodlands, climate change is likely to add an additional stress to this already extensively cleared and highly fragmented community. Although the changes to the vegetation elements of this community from climate change may be moderate, these changes could have major consequences for fauna. This community provides unusually rich resources and is of regional significance for fauna.

Although this community is not likely to be as sensitive to increased temperatures as some other grassy woodlands communities, some contraction up altitudinal gradients is likely, effectively causing the community to contract toward the eastern parts of its current range. A small expansion eastward may be possible where soils are suitable, possibly into areas currently occupied by mountain gum–dominated Tablelands clay communities. However, suitable soils are limiting and an overall contraction in range is likely.

The fragmented state of much of this community leaves it vulnerable to weed invasion. Weed problems are likely to be exacerbated under an increase in summer rainfall and increased temperatures, particularly on the most fertile basalt-derived soils. This is likely to alter the species composition of the understorey.

These effects are likely to place further pressure on those grassy woodland communities that are threatened, such as the Endangered Ecological Community white box yellow box Blakely’s red gum woodland (TSC Act), and the Commonwealth-listed Critically Endangered Community white box–yellow box–Blakely’s red gum grassy woodland and derived native grassland (Commonwealth’s EPBC Act).

This community occurs on high-nutrient soils and provides an unusually large abundance of resources for fauna. Climate change may affect these resources in a variety of ways: an increase in shrub abundance at the expense of grass species (in response to increased CO$_2$) could affect a range of seed-eating woodland birds that use this community. Hollow-bearing trees may be less abundant if fire frequency increases. An alteration in flowering events (particularly a decrease in winter flowering) could have a major impact on those less mobile nectar feeders such as squirrel gliders. A reduction in nectar production is also likely to affect invertebrates and insectivores. Species likely to be adversely affected by these changes include the swift parrot, flying fox, woodland birds such as the diamond firetail and brown treecreeper, and microchiropteran bats such as the eastern cave bat and eastern bentwing bat. This vegetation class supports many species at the western edge of their ranges, and a contraction of this community could result in the contraction of range for these species, such as the border thick-tailed gecko and five-clawed worm skink.

Floodplain transition grassy woodlands

The major impacts on floodplain transition grassy woodlands are likely to be due to seasonal changes in rainfall and increased severity of droughts.

Floodplain transition grassy woodlands include poplar box (Eucalyptus populnea) communities, which are currently showing signs of stress, possibly because of a lowering of the watertable, particularly in the southern end of their range. Tree mortality is likely to continue under more severe droughts during El Niño periods. If
evaporation increases and conditions are drier overall, this may also affect tree recruitment, as seedlings may not grow to sufficient size to reach the watertable during periods between droughts. A decline in poplar box would have flow-on effects for hollow-dependent fauna in this community, as poplar box trees are the main sources of hollows.

Some change in species composition is possible for this community. Some contraction from its range is possible in the south of this region, where the drier conditions may be most extreme. This community is limited by lithology, which limits opportunities for colonising alternative areas should the climate become unsuitable for persistence in situ.

Tableland clay grassy woodland

Kaputar is a western outlier for this community, a remnant from the last glacial period. This community would have once extended across the Nandewar range. Kaputar is the northern or western outlier for a number of flora species and supports a number of endemic species. This includes *Eucalyptus pauciflora*, *Eucalyptus campanulata*, *Cyperus secubans*, *Muehlenbeckia costata* and *Euphrasia orthocheila* subsp. *orthocheila*.

Tablelands clay grassy woodlands at Mount Kaputar are refugia for a number of fauna species in the region. Invertebrates have not been well surveyed here, but some endemic species are likely to occur. This vegetation class is important habitat for the greater glider and supports a number of other Bassian species. A significant breeding colony of the common bent-wing bat, *Miniopterus schreibersii*, occurs here.

Tableland clay grassy woodland is unlikely to tolerate the increased temperatures predicted. The impact of increased temperatures could be exacerbated by increased storm activity, lightening strikes and a subsequent increase in fire frequency. A radical change in species composition is likely, essentially loosing this community and many of its component flora and fauna species from Mount Kaputar and the region.

New England grassy woodland

The major impacts on this community from climate change are likely to be increased temperatures and changes to rainfall. This community occurs in high altitude areas with characteristically low rainfall and is edaphically limited.

Climate change could have a major impact on this community, with many component species likely to be affected and a substantial range contraction likely.

This community was considered unlikely to tolerate higher temperatures and an increase in summer rainfall. It could contract in the higher parts of its current range, retreating to the Nundle plateau and tablelands in the east and to Mount Kaputar in the west. However, movement of this community eastward is restricted: the distribution of suitable soils is limited and the higher rainfall present over much of the tablelands may prevent the establishment of the many component species that are adapted to lower rainfall. A small expansion may be possible in the west, for example expanding into areas currently occupied by Tablelands clay grassy woodlands on Mount Kaputar. However, overall a range contraction is likely for this vegetation class.

New England grassy woodland forms a vegetated link between Coolah Tops and the Liverpool Ranges. This corridor may be of high importance for fauna and could be lost if this community were to retreat from this area.
Changes to the fire regime may alter species composition in those parts of the community that persist. Some fauna species may be intolerant of warmer temperatures and could contract southward. Significant fauna found in this habitat include brown treecreeper, eastern falsistrelle, greater broad-nosed bat, powerful owl, Booroolong frog, yellow-bellied glider, tiger quoll and dusky antechinus. A contraction in range of this vegetation class would result in a reduction of overall habitat for these and other fauna.

There are a number of plants endemic to New England grassy woodland in this region, such as *Eucalyptus oresbia* (restricted to the Nundle area), *Euphrasia ruptura* (presumed extinct), *Caladenia subtilis, Eucalyptus malacoxylon, Eucalyptus nicholii* and *Eucalyptus mckieana* (occurring from Nundle to Torrington). These species may undergo a contraction in range.

### Freshwater wetlands

<table>
<thead>
<tr>
<th>Vegetation classes</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Inland floodplain swamps, inland floodplain shrublands, low-altitude fens</em></td>
</tr>
</tbody>
</table>

Substantial changes to this community are expected. An increase in temperature could cause the loss of low-altitude fens from this region, entirely due to alteration of soil chemistry from increasing length of dry periods and competition from other species. Waterbirds may also suffer substantial declines due to increased temperatures. If wet periods are less frequent and dry spells longer, this could cause the loss of inland floodplain shrublands from the region.

**Inland floodplain swamps and inland floodplain shrublands**

The presence, structure and species composition of these communities are influenced by flooding regimes. The communities are restricted to areas where topography permits inundation. They have been heavily cleared and also reduced in extent by reduced flooding frequency, and the remnants are highly fragmented. An estimated 10% of the original extent is left in this region. Many remaining patches are currently under threat from weeds, pest animals and altered water regimes.

These communities incorporate parts of two endangered ecological communities: the aquatic ecological community in the natural drainage system of the lowland catchment of the Darling River, incorporating the Border rivers (i.e. the Macintyre, Severn and Dumaresq), and that in the regulated tributaries (the Gwydir and Namoi rivers).

Longer, drier periods are predicted over winter, resulting in an increase in the variability of water availability over the course of a year. Inter-annual variability may also increase. It is less clear how the water regime in other months may be affected. The period from spring through autumn is predicted to have an increase in average rainfall, particularly in summer. However, this could be matched or overtaken by an increase in evapotranspiration because of higher temperatures. Two possible scenarios were considered during the course of discussions:

- water availability in spring through autumn will be similar to current levels
- evapotranspiration will increase more dramatically, causing on average lower water availability for most months of the year compared with current levels.

Although changes are likely to occur under both scenarios owing to increased temperatures, drier winters and increased inter-annual variability, the number and extent of these changes are likely to be far more severe under the drier scenario.
Human impacts have the potential to exacerbate climate change impacts on the water regime. Reduced winter rainfalls may increase the proportion of available water extracted for agricultural use, and diversion and drainage works could increase in area.

Many native water plants will be adversely affected if the frequency and duration of flooding decline. This altered water regime will favour the growth of those species with rapid life cycles, causing changes to species composition.

These wetlands provide a very important resource for a number of trans-equatorial birds, many of which are listed under JAMBA, CAMBA and Ramsar. A suite of threats was identified for the colonial wetland birds that depend on freshwater wetlands for foraging and breeding habitat:

- Extended hot periods could cause heat stress and death, particularly for nesting birds. This could have substantial localised effects on populations.
- The occurrence of flooding events every few years is crucial to those species (e.g. the straw-necked ibis) that have relatively short life spans. Numbers of this species are down to 30,000 pairs and may be plummeting; 2008 was the first in 10 years in which conditions were suitable for a major breeding event. Increased lengths of time between big wet seasons would further pressure this species and others with similar life cycle requirements.
- Flooding events must last a certain length of time for birds to complete nesting and rearing: if water levels drop too early, birds will abandon their nests.
- With substantial drying forecast for the south-west of the State, the overall availability of inland wetlands will further decline.
- Grasslands surrounding freshwater wetlands are an important foraging resource and may also be affected by climate (see Grasslands above in this section).
- Lignum is a key resource for many nesting wetland birds. There has already been an observed decline in lignum abundance, possibly because of a reduction in the frequency of inundation. Lignum requires at least 3 months' inundation before it germinates. Therefore, shorter periods of inundation may reduce lignum cover and occurrence.
- An increase in fire frequency and grazing would also reduce lignum cover: this vegetation may require 10- to 15-year intervals between fire events to reach the required level of structural complexity and can be completely excluded by grazing.
- Further conversion of floodplains surrounding freshwater wetlands (in response to increasing demand for arable land) would reduce foraging habitat for many wetland bird species, some of which are known to forage up to 50 km from breeding sites. Any increase in grazing in lignum-dominated wetlands would also reduce habitat.

Efforts that may facilitate the survival of wetlands birds include maintenance of environmental flows, appropriate grazing management in wetlands, and maintenance of surrounding native grasslands.

Bats could be adversely affected by the decline of this ecosystem: freshwater wetlands are typically hotspots for bats owing to their higher abundances of invertebrates than in surrounding ecosystems.

Other fauna dependent on this ecosystem include aquatic invertebrates, fish, broad-shelled, snake-necked and Murray tortoises, and an array of species of burrowing frog. The response of frogs to an altered water regime is difficult to predict. If the
frequency and duration of flooding decline, aquatic invertebrate species that depend on inundation to complete their life cycles are likely to decline in abundance and, in some cases, become regionally extinct. Reductions in the biomass and production of aquatic invertebrates would adversely affect consumers such as fish, tortoises and waterbirds. Native fish would also be adversely affected by a loss of feeding and breeding habitat with reduced inundation.

A reduced frequency of flooding might reduce the rate of spread of wetland weeds such as water hyacinth (which favours relatively constant inundation), water lettuce and salvinia. Weed control could be a beneficial result of climate change.

European carp may be disadvantaged by the altered water regime, because the breeding of this species is promoted by flooding. Gambusia (‘plague minnow’) are likely to benefit from increased temperatures.

Salinity was considered unlikely to become a major issue. There are currently very localised occurrences of salinity (e.g. near the town of Texas), but this was thought to be associated with local soil properties and unlikely to spread. It was assumed that there would be no rise in groundwater levels.

Both inland floodplain swamps and inland floodplain shrublands may be substantially affected by climate change. If the water regime remains similar to that under the current conditions but the temperature increases, species extinction (particularly wetland bird species) at a regional level is possible. If there is an overall drying, with less frequent inundation and shorter wet periods, the impact on waterbirds could be great, especially in terms of breeding events.

Inland floodplain shrublands may be additionally vulnerable to woody weeds and any increase in the duration of dry periods. This vegetation class is currently highly fragmented and is usually grazed, with little or no recruitment. The community is more reliant on flood duration than are inland floodplain swamps, and it is therefore more vulnerable to increases in drought duration. This region contains the easternmost part of the range of inland floodplain shrublands, and a change in the water regime may see this community disappear from the region altogether. Overall, the impacts of climate change on inland floodplain shrublands in this region could be extreme.

Low-altitude fens

Low-altitude fens occur in this region but are not featured in Keith’s 2004 mapping owing to their small and localised occurrence. The presence of these ecosystems is determined by water availability and temperature. These communities do not fit with the definition of the Endangered Ecological Community of montane peatlands and swamps. However, they are currently being considered by the NSW Scientific Committee either as a separate listing or in a broadened definition of montane peatland.

Fens in this region are highly vulnerable to climate change. The predicted temperature increases may be above the tolerance limits of many component species, and fens may be replaced by grasslands. Changes to inundation and temperature will change the soil chemistry. Longer dry periods over winter are likely to further stress many species. A loss of most component species is possible, essentially removing this community from the region.
Forested wetlands

<table>
<thead>
<tr>
<th>Vegetation classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inland riverine forest, eastern riverine forest</td>
</tr>
</tbody>
</table>

**Inland riverine forest**

Determining factors in this ecosystem are water availability, recruitment and topographic features. These communities require access to ground water and variable flows.

Examples of this ecosystem can be found along the banks of all major inland rivers, including the Macintyre, Gwydir, Namoi and Castlereagh. Reserves where this ecosystem occurs include Budelah Nature Reserve.

These systems are currently under significant stress, as evidenced by substantial tree dieback, particularly in forest patches surrounded by intense agriculture. High, sustained flows, as on many regulated rivers, can cause bank erosion, destabilising banks and killing large, mature trees.

It was unclear how the climate scenario would affect flooding. If large flooding events continue, inland riverine forested wetlands should persist, although some species may be lost from this community owing to the increased effects of weeds compounded by the continuation of current threatening processes. If flooding events increase in intensity because of increased rainfall in spring to autumn, this could exacerbate bank erosion and subsequent death of large mature trees, but it may also increase recruitment. If flooding events decrease, this would lead to fewer recruitment events.

Weeds (e.g. cat's claw) are currently a major problem in these ecosystems and are likely to worsen with increased temperature. Weeds can rapidly colonise these ecosystems because of the ecosystems' high level of connectivity. The potential for severe weed infestations may be greater for eastern riverine forest than for inland riverine forests, potentially causing major loss of species and reduction in range for the eastern community.

These communities form important landscape corridors, resulting in a high consistency of fauna between sites. Fauna dependent on forested wetlands include pale-headed snake, barking owl, koala, microchiropteran bats and (when a dense shrub layer is present), black-striped wallaby and curlew. Forested wetlands form the focus of an expanding koala population around Gunnedah. These ecosystems also provide suitable habitat for striped-faced dunnarts. Large, mature trees are important as foraging habitat for a suite of birds and for hollow-nesting and roosting species such as the red-tailed black cockatoo.

Forested wetlands often form the only vegetated remnants (including a source of mature and hollow-bearing trees) within cleared landscapes, and loss of these habitats could cause the loss, at a local scale, of many of the species listed above.

Longer dry spells may adversely affect some reptiles.

Salinity could become a greater issue than it is currently, particularly in the Macquarie catchment. During the workshop salinity was flagged as an issue that required further investigation.

Frequency of algal and cyanobacterial blooms may increase with higher temperatures and lower streamflows.
Feral animals may also increase in abundance—particularly pigs, foxes and cats. With increases in temperature and summer rainfall, cane toads could colonise the area.

Threatened flora is largely absent from this ecosystem: this is possibly an indication of the species loss this ecosystem may have already undergone. Significant plants in this community that could be lost with climate change impacts include *Lepidium* sp.

Further information should be sought on the potential for salinity problems and dieback in forested wetlands.

**Eastern riverine forest**

This ecosystem is present in the reserves of Kyambe, Kaputar, Coolah Tops and Warrabah. This community can be found in disjunct patches along all major streams in the study area.

Dieback and loss of mature trees along riverbanks are currently major problems. Dieback of this community is currently extensive in the region, with a notable (anecdotal) increase in the last 3 to 5 years. If this is associated with variability in rainfall and alteration of natural river flows, it could be exacerbated under climate change, particularly with drier winters. Hollows could be a limiting factor for some fauna using these sites.

Weeds are also a major problem and may be exacerbated by an increase in temperature; such weeds include giant reed (which is currently spreading downstream from Inverell), osage orange (*Maclura pomifera*), honey locust (*Gleditsia triacanthos*) and some species of willow.

Recruitment depends on river flow and could be affected (as discussed for inland riverine forests above).

Threatened species in this ecosystem include *Lepidium peregrinum* and the Booralong frog.

Change in seasonal patterns could alter phenological characteristics—particularly the timing of flowering events; this would in turn affect nectarivores such as arid zone honeyeaters.

Some flora species appear to be temperature limited and may not withstand an increase in temperature.

Major species loss and contraction of distribution is possible for this ecosystem. This ecosystem contains many cold-adapted aquatic invertebrates and some cold-adapted native fish, which are likely to undergo a contraction in their distribution and become more vulnerable to extinction.

**Dry sclerophyll forest: shrubby subformation**

<table>
<thead>
<tr>
<th>Vegetation classes</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Yetman dry sclerophyll forest</em>, <em>Western Slopes dry sclerophyll forest</em>, <em>North West Slopes dry sclerophyll woodlands</em>, <em>Northern Tablelands dry sclerophyll forest</em></td>
</tr>
</tbody>
</table>

In all DSF shrubby communities, if stream flows are reduced in frequency there may be an impact on some fauna, particularly frogs.

**Yetman dry sclerophyll forest**

A determining factor in the distribution of this community is the presence of sandstone and granite substrates. Some species are likely to be temperature limited.
This community is more prevalent in Queensland and is likely to respond favourably to a hotter climate. It occurs on relatively low-nutrient soils and is therefore at reduced risk of weed colonisation. Minor increases in fire frequency and intensity are likely to be within the tolerances of this community.

Long periods between rainfall events in these communities can cause surface hardening and increase surface runoff. The potential impacts of climate change on soils and the flow-on effects for biodiversity need to be further examined.

There may be potential for this community to move southward. Suitable soils may be a limiting factor, and any increase in distribution is likely to be minor.

*North West Slopes dry sclerophyll woodlands*

This includes shrubby white box woodland on volcanic substrate. This ecosystem is widespread and able to tolerate a wide range of climate conditions. It is likely to be more resilient than other ecosystems under the climate scenario provided.

*Western Slopes DSF*

Current threats to this community include infestation by weed species such as African love grass and Coolatai grass.

If fire frequency increases there could be a substantial alteration in the structure and composition of these forests.

Recent major fires and an intensive and extensive ironbark logging history in the Pilliga have dramatically reduced the abundance of large mature ironbarks, resulting in cypress/bulloak dominance of forests.

*Allocasuarina* species could be dramatically reduced in abundance by increased temperatures and increases in fire frequency and intensity. Massive structural and species compositional changes are possible, with the understorey potentially becoming grassier, or replaced by more fire-resistant and arid-adapted species such as broom bush or wattles. Grassy flats have the potential to carry more fire than shrubby understoreys, adding another variation to the natural disturbance regime, with the potential to change the structure and composition of this community.

Increased fire frequency could reduce *Callitris* abundance, particularly if fire occurs more frequently than every 7 or 8 years in areas where it has been historically rare.

Previous extreme fire events have caused massive losses of hollow-bearing trees, with a resultant loss of the hollows required by hollow-dependent fauna such as the greater long-eared bat (*Nyctophilus timoriensis*) and squirrel gliders, which are more frequent in this ecosystem than in Tablelands DSF. Koalas, which feed on mature ironbark, are also likely to be affected. A massive structural change is possible: once these old-growth trees are lost, they are unlikely ever to be replaced. Increased management of land for fire control will lead to increased potential for weed invasion. Higher fire frequency is also likely to lead to sediment movement into drainage areas because of increased rates of erosion of exposed soils.

Bassian species (species typical of southern and eastern Australia) could be pushed farther south. The Pilliga mouse could also be adversely affected. This species is dependent on broom bush in areas where fire occurs at relatively low frequencies.

*Northern Tablelands DSF*

This community is restricted to areas of cooler temperatures and higher altitudes within the region.
Although Keith (2004) maps Mount Kaputar as Tableland clay grassy woodland, the panel considered the community in this area to fit more appropriately within Northern Tablelands DSF and included Mount Kaputar in the discussion of this vegetation class.

Tablelands DSF in this region includes some historic refuges in relatively isolated areas. Substantial warming may cause the loss of this community from some locations [e.g. the loss of snow gum (*Eucalyptus pauciflora*) forest from Coolah Tops]. There may be some potential for altitudinal migration in Kaputar, but contraction from the current range is likely.

Major flowering events could shift or become less frequent in species such as mugga ironbarks owing to changes in seasonality and/or rainfall, affecting a suite of fauna that depends on these events. Examples include the greater gliders in Kaputar. Flowering of mistletoes could also be affected.

Regent honeyeaters may be particularly vulnerable to changes to flowering events: no breeding was recorded for many years during the most recent drought, possibly because of the lack of major flowering events. Some species, such as squirrel gliders, have small ranges, leaving them more vulnerable to losses of resources at a local scale.

Booralong frog could be affected if stream flows are reduced. This species has become greatly reduced in range and could disappear from the region altogether with climate change impacts.

Bassian species that may be sensitive to an increase in temperature include the southern forest bat, red wattle bird, white-lipped snake, crimson rosella and ring-tailed possum.

Many fauna species in this community could be adversely affected by the direct impacts of higher temperatures and by the indirect impacts of reduction or loss of key habitat resources such as nectar and hollows. An altitudinal retreat is possible for some fauna and flora, although some species already occupy the highest altitudes available in their region (e.g. snow gums in Coolah Tops). A range reduction is likely for some species.

Serpentine dry sclerophyll forest is an example of a highly restricted community that may not be able to persist in areas where it currently occurs, and due to its unique requirements could not occur elsewhere.

Serpentine dry sclerophyll forest is not recognised as a separate community by Keith (2004), but it was considered significant enough in this region to warrant separate consideration. Serpentine communities are located on an unusual geology derived from a deep ocean floor. This community is found on skeletal soils with very high levels of trace elements toxic to many plants, thus favouring species with high mineral tolerances. It occurs in Warialda south to Manilla and Dungowan. Its shallow stony soils support unique vegetation, with many endemic species. The shallow soils make this community vulnerable to drought. The ability of species in this community to tolerate higher temperatures and changes in rainfall is unknown but, if they are sensitive, the impacts of climate change could be dramatic, as the unusual geology required by this community is not found elsewhere.
Dry sclerophyll – shrubby/grassy subformation

<table>
<thead>
<tr>
<th>Vegetation classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pilliga outwash DSF</td>
</tr>
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</table>

This vegetation class occurs on sandy, deep soils that are boggy when wet and is confined to the central part of NSW. Examples include Pilliga West Community Conservation Area.

The predicted changes to climate may fall within the climatic tolerances of many component species.

More substantial impacts are possible if fire frequency increases. An increase in fire frequency could reduce species composition and remove some species such as *Callitris glaucophylla* (currently a minor component) from much of the community. An increase in fire frequency may also reduce the number of mature hollow-bearing trees.

This community may be at risk of increased weed invasion by species such as African love grass and Coolatai grass.

Potential indirect impacts on fauna may result from foliage changes, phenology changes (timing of flowering events) and loss of hollow-bearing trees if fire frequency increases.

The most important NSW population of barking owl occurs in this region. It also provides relatively intact habitat for a range of woodland bird species. Other dependent species include bush stone-curlews, greater long-eared bats (a substantial population) and a range of other microchiropteran bats. A decline in hollow-bearing trees, a decline in nectar resources (and potentially a consequent decline in invertebrate abundance) and changes to the understorey due to weed invasion would affect these species. Mugga ironbark is a particularly important nectar resource in this habitat, and a reduction or change in its patterns of flowering would affect nectar-dependent species.

Although not quantifiable, increased atmospheric CO₂ levels could alter levels of nitrogen and phenolics in the foliage, with flow-on effects for folivores, insects and insectivorous species. Alternatively, warmer conditions and an increase in summer rainfall could increase insect abundance.

Rainforest

<table>
<thead>
<tr>
<th>Vegetation classes</th>
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</thead>
<tbody>
<tr>
<td>Dry rainforest, western vine thicket</td>
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</table>

Examples of dry rainforest are found in reserves at Mount Kaputar and at Planchonella Nature Reserve near Bonshaw, as well as at Moema Community Conservation Area and Terry Hie Hie, generally occurring on scree or in riparian areas. Frugivorous birds are important seed dispersers for many flora in this ecosystem. It provides refugia for black-striped wallaby and brush-tailed rock wallaby and habitat for the Endangered Ecological Community *Cadellia pentastylis* (ooline) community in the Nandewar and Brigalow Belt South bioregions. The Commonwealth has listed semi-evergreen vine thickets of the Brigalow Belt (North and South) and Nandewar bioregions as a Threatened Ecological Community (Endangered) under the EPBC Act.
Fire frequency could encroach in some areas where dry rainforest is adjacent to dry sclerophyll forest (e.g. in the southern section of Mount Kaputar National Park). Remnants of dry rainforest surrounded by agricultural land are likely to be buffered from fire. This ecosystem is probably able to withstand fire intervals of 10 to 20 years and undergo sufficient recruitment, provided that the fire intensity is not too high.

Weeds are not currently a major issue for this ecosystem, with the possible exception of the African boxthorn (*Lycium ferocissimum*), and weeds are not foreseen as a major problem under climate change.

This ecosystem provides preferred habitat for an endangered population of the Australian brush-turkey occurring in the Nandewar and Brigalow Belt South bioregions (this area is a western outlier for this species and the western extent of its range).

Dry rainforests support Tumbunan species, relict rainforest species typical of more montane and submontane areas, which in NSW are mostly confined to the Great Dividing Range. If this habitat becomes drier and hotter, some Tumbunan species, such as Lewin’s honeyeater, white-throated tree creeper and white-browed scrub wren, may decline.

Many component species in this ecosystem are limited in their potential for geographic spread by their dispersal mechanisms. Expansion of existing patches of western vine thicket into adjacent areas currently dominated by belah, white box or poplar box is possible. Western vine thicket has been observed spreading in recent years in the Moema Community Conservation Area and at Terry Hie Hie. Western vine thicket could undergo a small increase in geographic area with increased temperatures and seasonal extremes in rainfall. As dry rainforest is restricted to screes, its capacity to spread is likely to be limited and a minor reduction in range due to climate change is possible.

**Heathlands**

<table>
<thead>
<tr>
<th>Vegetation classes</th>
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</thead>
<tbody>
<tr>
<td><em>Northern montane heath</em></td>
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</tbody>
</table>

This ecosystem is currently limited in occurrence by altitude (temperature and rainfall) and soils (occurring on skeletal soils). Examples can be found at Goonoowigal, Rockview, Ironbark, Howell (including in the Howell shrublands, which contain many threatened species) and Torrington outcrops.

Many of these heathlands are surrounded by cleared agricultural land. Large, mature trees—remnants of now-cleared woodlands—are often present on their margins. These trees are often the only sources of hollows for some distance and are likely to be vulnerable to climate change.

Phenological changes to flowering could affect a range of species that utilise nectar from flowering shrubs.

Skeletal soils leave these ecosystems vulnerable to extended dry periods. Reduced winter rainfall could result in replacement of shrubs by grasses that can capitalise on more variable rainfall patterns and are better able to cope with extended dry periods. Climate change could bring about the loss of most shrubs from all areas, causing substantial structural and compositional change. Further, given that the distribution of this ecosystem is limited to its present location by altitude and soils, it is possible that this ecosystem could be lost from the region.
Wet sclerophyll forest

<table>
<thead>
<tr>
<th>Vegetation classes</th>
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</thead>
<tbody>
<tr>
<td><strong>Northern Tablelands wet sclerophyll forests</strong></td>
</tr>
</tbody>
</table>

This is a western outlier of a predominantly tablelands community. Examples of this vegetation class can be found at Ben Halls Gap, at Coolah Tops, and on the eastern side of Mount Kaputar National Park.

Significant species include *Eucalyptus volcanica* (endemic to the Nandewar and Warrumbungle ranges), and the threatened species *Tasmannia purpurascens* and *Tasmannia glaucifolia*.

A number of component flora species are high temperature and and low rainfall limited. More severe droughts, increased temperatures and potentially greater fire frequency may cause the loss of a number of flora species, resulting in a simplified ecosystem with a small proportion of the original species composition present.

This ecosystem provides habitat for a number of woodland birds, the greater broad-nosed bat, powerful owl, yellow-bellied glider, dusky antechinus and the greater glider. Substantial compositional change to the vegetation is likely to reduce the habitat quality of this ecosystem for fauna.

The eastern falsistrelle, a Bassian species, may be intolerant of increased temperatures, and its range could contract southward. Wombats are a significant species for this ecosystem, but the panel was uncertain as to the potential impacts of climate change on this species.

Coolah Tops is the western limit for many species.

It is likely that most species in this ecosystem will be affected, with dramatic changes to abundance and composition. Some of the more resilient species may persist in the more sheltered parts of Coolah and Kaputar, but most, or all, of this community could be lost from the region.

Semi-arid woodlands: grassy subformation

<table>
<thead>
<tr>
<th>Vegetation classes</th>
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</thead>
<tbody>
<tr>
<td><strong>Clay plains brigalow woodlands, subtropical semi-arid woodlands, riverine plains woodlands, north-west floodplains woodlands</strong></td>
</tr>
</tbody>
</table>

The brigalow clay plains woodlands on the NSW North West Slopes are the southern representatives of a community that stretches into hotter areas to the north into Queensland. This suggests that they are likely to be tolerant of the projected temperature rises.

The community is restricted to relatively fertile clay plains and generally occurs as remnants within agricultural lands. Some examples are found within the Brigalow–Casuarina Reserves at Brigalow Park, Moema and Careunga. It is listed as an Endangered Ecological Community at both State and Commonwealth levels.

Species composition is largely determined by micro-relief variations. The threatened species *Lepidium aschersonia*, glossy black cockatoo and black-striped wallaby occur. *Paspalidium constrictum* is endemic to this vegetation class but abundant where it occurs.
Where the canopy is less dense there are some infestations of weeds such as African boxthorn and mother of millions.

Although some native species and weeds might be adversely affected by climate change, overall this community could be slightly advantaged by the projected climate change, and it may increase in geographic range where it is not restricted by agriculture or edaphic factors.

**Subtropical semi-arid woodlands**

As with the brigalow clay plains woodlands, subtropical semi-arid woodlands occur predominantly in the more northerly hotter areas and in Queensland. In NSW they occur in isolated patches, in rainshadow areas on the northern plains.

The class contains the significant species *Hakea purpurea*, *Dodonaea macrossanii* and *Diuris tricolor*, and an eastern outlier population of *Calytrix longiflora*.

The panel considered that increased summer rainfall and temperatures may slightly advantage the community, and its range may expand into adjoining bimbi and ironbark DSF in areas such as the northern end of Bebo State Forest. Any potential expansion will be limited the by availability of suitable soils.

**Riverine plains woodlands**

This community is restricted by drainage and occurs on the deeper alluvial soils. It is listed as an Endangered Ecological Community and rarely occurs in stands larger than 10 ha, and is surrounded by agriculture. Most remnants are highly disturbed. It occurs in some reserves at Midkin, Kaputar and Trinkey, but fragmentation and disturbance might render the community—particularly the understorey species component—vulnerable to any increased stress from climate change.

The community contains threatened flora such as *Digitaria porrecta*, *Desmodium campylocaulon*, *Phyllanthus maderaspatensis* and *Swainsona murrayana*.

Warmer wetter conditions and CO₂ fertilisation may advantage woody understorey species and some weed species and may alter the ratio of C3 to C4 grasses. These changes—particularly the weed invasions—might cause local extinctions of some already declining understorey flora.

This community is important habitat for the striped-faced dunnart, five-clawed worm skink, curlews and bustards. Many birds and reptiles are at their eastern limits in this community and may move farther east in response to climate change.

Although flora may also have the potential to move east in response to the projected climate factors, edaphic factors, agricultural clearing, fragmentation of suitable habitat and disturbance are likely to prevent this.

Climate change alone may not have substantial effects on this community, but it will add yet another pressure to this already highly stressed ecosystem. Dominant species are likely to persist, but a number of species could be lost, resulting in an overall simplification of this community.

**North-west floodplains woodlands**

This vegetation class is listed as an Endangered Ecological Community under the TSC Act but also falls within the definition of an invasive native scrub under the *Native Vegetation Act 2003*. As such, it is still being actively cleared. Where it has regenerated it often forms dense co-dominant stands that restrict the recruitment of large, hollow-bearing trees.
The community may be affected by temperature changes, drought intensification, increases in summer rainfall, CO₂ fertilisation and possible increases in flooding in wetter summers.

Increased summer rainfall and elevated CO₂ levels may favour C3 grasses over C4 grasses, and shrubby species over grasses.

Weed species such as African boxthorn and mimosa (*Vachellia farnesiana*) are also likely to be advantaged. If there are longer drought periods, deep-rooted saltbush may be promoted. The already serious *Lippia* weed infestations are likely to continue regardless of climate changes. There is some potential for an influx of more northerly species, such as black box. Warmer, wetter conditions may allow cane toads to colonise.

Koala populations may be affected by CO₂ promotion of phenolics in eucalypt leaves and by summer heat stress. Superb parrots and other seed eaters may be disadvantaged by a loss of grasses. These woodlands are important drought refuges for many arid species and are the eastern limit for species such as the white-winged wren, crimson chat, grey-crowned babbler, narrow-nosed planigale, stripe-faced dunnart, fat-tailed dunnart and five-clawed worm skink (see comprehensive lists in Appendixes 2 and 3). The availability of tree hollows is important for microchiropteran bats, blue bonnet, Major Mitchell cockatoo, pale-headed snake and barking owl.

Climate change may cause a change in species composition and structure, particularly in the understorey. There may be some change to the community’s range.

**Semi-arid woodlands: shrubby subformation**

<table>
<thead>
<tr>
<th>Vegetation classes</th>
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</thead>
<tbody>
<tr>
<td><em>North-west alluvial sands woodland</em>, <em>inland rocky hill woodland</em>, <em>western peneplain woodland</em></td>
</tr>
</tbody>
</table>

As this ecosystem has a characteristically shrubby understorey, no structural change is expected as a result of increased levels of atmospheric CO₂.

**North-west alluvial sands woodland**

Soils, drainage and temperature dictate the occurrence of this ecosystem. Examples in reserves include Budelah, Killarney (north of Narrabri), Bebo (Dithinna Dthinnawan Community Conservation Area) and the northern part of the Pilliga. This community has been substantially cleared and tends to occur in remnants.

This vegetation class incorporates the Endangered Ecological Community carbeen open forest, on the Darling Riverine Plains, and the Brigalow Belt South bioregions (NSW TSC Act). Carbeen is a tropical species, and increased temperatures and seasonal rainfall may result in conditions favourable for this community.

This ecosystem provides an important source of hollow-bearing trees in isolated remnants, usually surrounded by agricultural land.

A number of invasive weeds are likely to be advantaged by the changed climate conditions; they include African boxthorn (*Lycium ferocissimum*) (advantaged by increased temperature and tolerant of prolonged dry spells) and buffel grass (*Cenchrus ciliaris*) (advantaged by increased seasonal extremes in rainfall and temperature).

Although the altered climate may improve conditions for these communities, weed infestation is likely to be substantial.
Inland rocky hill woodland

This is a highly variable community grouped by topographic features. Examples can be found in reserves at Bingara ridge and Kaputar, (some on sandstone), on the western edge of Torrington plateau, in Trinkev State Forest, and in parts of Bebo State Forest. This region contains the eastern outliers of this predominantly central western NSW community.

There is a possibility of some modification of this community by climate change, with the major impacts likely to be from increases in weed abundance and changes to the fire regime.

This community is important habitat for cave bats more typical of eastern NSW, including horseshoe bats, eastern cave bat and large-eared pied bat. Loss of vegetation cover from rocky outcrops can alter the microclimate of caves and influence the suitability of these areas for cave dwellers.

Goats are an existing problem for this community, degrading vegetation, forming and eroding tracks, and competing with native fauna. Hotter, drier conditions could exacerbate plant stress in degraded areas, whereas more intense summer downpours could increase erosion.

Fuel is slow to develop in this community, thus tending to keep fire intensity lower. Higher summer rainfall under climate change could increase plant productivity and fire intensity, although this may be moderated by grazing. Remnants are often relatively large, assisting recolonisation from unburnt patches.

This community supports woodland birds such as brown treecreeper, diamond firetail and hooded robins, as well as thornbills and turquoise parrots, all of which could be affected if this community degrades.

Western peneplain woodland

The presence/absence of this community is dictated by temperature and rainfall.

Examples of this community can be found in Pilliga Nature Reserve, Midkin Nature Reserve (although this community is highly degraded with a Lippia understory), and Baronga Nature Reserve near Boomi. It contains the threatened flora species Capparis canescens.

The changed climate could provide favourable conditions for this community. Shrubiness could be enhanced by higher summer rainfall. Fuel loads and fire intensity are usually low. However, an increase in shrubbiness under climate change could increase fuel loads. This community is likely to be tolerant of dry winters and an increase in temperature.

The vegetation components of this community are likely to tolerate the predicted changes to climate, although weed cover [particularly of African boxthorn (Lycium fercissimum)] could increase. Conditions may be suitable for this community to expand from its current extent, although adjacent land use is likely to be a limiting factor and any increase in extent is likely to be minor.

These are relatively productive communities that contain a diversity of habitats and often provide refuges on otherwise cleared floodplains. Fauna present in this community include insectivorous species (particularly microchiropteran bats), koalas, and threatened woodland birds such as the brown treecreeper and the grey-crowned babbler. It may provide habitat for Major Mitchell cockatoos.

Species for which this is the westerly part of the distribution could be sensitive to heat stress. If increased CO₂ levels result in lower nitrogen to carbon ratios, this could have negative implications for foli vores and leaf-foraging insectivores.
Although the vegetation may remain similar in terms of species composition and structure, the combined effects of loss of nutrients in the foliage, phenological changes to flowering, and heat stress may adversely affect many fauna species. As this community often occurs in isolated patches, there are limited opportunities for re-colonisation once species populations are lost. Thus, climate change could have a negative effect on fauna and a slight positive effect for flora components of this community.

Comments applicable to more than one ecosystem

*Fragmented ecosystems on the North Western Slopes*

Western Slopes grasslands and Western Slopes woodlands occur on fertile soils in the sheep-wheat belt, and both have been cleared to less than 30% of their original coverage. Few remnants are reserved. Most remnants are small and isolated, and almost all are degraded to some degree. The best and largest remnants may be found in Travelling Stock Reserves. Heavy grazing within remnants causes changes to species abundances and composition and prevents the regeneration of trees. The fragmented nature of these ecosystems makes them particularly vulnerable to weed invasion.

Climate change may add yet another pressure on these already highly stressed ecosystems: many species may not be able to cope with the increase in temperature and may be lost from lower altitudes. Many weed species are likely to favour the warmer conditions and increase in abundance, and new weed species may colonise the areas, altering the understorey. More frequent fire is possible with increasing temperatures, hastening the death of the large, mature trees on which many fauna depend for nesting and roosting. Fauna likely to be affected includes the squirrel glider (for which Western Slopes grassy woodlands is core habitat), swift parrot and flying-fox.

The capacity of these ecosystems to persist in an altered climate would improve with grazing exclusion and active conservation management. Priority areas for protection are larger remnants (particularly those at higher altitudes) and areas where these remnants are relatively well connected with other vegetation.

*Climate-change-induced or -encouraged tropical weed invasions from the north*

A number of weed species that occur in this region favour more tropical weather. They include the African boxthorn (*Lycium ferocissimum*), buffel grass (*Cenchrus ciliaris*) and Coolatai grass. Some of these species are already a problem in many habitats, outcompeting native species. The warmer temperatures, (and, for some species longer dry spells) may further advantage these species and could create conditions suited for many more. Those ecosystems that are most vulnerable may require active management if threatened flora are to persist.
6 North and South Western regions

6.1 Description of the regions

North Western region
The North Western region covers the semi-arid to subhumid plains of NSW in the summer and mixed rainfall zones. The reporting regions for this study are based on the regions used in the NSW State Plan. The North Western region largely corresponds to the Western NSW State Plan region; however, the tablelands area south of Wellington and the Mallee country in the south-western corner have been put into other regions.

South Western region
The South Western region covers the semi-arid to subhumid plains of NSW in the predominantly winter rainfall zones. It covers most of the large floodplains of the Murray, Murrumbidgee and Lachlan valleys. The reporting regions for this study are based on the regions used in the NSW State Plan. The South Western region largely corresponds to the Riverina NSW State Plan region; however, the tablelands area east of Albury has been put into another assessment area. Likewise, the south-western slopes around Boorowa and Harden, and the Murray Mallee country, have been moved into this region.
6.2 Climate projections presented to the expert panel

North Western region

- The weather will be hotter:
  Minimum temperatures will be between 0.5 and 2 °C warmer. The northern and eastern parts of the region will experience a greater rise than the southern parts. Maximum temperatures will increase by 1.5 to 3 °C. Spring and winter daytime maximums will increase the most (on average, 2.5 to 3 °C warmer).

- Summers will be generally wetter:
  Most of the region will receive between 10% and 20% increases in summer rainfall. The Central Western Slopes and Plains will receive a 20% to 50% increase. The amounts generally fall within the upper ranges observed in the 20th Century.

- Winters will be generally drier:
  There will be a 10% to 20% decrease in precipitation during winter, the intensity of deficit being greater with increased latitude. The amounts generally fall within the lowest ranges observed in the 20th Century.

- Spring and autumn will be slightly wetter or close to average:
  Compared with the long-term seasonal variability, rainfall in spring and autumn are generally within the ranges observed in the 1900–2000 period. Autumn is generally in the drier end of the observed range and spring in the wetter end.

- Leading to a predicted overall increase in annual precipitation for the region
Table 9  Temperature and rainfall summary for north-western NSW under the 2050 A2 Climate Scenario

<table>
<thead>
<tr>
<th>Season</th>
<th>Minimum temperature</th>
<th>Maximum temperature</th>
<th>Precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>1.5–2 °C warmer</td>
<td>2.5–3°C warmer</td>
<td>0–5% increase over most of the area. Wetter (5–10% increase) in the north-east of the region.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Milder in the Central West (2–2.5°C)</td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>1–1.5°C warmer</td>
<td>1.5–2°C warmer</td>
<td>10–20% Increase in summer rainfall over most of the area. Wetter (20–50% increase) in the Central West.</td>
</tr>
<tr>
<td></td>
<td>More in the east</td>
<td>Hotter in the west</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1.5–2°C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Autumn</td>
<td>1–1.5°C warmer</td>
<td>2 -2.5°C warmer</td>
<td>0–5% increase over most of the area. Wetter (5–10% increase) in the far north of the region.</td>
</tr>
<tr>
<td></td>
<td>More in the north and east (1.5–2°C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter</td>
<td>0.5–2°C warmer</td>
<td>2–3°C warmer</td>
<td>10–20% decrease over most of the region. Reduction more severe (20–50% less) south of about Broken Hill.</td>
</tr>
<tr>
<td></td>
<td>Gradual range</td>
<td>Gradual range</td>
<td></td>
</tr>
<tr>
<td></td>
<td>increase from south to north</td>
<td>increase from south to north</td>
<td></td>
</tr>
</tbody>
</table>

South Western region

- The weather will be hotter:
  Daytime maxima will be 1.5 to 3°C hotter, particularly in spring and winter (2 to 3°C). Overnight minimum temperatures will be warmer but not to the same degree as daily maxima (mostly 0.5 to 1.5°C).

- Summers will be much wetter:
  Most of the region will receive between 10% and 20% increase in summer rainfall. The eastern Riverina and Southwest Slopes will receive the greatest increase. The predicted amounts generally fall within the upper ranges of the wettest summer periods observed in the 20th Century.

- Winters will be drier than any period observed in the 20th Century:
  There will be a 20% to 50% decrease in precipitation during winter, the intensity of deficit being greater with increased latitude. The predicted amounts fall well below the lowest ranges of the driest winter periods observed in the 20th Century, except on the South West Slopes, where the 1960–1989 period was as dry at times (although preceded and followed by much wetter springs and autumns than the projected climate).

- Spring and autumn will be very much drier:
  Spring and autumn rainfall predictions show a similar pattern of a 0% to 50% decrease, with the severity of the deficit increasing rapidly with latitude. Comparison with long-term seasonal variability indicates that rainfall in spring and autumn are very much lower than anything observed in the 1900–2000 period (with the exception of the 1990–2006 period, which also had exceptionally dry spring and autumns).

- Leading to a predicted overall decrease in annual precipitation for the region
### Table 10 Temperature and rainfall summary for south-western NSW under the 2050 A2 Climate Scenario

<table>
<thead>
<tr>
<th>Season</th>
<th>Minimum Temperature</th>
<th>Maximum temperature</th>
<th>Precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>1–2°C warmer (warmer in the eastern Riverina and on the South West Slopes)</td>
<td>2–3°C (warmer in the eastern Riverina and on the South West Slopes)</td>
<td>0%–50% decrease. Severity of reduction increases with latitude across the region.</td>
</tr>
<tr>
<td>Summer</td>
<td>0.5–1.5°C warmer</td>
<td>1.5–2.5°C warmer</td>
<td>10%–50% increase in summer rainfall over most of the area. Wetter (20%–50% increase in the eastern Riverina and on the South West Slopes).</td>
</tr>
<tr>
<td>Autumn</td>
<td>0.5–1.5°C warmer</td>
<td>1.5–2.5°C warmer</td>
<td>0%–20% decrease. Severity of reduction increases with latitude across the region.</td>
</tr>
<tr>
<td>Winter</td>
<td>0.5–1°C warmer</td>
<td>2–2.5°C warmer</td>
<td>20%–50% decrease throughout entire region.</td>
</tr>
</tbody>
</table>

### Table 11 Summary of impacts by ecosystem: North and South Western regions

<table>
<thead>
<tr>
<th>Ecosystem</th>
<th>Community</th>
<th>Main reasons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grassy woodlands</td>
<td>North Western region</td>
<td>Large changes in species composition and community structure are predicted.</td>
</tr>
<tr>
<td></td>
<td>South Western region</td>
<td>Vulnerable to increasing levels of human disturbance and increased frequency of storms and fire.</td>
</tr>
<tr>
<td>Dry sclerophyll forest</td>
<td>North Western region</td>
<td>Changes in rainfall and fire regimes will cause changes in species composition are predicted.</td>
</tr>
<tr>
<td></td>
<td>South Western region</td>
<td>Patchy declines in viability and changes in community structure are likely.</td>
</tr>
<tr>
<td>Semi-arid woodlands</td>
<td>North Western region</td>
<td>Human land management will be the most important factor influencing the condition of this community.</td>
</tr>
<tr>
<td></td>
<td>South Western region</td>
<td>Major changes in structure and composition are predicted with reduction in water availability compounding the situation.</td>
</tr>
<tr>
<td>Ecosystem</td>
<td>Community</td>
<td>Main reasons</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>---------------------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Semi-arid woodlands North and South</td>
<td>Western peneplain and inland rocky hill woodlands</td>
<td>Increasing aridity will play a major role in determining changes in species composition and structure.</td>
</tr>
<tr>
<td>Semi-arid sand plains</td>
<td>Expected to experience continual decline in geographic extent and condition.</td>
<td></td>
</tr>
<tr>
<td>Sand plain mallee woodlands</td>
<td>Loss of grassy understorey and associated fauna is predicted to occur with decreased seasonal rainfall.</td>
<td></td>
</tr>
<tr>
<td>Dune mallee woodlands</td>
<td>Hotter conditions are likely to amplify the effects of grazing.</td>
<td></td>
</tr>
<tr>
<td>Riverine sandhill woodlands</td>
<td>Unlikely to persist as they are currently known with severe degradation expected.</td>
<td></td>
</tr>
<tr>
<td>Subtropical semi-arid woodlands</td>
<td>May somewhat resilient to changing climatic conditions.</td>
<td></td>
</tr>
<tr>
<td>North-west alluvial sand woodlands</td>
<td>Changes in structure and composition are expected.</td>
<td></td>
</tr>
<tr>
<td>Grasslands</td>
<td>North Western region</td>
<td>May be slightly advanced from projected climate change.</td>
</tr>
<tr>
<td>South Western region</td>
<td>A large proportion of the species composition and community structure is likely to be affected.</td>
<td></td>
</tr>
<tr>
<td>Forested wetlands</td>
<td>Northern-sourced rivers</td>
<td>Impacts dependent on river regulation levels as the primary determinant of the physiological impacts of climate change.</td>
</tr>
<tr>
<td>Southern-sourced rivers</td>
<td>Likely to suffer from moisture stress while responses to climate change will differ among wetland types.</td>
<td></td>
</tr>
<tr>
<td>Freshwater wetlands</td>
<td>North Western region</td>
<td>Impacts dependent on factors such as changes to river regulation levels and evaporation rates.</td>
</tr>
<tr>
<td>South Western region</td>
<td>Impacts dependent on factors such as changes to river regulation levels and evaporation rates.</td>
<td></td>
</tr>
<tr>
<td>Ecosystem</td>
<td>Community</td>
<td>Main reasons</td>
</tr>
<tr>
<td>--------------------</td>
<td>------------------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Saline wetlands</td>
<td>Some possible changes in geographic extent.</td>
<td></td>
</tr>
<tr>
<td>Arid shrublands</td>
<td>Acacia subformation NW region</td>
<td>Likely to experience varying levels of impact in different areas depending on sources of disturbance.</td>
</tr>
<tr>
<td></td>
<td>Chenopod subformation NSW</td>
<td>Difficult to assess impacts due to unknown effects of increased temperature and the influence of human land use patterns.</td>
</tr>
<tr>
<td></td>
<td>SW region</td>
<td>Marked changes in species composition and community structure are expected.</td>
</tr>
</tbody>
</table>

### 6.3 Assessment of impacts on each ecosystem

#### Grassy woodlands – North Western region

This ecosystem is already adapted to a very variable climate. However, the impacts predicted to occur from climate change are likely to be exacerbated by the extent of fragmentation of these habitats, as the dispersal capacity of this community is extremely limited. All species except those that are highly mobile will be required to deal with the impacts of climate change in situ. Large changes in species composition and community structure are predicted, primarily because of the change in seasonality with increased summer growth and decreased winter growth and resultant changes in human disturbance levels through differing land use practices. This is likely to lead to some decreases in geographic extent, with the potential loss of some remnants of these grassy woodlands. Due to clearing and habitat modification for agriculture, the woodlands are already among Australia’s most threatened ecosystems. The impacts of climate change are likely to aggravate levels of degradation, with negative impacts on a range of Endangered Ecological Communities.

**Major impacts**

**Increased** summer rainfall and change in growth season:

- potential for change in agricultural regimes from cropping to grazing:
  - increase in abundance of non-palatable species through overgrazing and summer grazing patterns
  - increased competition between native herbivores and stock
  - decreased eucalypt recruitment: die-off of canopy species
  - direct impacts on fauna habitat and food resources
  - decreased species diversity

- changes in species composition:
  - decrease in perennial species abundance, increase in annuals
  - increase in abundance of more arid-adapted species
— annual spring weeds favoured (favoured also by potential increase in grazing levels), e.g. Paterson's curse (*Echium plantagineum*), Chilean needlegrass (*Nassella neesiana*) and Coolatai grass (*Hyparrhenia hirta*); the last of these already dominates the ground layer in many Travelling Stock Routes and has taken over in less than 10 years.

- changes in timing of flowering events of eucalypts:
  - effects on resource availability for fauna

**Increased** CO$_2$ concentrations:

- may increase shrubbiness of understorey of grassy woodlands and lead to decline in grassy species; change in understorey structure and habitat heterogeneity.

The change in seasonality of moisture availability will have wide-ranging impacts throughout the ecosystem, with impacts on plant species composition and resulting impacts on resource availability for fauna species. Summer-growing plants will be favoured where they have previously been limited, with corresponding reductions in the cover of plants adapted to growth in other seasons. Yellow box (*Eucalyptus melliodora*) is at present flowering months earlier than normal, potentially because of changes in climate patterns. This may cause asynchrony of flowering events with the arrival and breeding season of migrant birds using these seasonal resources [e.g. regent honeyeater (*Xanthomyza phrygia*) and swift parrot (*Lathamus discolor*)]. Also, resident species may be affected by changes in the resource availability of nectar, insects and pollination. Spring- and summer-breeding nectivorous birds will be heavily disadvantaged by this earlier flowering. Early indications are of decreased numbers of these birds, rather than adaptive changes in breeding season, with some migratory birds not visiting these woodlands at all. These grassy woodlands are noted for their high bird diversity and numbers. Changes in resource availability will have negative impacts on the species diversity and productivity of this community.

Decreased winter rainfall will lower the viability of cropping in the region, with a potential change in agricultural management from cropping to grazing and the prospect of increased degradation of these ecosystems because of elevated grazing levels. An increase in summer rainfall and resulting increased grazing levels when plants are flowering will disadvantage palatable species that recruit from seasonal seed production, including eucalypts. At present, grazing regimes allow for only sporadic recruitment of canopy species in these fragmented ecosystems; an increased level of grazing will result in decreased tree recruitment and may eventually lead to die-off of the overstorey. This will result in the reduction of these productive (though degraded) ecosystems, first into highly modified, weedy, species-poor grassy woodlands and eventually into poor-condition, low-productivity secondary grasslands. Threatened flora species in this community, such as mountains Swainson-pea (*Swainsona recta*), are heavily affected by grazing, and as such they will be negatively affected by any increases in stocking levels.

Found in the more fertile areas of the landscape, the grassy woodlands have the potential to experience an increase in shrubbiness due to the predicted increased grazing of grasses and increased CO$_2$ concentration; however this effect may not be significant by 2050. Post-2050, this ecosystem is likely to see a decrease in species diversity, with reduced grass and forb coverage, causing changes in vegetation structure and plant species composition, with consequential reductions in productivity and resource availability for fauna.

Fire is not as much of an issue in the areas affected by grazing, owing to fuel reduction and high levels of habitat fragmentation and small remnant sizes, but it could have an impact in the reserves, which are larger areas without the ongoing
effects of heavy grazing. This will be contingent on potential increases in rates of
macropod grazing in these larger remnants, and on whether the increased grazing
will serve to reduce fuel loads in these woodlands. Any changes in fire regime will
have an effect on hollow formation, a process that provides an important source of
habitat in woodlands ecosystems, as will changes in storm intensity and frequency.

**Grassy woodlands – South Western region**

The impacts of climate change are likely to be displayed much sooner and to a much
greater extent in the grassy woodlands of the South Western region than in those of
the North Western region, because the former has lower overall annual moisture
availability and is projected to have substantially less precipitation over spring,
autumn and winter months. (The north-west woodlands should gain some reprieve
because of an expected large increase in summer rainfall.) The south-western
community is already less resilient owing to greater levels of fragmentation over
longer periods of time, resulting in more depauperate seedbanks and ensuing low
levels of recruitment. This will be compounded by the effects of climate change, with
significant changes in species composition and decreasing condition of the
community, as well as eventual severe decreases in geographic extent; these effects
may not necessarily be evident by 2050, but they will develop much faster than those
in the grassy woodlands of the North Western panel region. The distribution of this
ecosystem is currently limited to the west by low rainfall levels, implying a potential
shift to the east and south given the ability to do so (if not isolated because of
fragmentation). The lower resilience levels of this community in the South Western
region leave the community vulnerable to increasing levels of human disturbance as
well as natural disturbances such as increased frequency and intensity of storms and
fire, with the potential to push species, and perhaps entire communities, over the
edge. Degradation of the condition of these ecosystems will also lower their value as
refugia for western species during harder times, with negative impacts on more
western species.

**Major impacts**

**Major decrease** in winter rainfall and change in seasonality:

- changes in species composition—fewer winter-growing species:
  - increase in abundance of annual species and decrease in perennial species
  - increase in abundance of the more arid-adapted species
  - fewer winter weeds, e.g. ryegrass (*Lolium* spp.) and capeweed (*Arctotheca
calendula*)

- changes in agriculture from cropping to grazing:
  - increase in abundance of non-palatable species through overgrazing and
    summer grazing patterns
  - increased competition between native herbivores and stock
  - decreased eucalypt recruitment; die-off of canopy species
  - direct impacts on arboreal fauna habitat and food resources

- changes in flowering regime:
  - Earlier flowering has potential to favour timing of Swift Parrot migration –
    change from winter-flowering to autumn
potential for increased dieback:
  — increased patch deaths from insect attack on eucalypts because of increased stress from lack of moisture
  — increased levels of mistletoe infestation on stressed trees

Increased temperatures:

• invasion of areas by species currently limited by lower temperatures, e.g. Indian myna (*Acridotheres tristis*).

The change in seasonality of moisture availability will have wide-ranging impacts throughout the ecosystem, with impacts on plant species composition and resulting impacts on resource availability for fauna species. Summer-growing plants will be favoured over winter-growing plants because of increased summer rainfall, with corresponding reductions in the abundance of winter species, including winter grasses, which make up a large proportion of the ground cover, as well as forbs and herbs, which are adapted to the current winter rainfall regime. Species that are tolerant of drier conditions will be advantaged over those that depend on higher moisture levels. These changes in plant species composition will result in decreased productivity of these woodlands, with implications for resource availability for fauna.

Decreased winter rainfall will lower the viability of cropping in the region, with a potential change in agricultural management from cropping to grazing and the prospect of increased degradation of these ecosystems because of elevated grazing levels. An increase in summer rainfall and the resulting increased grazing levels when plants are flowering will disadvantage palatable species that recruit from seasonal seed production, including eucalypts, whereas the less palatable species will proliferate. At present, grazing regimes allow for only sporadic recruitment of canopy species in these ecosystems; an increased level of grazing will result in decreased tree recruitment and and may ultimately result in the die-off of the overstorey, with resulting impacts on all faunas in the system. There will be a direct impact on arboreal species such as squirrel gliders (*Petaurus norfolcensis*), because of a decrease in nesting habitat and food resource availability. This will result in the reduction of these productive (though degraded) ecosystems, first into highly modified, poor, grassy woodlands with an abundance of weedy species, and eventually into secondary grasslands of poor condition and low productivity. Grazing-tolerant perennials will potentially be favoured in the east of the region (areas of higher moisture availability). With increased stocking levels, transport and dispersal potential will be elevated for weeds such as spiny burrgrass (*Cenchrus incertus*). An invasive environmental weed, this species has the potential to displace native species already present. With a lack of grazing pressure, these ecosystems may be regenerated to woodlands with dry-tolerant species, though they may not necessarily be species-rich.

Changes in rainfall and temperature will influence the flowering of eucalypts, with the potential for asynchrony with the breeding patterns of fauna that utilise these resources—in particular, nomadic species such as the regent honeyeater and swift parrot. Of particular impact will be changes in the timing of flowering of currently winter-flowering eucalypts, which provide essential resources to many fauna species during periods of low resource availability.

Because of fuel reduction, high levels of habitat fragmentation and small remnant sizes, fire is not as much of an issue in the areas affected by grazing, but it could have an impact in reserves, which are larger areas without the ongoing effects of heavy grazing. This will be contingent upon potential increases in rates of macropod grazing in these larger remnants, and on whether these increases will serve to reduce fuel loads in these woodlands. Any changes in fire regime will have an effect.
on hollow formation, a process that provides an important source of habitat in woodlands ecosystems, as will changes in storm intensity and frequency.

Species that are currently limited by cold temperatures will be able to expand their range with increased minimum temperatures. The Indian myna is a predominantly subtropical species and as such will be suited to warmer temperatures. Although the species prefers wetter climates, it has been able to expand its range during drought periods and so will not necessarily be limited by lower rainfall levels. An increase in abundance of this highly competitive species will have serious implications for native hollow-nesting species such as parrots and arboreal mammals. This will be more of an issue in smaller remnants than larger ones.

**Dry sclerophyll forest (grassy and shrub/grass subformations combined) – North Western region**

The dry sclerophyll forests of the North Western region are primarily represented by the ‘Pilliga Scrub’, comprised of Western Slopes dry sclerophyll forests and Pilliga outwash dry sclerophyll forests. Although these two vegetation classes cover two separate subformations—the shrub/grass subformation and shrubby subformation—it was decided that the impacts of climate change on these forests were similar enough for the assessment to be done at the formation level. Changes in rainfall seasonality and fire regime will cause significant shifts in species composition and physical structure of the ecosystem, with predicted significant losses of hollow-dependent fauna because of loss of canopy trees. Increased temperatures will impact on organisms within these ecosystems, particularly those near the upper limit of their temperature threshold. Although the magnitude of the impacts is unknown, some losses in geographic extent due to western range retractions were predicted by 2050.

**Major impacts**

**Increased** summer rainfall, lower winter rainfall (change in seasonality):
- summer growth currently limited by lack of moisture
- change in species composition:
  - eucalypt recruitment favoured over cypress recruitment
- lower resource levels for winter- and spring-flowering eucalypts:
  - potential change in seasonality of budding/flowering/seeding time
  - resultant effects on availability of resources to nectivorous fauna; potential problems with asynchrony of breeding events with periods of resource availability
  - flow-on effect of insectivorous species, with lack of nectar for invertebrates
- effects on species biology and behaviour:
  - e.g. ornate burrowing frog (*Limnodynastes ornatus*): increased summer rainfall and intensity of events has the potential to affect emergence times of this (and other burrowing frog) species

**Increased** fire frequency and intensity in drier years:
- increased biomass from increased summer rainfall, leading to higher fuel loads
- decrease in abundance of hollow-bearing trees:
  - loss of nesting habitat for fauna
• shift in species composition:
  — combined with limited winter rainfall, could result in loss of *Casuarina/Allocasuarina* spp.
  — resultant effects on availability of resources to granivorous (seed-eating) fauna
  — increased potential for weed invasion

**Increased temperature:**
• faunal species may be exposed to temperatures higher than their physiological thermal limits:
  — remains to be seen: hotter in the west, but fauna may be better adapted to higher temperatures
  — nesting birds may be susceptible to number of extreme temperatures for days in a row
• species on the western edge of their ranges may exceed their thermal thresholds, and these species may contract in these parts of their ranges:
  — e.g. the Warrumbungles have a mix of eastern and western influences resulting in high diversity; there may be loss of diversity in these areas
  — increased rainfall may favour eastern species (tropical influence).

The understories of these communities are currently dominated by *Allocasuarina* species, which require above-average rainfall for recruitment to occur—in both autumn and winter for flowering and in spring for setting seed. Instead, the wetter summers and more burned environment predicted to occur as a result of climate change would favour eucalypt recruitment, with the potential to cause a major shift in species composition. This change in moisture availability will lead to a reduction in the amount of seed produced by *Allocasuarina* species in these forests. This could result in reduced resilience of these species within the community (less seed in the soil seed bank) and the potential for large disturbance events such as fire to wipe out entire stands of these trees, with no chance for regeneration. Decreased seed production due to lower rainfall levels also has effects on resource availability for granivorous fauna [e.g. threatened cockatoos and the Pilliga mouse (*Pseudomys pilligaensis*)]. There is also the possibility for *Allocasuarina* species to be lost entirely from the community, because more intense droughts and hotter temperatures may cause increased dieback; extreme events are already known to have severe effects (approximately 75% loss of *Allocasuarina* species in the 2002 drought).

Decreased winter rainfall and increased summer rainfall will also have wide-ranging effects on eucalypt species composition in these forests, as winter- and spring-flowering eucalypts will be heavily disadvantaged by this change in seasonality of moisture availability. This will have flow-on effects to fauna, with changes in seasonality of resource availability affecting the breeding patterns and recruitment of nectivorous and insectivorous species. In this already highly disturbed community, increased levels of summer rainfall will also increase the potential for invasion by weeds and pest species by creating a more tropical climate.

An overall increase in annual rainfall may lead to increases in surface water availability, as this area is a recharge zone for the Great Artesian Basin. Any increases in surface water availability will result in increased numbers of herbivores (goats, pigs, kangaroos) and consequentially increased levels of grazing in these forests. This surface water availability will depend entirely on rates of evaporation, which were unable to be predicted using the current climate models. There is also
the possibility of increased construction and maintenance of fire dams with increased rates of fire management.

Fire is a major ecological process in these communities. The potential exists for a change in fire regime, combined with past and present forestry practices in the region, to irreversibly alter the structure and composition of these forests. Selective logging over the last 50 years has resulted in stands of primarily cypress/bulloak forests, with all ironbarks removed for fence posts. With the predicted loss of Allocasuarina species because of decreased rainfall and increased temperatures, and with predicted increases in fire frequency and intensity with climate change, massive structural and species compositional changes are imminent, with the understory potentially becoming grassier or being replaced by more fire-resistant and arid-adapted species such as broom bush or wattles. Grassy flats have the potential to carry more fire than shrubby understories, adding to the natural disturbance regime another variation with the potential to change the structure and composition of this community. Previous extreme fire events have caused massive losses of hollow-bearing trees (90% to 95% over 25 000 ha), with a resultant loss of hollow-resources to hollow-dependent fauna [e.g. the greater long-eared bat (Nyctophilus timoriensis)] and massive structural changes to forests; once these old-growth trees are lost, because of their great age they are unlikely to ever be replaced. Increased management of land for fire control will lead to increased potential for weed invasion. Higher fire frequency is also likely to lead to sediment movement into drainage areas owing to increased rates of erosion of exposed soils. Some species may be favoured by increased fire frequency, with the recruitment of threatened plants such as Keith's zieria (Zieria ingramii) and Rulingia procumbens currently thought to be suppressed by lack of fire throughout these forests.

A reduction in the shrub layer and increased abundance of grasses in the shrub/grass subformation may also lead to increased grazing pressure in these areas. An opening of the shrubby understory will also favour predation by feral carnivores on already threatened species; for example, there may be increased pressure on malleefowl (Leipoa ocellata) populations. This species is also likely to be adversely affected by increased temperatures (see Sand plain mallee woodlands for more detailed discussion).

Looking beyond the next 40 years, the value of these areas as refugia may actually be increased because of increased summer rainfall and a more tropical climate, with species moving in from less favourable areas in the south and the west. This is likely to be contingent upon any potential changes in management regimes, with regeneration of these forests facilitated by reductions in forestry and grazing practices. However, the opposite may also occur: with current levels of degradation continuing into the future, combined with the added pressures of climate change, the potential of these areas as refugia may in fact be decreased.

Increased temperatures in the region may cause species to be exposed to temperatures higher than their physiological thermal limits, although further research needs to done to investigate the specificity of these effects. Species in the west of the range may be better adapted to higher temperatures, although relative increases may still push species beyond their physical capabilities (e.g. nesting birds are quite susceptible to a number of extreme temperature days in a row). Species on the western edge of their ranges may exceed their physical thresholds and lose their foothold, resulting in range retractions to the east. Areas of high diversity, such as the Warrumbungles National Park, are a mix of eastern and western influences, and range retractions from the west would likely result in losses of biodiversity to these forests.
Dry sclerophyll forest (grassy and shrub–grass subformations combined) – South Western region

(This discussion excludes the Southern Tablelands DSF, which was addressed by the Alps/Tablelands panel.)

The geographical extent of these forests is unlikely to decrease to a large degree in the next 40 years, but it will potentially experience range retractions post-2050. Already fairly fragmented because of their topographical location and through clearing for pastoral development, the dry sclerophyll forests of the South Western region—namely the Western Slopes and Upper Riverina dry sclerophyll forests—will not experience nearly as much decline as the grassy woodlands, but small-scale extinctions of the community may occur. This ecosystem is highly likely to experience patchy, in situ declines in viability as climatic conditions change. Changes to community structure and function and to species composition resulting from decreases in annual rainfall and changes in the seasonality of moisture availability are likely to cause an overall decline in species diversity.

Major impacts

Increased summer rainfall and much lower winter rainfall (change in seasonality):

- overall decrease in moisture availability:
  - level of resources will decline, leading to decreased productivity
  - there may be problems of latent degradation in this community
  - species that are more dry-tolerant will be favoured, as will summer-flowering plants
  - decreased shrubbiness of understorey may cause a change in habitat resources for fauna species
  - may favour noisy miners (*Manorina melanocephala*) and brown treecreepers (*Climacteris picumnus*)

- change in seasonality of resource availability:
  - effects on timing of migration of nomadic fauna.

This ecosystem occupies high topographic levels throughout the landscape of the South Western region and is therefore under less pressure from agriculture than are other ecosystems such as the grassy woodlands. However, the dry sclerophyll forests of the South Western region are much more highly fragmented than those of the North Western region and therefore have a reduced dispersal capacity. The higher topography also brings added pressure of lower moisture availability, a factor that will be compounded by reduced annual rainfall, resulting in a decline in productivity throughout the community and reduced importance of these areas as refuge for arid/semi-arid species.

The community is at risk from a lack of recognition of degradation. The effects of disturbance are latent throughout the ecosystem: e.g. conspicuous features of the community include stringybarks, which produce copious amounts of seed, providing food resources for species such as gang-gang cockatoos (*Callocephalon fimbriatum*). Low-intensity fire can decrease seed production of brown stringybark (*Eucalyptus baxteri*) for up to 10 years, with flow-on effects of reduced resource availability to fauna species. So while the community can look healthy and intact, with the trees appearing to be in good physical shape, the community's ecological functions can, in fact, be disrupted.

Dry sclerophyll forests are stepping stones in the landscape with respect to the movement of nomadic fauna species—especially those with North–South migrations.
Mugga ironbark (*Eucalyptus sideroxylon*) is known for its profuse flowering, which is relied upon by nomadic/migratory nectivorous species such as the swift parrot (*Lathamus discolor*). This ironbark is likely to be adversely affected by lower moisture availability, as well as by changes in seasonality. The potential also exists for synchronised failed flowering events in this ecosystem over different regions of the State with changing seasonality (e.g. in the mugga forest in the south-west and the swamp mahogany on the coast), with possible decreases in the abundance of mobile nectivores [e.g. swift parrots and little red flying-foxes (*Pteropus scapulatus*)] and eventual patch deaths of trees. Extended bottlenecks of resource availability are also likely to affect sedentary nectivores/insectivores, with generalist, dry-tolerant (semi-arid) fauna species favoured.

Levels of resources within these forests are likely to decline with higher levels of moisture stress, resulting in decreased productivity (lower levels of biomass) throughout the ecosystem. Decreased water availability will result in the loss of some *Acacia* species because of moisture stress, with consequential changes to understorey structure and function and fauna habitat. The opening of shrubby forests will serve to increase suitable habitat for the noisy miner, a competitive native honeyeater species. Other species, such as the brown treecreeper, prefer heterogeneous ground habitat and as such may also benefit from an opening of the understorey, provided that the current impacts of fragmentation are not too great. In general, however, the more aggressive, generalist species such as wattlebirds and friarbirds will be favoured over species that utilise more specialised resources.

The higher levels of fragmentation in these forests mean that fire is not as much of an issue as in the forests in the North Western region. Moreover, in the South Western region, fire management by private landholders has reduced the levels of biomass accumulation, and hazard reduction burns are more common.

**Semi-arid woodlands (grassy subformation) – North Western region**

These ecosystems consist of primarily coolabah – black box woodlands of the Darling floodplain, with some brigalow–gidgee woodland. They are highly fragmented in the North Western region and exist primarily as small fragments in varying states of degradation, found almost entirely on pastoral land. They remain intact in some areas but exhibit a highly disturbed understorey because of the effects of grazing by stock and goats (both domestic and feral), although some larger areas of woodland are protected in reserves west of Walgett. Predicted changes in climate will serve to increase pressure on this ecosystem in the future, with higher pressure from agriculture and river regulation having direct impacts on vegetation structure and species composition. Some changes in the structure and composition of both brigalow clay woodlands and floodplain woodlands are expected with the projected effects of climate change. However, human land management of these woodlands (notably grazing and water regulation/dam expansion) is the most important factor influencing the potential increase or decrease in condition of this community.

Increased grazing pressure may affect the composition and function of the community, with the magnitude of degradation of the community entirely dependent on management strategies, especially in the brigalow-gidgee woodlands; grazing will restrict the dispersal capacity of this latter class to virtually nil. The brigalow woodlands are already declining, and ongoing management practices are likely to have more of an impact than climate change on the condition of these woodlands. The prospective geographic range of floodplain woodlands is expected to be increased, as within their existing range these woodlands may have the potential to expand into grasslands. These potential increases are likely to be offset, however, by water regulation and potential increases in agriculture. They may not be observed.
within the 2050 time frame, although the southern extent is predicted to decline earlier because of its drier conditions.

**Major impacts**

**Change** in moisture availability and seasonality (increased summer rainfall; decreased winter rainfall), with an overall slight increase in annual rainfall:

- potential increase in agricultural pressure and river regulation
- increased severity of drought (unsure of frequency):
  - growth in this ecosystem follows rainfall pulses
- decreased photosynthetic capability of lichens in soil crusts, resulting from increased temperatures:
  - reduced nitrogen fixation
- post-flood colonisers favoured by increased summer rainfall
- change in understorey structure, with a shift from a grassy understorey
- increased humidity may decrease the effects of calicivirus
- wetter summers may increase the potential for locust plagues
- summer-growing species may be favoured over winter-growing ones
- possible increase in fire frequency

**Increased** temperatures:

- herpetofauna potentially favoured
- birds may reach the edge of their physiological limits [e.g. red-tailed black cockatoos (*Calyptorhynchus banksii*)]
- potential for frost-sensitive species to increase in abundance [e.g. cane toads (*Bufo marinus*)]
- increased importance as refugia for more northerly distributed species
- survivorship of species that germinate after summer rain may be reduced because of higher summer temperatures

**Increased CO₂** levels:

- C4 grasses are quite sensitive to grazing; also threatened herb species.

The boom and bust cycle of the semi-arid climate is the foremost ecological factor driving this community, with its distribution primarily concentrated on the floodplains of the Darling River. This community is already highly modified by river regulation, and the trend is expected to continue under the predicted changes in climate, with a potential expansion of agriculture (cotton farming) predicted in the region because of increased water availability. The natural cycle of flood and drought is likely to be exaggerated if agriculture increases in the area, with the higher stock and cropping levels reached in times of good rainfall unable to be supported during times of drought (drought years being significantly hotter as well under predicted climate change), with resulting consequences for drought relief.

Regeneration of this community is likely to be hindered by the increased impacts of grazing by goats and native herbivores such as kangaroos. With habitat suitability greatly improved by increased surface water levels there may be a shift in agriculture to goat farming. Increased grazing levels will lead to a reduction in the abundance of palatable ground species and a reduction in the regeneration of palatable overstorey
species, as well as degradation in soil condition. Shifts in grass species composition from winter-growing C3 grasses to summer-growing C4 grasses are expected with changes in seasonal moisture availability and increased temperatures; these C4 grasses are quite susceptible to overgrazing and may suffer if stocking levels are increased. Ground-foraging native fauna (e.g. parrots, quails, pigeons, finches, curlews, mammals) are expected to be negatively affected by increased physical disturbance around water sources by grazing herbivores, with a reduction in resource availability.

Resources will temporarily increase with the increase in water availability (provided that the water is not dammed or extracted upstream), but this increase is likely to be counterbalanced by increases in grazing pressure, which may not be as evident within reserves. Large differences in condition exist between woodlands within reserves and those elsewhere, and the importance of reserves as areas of refugia will be greatly increased if grazing by macropods and goats is controlled.

The brigalow-gidgee woodlands (an Endangered Ecological Community) are located on higher topography in the landscape and as such will be less affected by increased surface water availability. This community relies more on local rainfall to regenerate, rather on than floodwater pulses; therefore, it will have a reduced potential for regeneration when compared with the floodplain woodlands. Local rainfall will be increased in summer but will occur more often as storm events, with water retained only for short periods of time in this community. The extent of these woodlands is not expected to increase, despite increased surface water availability, because of the woodlands' differential response to rainfall when compared with the floodplain woodlands. A lack of control of feral goat populations will result in surges in population numbers, especially in the brigalow-gidgee woodland because of its habitat suitability. These woodlands are already heavily affected by high levels of grazing, with resulting senescent vegetation and low levels of recruitment. This has implications for the painted honeyeater (Grantiella picta), which is a specialist consumer of the fruits and seeds of mistletoes growing on the trees of these woodlands and is likely to be negatively affected by the loss of overstorey trees.

Species that colonise the floodplain woodlands with post-flood disturbance are likely to persist for longer periods because of increased summer rainfall, with the potential for thick regeneration of small herbs and grasses with improved survivorship in good years. This environment will favour granivorous fauna such as finches and rodents because of the greater abundance of grasses; it will also provide more favourable habitat for fauna such as termites and burrowing frogs. This growth will be primarily regulated, however, by changes in grazing levels.

An increase in the amounts of water moving through the landscape will lead to increased dispersal potential for exotic species and tropical weeds such as lippia (Phyla canescens), mimosa bush (Vachellia farnesiana) and Noogoora burr (Xanthium occidentale), the latter two being thicket-forming and dispersed by herbivores. With increased surface water levels during flood periods and increases in maximum temperatures over winter, the potential exists for colonisation of these floodplains by cane toads, considering the fact that they already inhabit these woodlands farther north in Queensland.

Increased nectar yields are predicted with increased rainfall levels, depending on the timing of the increased falls. This has the potential to increase activity by apiarists and the ensuing removal of resources from nectarivorous species. Apiary sites presently exist within OEH reserves in these communities in the region.

Soil crusts occupy 70% of the ground cover in the arid zone. Increased moisture availability, combined with predicted temperature increases in the region, will decrease the photosynthetic capabilities of the cyanobacteria contained within
biological soil crusts, reducing the occurrence of these bacteria in the ground layer. The loss of these crusts will result in decreased levels of nitrogen fixation occurring in the soil, which will elevate the importance of nitrogen-fixing plants, including grasses, palatable forbs and peas; these plants however, are already at increased risk through predicted increases in the levels of grazing. Decreased nitrogen levels in the soil will have unknown but potentially dramatic effects on soil food webs, further degrading these communities. The loss of soil crusts will also potentially destabilise the soil and increase rates of erosion, as well as affecting the habitat of burrowing fauna such as dunnarts, lizards, frogs and termites.

Wetter summers are also likely to increase the biomass of summer-growing plants such as button grass (*Dactyloctenium radulans*), increasing the susceptibility of these areas to locust plagues. Locust plagues reduce the availability of resources to other herbivorous species within the community, and although insectivorous species are advantaged in the short term by an increase in prey numbers, use of chemicals to control locusts may cause inadvertent fauna deaths because of the non-specificity of such chemicals and their bioaccumulation throughout the food chain.

Fires could be an issue on reserves with increased fuel loads because of increased rainfall levels. Increased moisture availability in wet years is likely to decrease the chance of ignition; however, more frequent storm events and increased temperatures during drier times could lead to an increased frequency of fires. As fire has not been an ecosystem process in the past in some of these woodlands, it may cause fundamental changes to the structure of the vegetation, with resultant effects on resource and habitat availability to fauna. Predicted increased grazing pressure outside reserves may serve to decrease the fuel load; there is potential for this to occur within reserves, too, if feral goat populations are not properly controlled.

**Semi-arid woodlands (grassy subformation) – South Western region**

Climate change is likely to exacerbate the current degradation and decline of this ecosystem in the South Western region, especially during times of high stress. The inland floodplain (black box) woodlands are already under significant levels of moisture stress, with little water availability from local rain, stream flow and farm runoff and increasing pressure of groundwater extraction and water harvesting. These changes have already contributed to the extinction of southern bell frog (*Litoria raniformis*) populations in the region (e.g. in barren box swamp). The regeneration of black box and riverine plain (boree) woodlands is also suppressed by the current grazing regimes, with these impacts predicted to continue or increase with lower levels of annual rainfall throughout the region. Major changes in these ecosystems are predicted, as upper level floodplain woodlands are likely to be lost entirely without active management to provide environmental water flows into their depressions. Most of the overall structure and composition of these woodlands is predicted to change with the modelled changes in climate, with large reductions in water availability compounding the already degraded state of these woodlands. Large losses of biodiversity and geographic extent are expected.

**Major impacts**

**Reduced** water availability (overall decrease in annual rainfall):
- increased pressure for water harvesting for agricultural and urban use
- general decrease in ecosystem condition and species diversity:
  - reduced germination rates and fewer flowering events
  - decreased abundance of winter-growing plants
change in species composition towards shrubbier, summer-growing, better arid-adapted plant species
- decreased resources for fauna

- increased requirement for drought fodder in boree woodlands:
  - continued or increased grazing suppression of regeneration
  - decreased food resources for painted honeyeaters and superb parrots (*Polytelis swainsoni*).

The regeneration opportunities of the floodplain woodlands have been significantly decreased by existing water stress caused by reduced local rainfall levels and decreases in river flows as a result of water extraction for agricultural purposes. Watertable levels have also been lowered because of increased groundwater extraction. As moisture availability in this region decreases with the effects of climate change, the pressures on water harvesting are only likely to increase, further increasing moisture stress on these woodlands and resulting in considerable reductions in ecosystem condition and species diversity. The Darling River may have flooding potential with increased rainfall to the north, and woodlands along this river may therefore not be under as much pressure as those along the southern rivers, provided that management ensures that sufficient environmental water flows reach these communities.

A general decrease in species diversity is predicted, with decreased levels of winter rainfall reducing the amounts of resources available overall throughout the ecosystem. This is likely to be manifested through reduced spring germination rates of palatable annual plants, as well as lowered levels of foliar nutrients and decreased tree flowering events. Perennial forbs are also winter growing and will be greatly affected by the lack of rain, as will winter-growing weeds [e.g. rye grass (*Lolium* spp.) and barley grass (*Hordeum leporinum*)]. Geophytic species such as lilies, irises and orchids (e.g. *Pterostylis* species) will be heavily disadvantaged, requiring winter rains for shooting; although they possess underground storage organs there is a limit to the length of time they can survive without rain. Summer-growing grasses and weeds [e.g. African boxthorn (*Lycium ferocissimum*)] may be advantaged in wetter years. A general shift in species composition towards opportunistic, less-palatable species (e.g. saltbush, cotton bush) is expected, with these plants able to tolerate tougher growing conditions, including drier winters. All of these changes in vegetation will have wide-ranging consequences on resource availability for fauna.

Structurally, black box (*Eucalyptus largiflorens*) and river red gum (*Eucalyptus camaldulensis*) populations are currently senescing at an increased rate, showing signs of dieback from increased water stress and resultant insect and mistletoe infestations, as well as being affected by salinity issues, firewood collection and potential problems with acid-sulfate soils. It is highly likely that these woodlands, under additional climate change stresses, will undergo major structural changes due to a loss of canopy trees, with ensuing loss of habitat resources for hollow-nesting species (e.g. bats, gliders, cockatoos, owls) and loss of food resources for nectivores and insectivores (e.g. swift parrot, superb parrot, painted honeyeater). These changes in habitat will also have major consequences for fauna species composition in this community, with a predicted shift towards more arid-adapted species (e.g. the saltbush morethia skink (*Morethia adelaidei*) would be favoured over the south-eastern morethia skink (*Morethia boulengeri*)) or species preferring more open habitats (e.g. *Mormopterus* species bats over *Vespadelus* species).

Moisture-dependent fauna such as frogs will be significantly affected, with species such as burrowing frogs (e.g. the giant banjo frog, *Limnodynastes interioris*) requiring significant rainfall events for breeding to occur. Some burrowing frog species are
tolerant to dry periods and are opportunistic breeders; these are less likely to be sensitive to the shift to summer rainfall. However, other species, such as the painted burrowing frog (Neobatrachus sudelli), are winter breeders and may experience reduced breeding opportunities and undergo local extinctions. Although rates of metamorphosis are faster in summer because of higher temperatures, high evaporation rates may reduce the hydroperiods of rain-fed wetlands to an extent where mass mortalities of tadpoles are more common. Reductions in flooding frequency as a result of flow regulation have already contributed to reduced diversity of frog communities and local extinctions of flooding-dependent species such as the southern bell frog and the green tree frog (Litoria caerulea). The predicted decreases in flooding frequency owing to the effects of climate change are likely to compound these declines.

A number of threatened flora species [e.g. slender Darling pea (Swainsona murrayana)] are supported by these woodlands in the South Western region. These species are likely to be significantly disadvantaged by decreases in resource abundance throughout the community and by increased pressure from grazing. Other non-threatened species, such as ruby saltbush (Enchylaena tomentosa), will also be negatively affected. Relying on perching birds for seed dispersal, this species is likely to decline with predicted changes in bird species composition owing to overall reductions in resource abundance. The boree woodlands are likely to experience an increase in pressure for drought fodder for livestock with reductions in rainfall; this will reduce the abundance of food resources available to threatened fauna species such as painted honeyeaters and superb parrots.

These semi-arid woodlands may gradually shift their range to the east, potentially replacing grasslands. The riverine plain (boree) woodlands are likely to contract from the west because of increased levels of moisture stress, but they are restricted in geographic range by edaphic factors. Decreases in the geographic extent of this system may be offset by increases in the distribution of shrubby semi-arid woodlands; the winter grasses disadvantaged by changing seasonality will be replaced by arid-adapted species such as dillon bush (Nitraria billardierei), cotton bush (Maireana aphylla) and copperburrs (Sclerolaena spp.). These woodlands are eventually expected to be replaced by highly degraded, species-poor chenopod shrublands, with shrubbier areas and loss of ground debris detrimental to specialist species such as the bush stone-curlew (Burhinus grallarius). Remnant sites are likely to remain, perhaps more so in the far east of the geographic range.

**Semi-arid woodlands (shrubby subformation) – North Western and South Western regions**

This formation was broken down into its component vegetation classes as ecological boundaries for discussion, as it was decided that the landscape, vegetation, and fauna were too disparate to allow for accurate comparison across the entire formation. Different classes were anticipated to experience different impacts and were therefore discussed at the class level, with some not separated by regional boundaries, as the impacts were predicted to be primarily the same between the North Western and South Western regions. Desert woodlands have been discussed with the mulga shrublands as part of the Arid shrublands (Acacia subformation). An overview of each class considered within this formation is provided below, followed by a synthesis of the major impacts across the entire formation and a subsequent breakdown of the details that these impacts will have on each of the classes.

The western peneplain and inland rocky hill woodlands have suffered heavy clearing in the past for agricultural purposes. The combination of overgrazing and partial land clearing for cropping has already led to increased incidences of erosion and scalding throughout this community, as well as the proliferation of unpalatable
shrubs (‘woody weeds’). In addition to this, these woodlands are currently being further degraded by continuing drought conditions, with loss of tree species occurring throughout the region. Increasing aridity, especially in the southern parts of the distribution of these woodlands, will play a major role in both species composition and structure, with decreased moisture levels predicted to open the canopy, providing less shelter, with potential conversion to shrublands in some areas. Ultimately, however, the severity of predicted climate change impacts will depend upon changes in the interplay between fire regime and changing land use practices, which are unable to be predicted at this time. These communities are defined primarily by edaphic factors, with the woodlands inhabiting these areas more likely to undergo in situ changes in response to climate change, rather than shifts in distribution.

The semi-arid sand plains (belah–rosewood) woodlands are unlikely to persist as they are currently known, existing primarily in large remnants of senescent, poor-quality woodland. This ecosystem is already heavily degraded by the impacts of overgrazing and extended drought conditions, and with recruitment and regeneration heavily suppressed, the effects of climate change—notably decreased winter rainfall—will lead to further losses of productivity. This community is unlikely to shift in geographic range owing to edaphic restrictions on its constituent vegetation; it is expected to experience continual decline in geographic extent and in general condition—perhaps not to extinction level within the 2050 time frame, but potentially beyond it. The persistence of these woodlands depends entirely on the removal of grazing to give them the potential to remain in remnants.

The sand plain mallee woodlands are currently highly fragmented and degraded because of extensive land clearing and grazing. Loss of the grassy understorey and associated fauna is predicted to occur with decreased winter rainfall, with a consequential trend towards lower productivity and extensive simplification of the ecosystem. This will also result in changes in fire regime, with changes in structure and function evident throughout the ecosystem and resulting small losses in geographical extent.

The dune mallee woodlands are already heavily affected by grazing throughout their distribution, with ongoing grazing by goats affecting the structure and composition of this ecosystem by the suppression of mallee regeneration and the increased prevalence of unpalatable plants. Hotter, drier conditions and increased fire risk are likely to amplify these sources of disturbance; additional reductions in productivity and simplification of overall diversity will cause changes to a large proportion of the structure and composition of this ecosystem, with ensuing losses of geographic extent predicted to occur. High levels of fragmentation of remaining woodlands are likely to exacerbate these impacts. Increases in pressure from agricultural practices, similar to those in other mallee communities, are likely to be experienced, with changes in land use practices (in conjunction with changes in fire regime) having the potential to influence the eventual condition of these woodlands.

The riverine sandhill woodlands have experienced previous heavy clearing to supply wood for farm infrastructure and for wheat cropping areas. Regeneration opportunities for this community are highly limited because of the effects of current grazing by domestic livestock and rabbits. The increased drought severity due to climate change and continued effects of grazing are likely to exacerbate the decline in quality of these woodlands, with conditions unlikely to allow the community to regenerate. As a consequence, these ecosystems are unlikely to persist as they are currently known; instead, they are likely to be replaced by species-poor, weedy grasslands, or alternatively reduced to nothing more than the sandhills they currently occupy. A great deal of intervention, including the removal of grazing, is required for
the continued survival of this community by allowing potential recruitment in the overstorey given the opportunity for resource (water) availability.

The **subtropical semi-arid woodlands** in the North Western region are unlikely to experience the severity of climate-change related impacts that will be suffered by other classes within this formation, as they are at the southern extremity of their distribution in this region and may actually persist where the northern woodlands retract. Because of the infertility of the soils, increased summer rainfall is unlikely to influence grazing practices in a major way. Because the woodlands are already well adapted to fire, it is doubtful whether increases in fire frequency will have any major impacts on their species composition or structure.

The naturally restricted range of the **north-west alluvial sand woodlands** has been greatly reduced by land clearing, most of it occurring relatively recently. Predicted changes in climate will serve to increase pressure on this ecosystem in the future, with higher pressure from agriculture and river regulation having direct impacts on vegetation structure and species composition. Some changes in structure and composition are expected with the projected effects of climate change. However, human land management of these woodlands (notably grazing and water regulation/dam expansion) is the most important factor influencing the potential increase or decrease in condition of this community.

*Major impacts – formation-wide*

**Change** in moisture availability and seasonality (increased summer rainfall; decreased winter rainfall), with an overall increase in annual rainfall in northern regions and an overall slight decrease in annual rainfall in southern regions:

- potential for summer-growing species to be favoured over winter-growing species
- change in agricultural pressure, with increased pressure from grazing (most areas) and cropping (some areas):
  - change in understorey structure (increased shrubbiness)
  - problems with woody weeds
- combined with higher temperatures, the moisture changes will increase the severity of drought (unsure of frequency):
  - lack of recruitment of species requiring good rainfall
- increased productivity in northern areas
- decreased productivity in southern areas
- increased fire frequency and intensity (depending on grazing practices)
- decreased photosynthetic capability of lichens in soil crusts as a result of increased temperatures:
  - reduced nitrogen fixation
- wetter summers, increasing the frequency of locust plagues in grassy areas

**Higher** temperatures:

- herpetofauna potentially favoured
- physiological limits may be reached (e.g. for cockatoos, or for flowering and seeding of eucalypts)
- potential for frost-sensitive species to increase in abundance
- increase as refugia for more northerly distributed species
• survivorship of species that germinate after summer rain may be reduced because of higher summer temperatures

**Increased CO₂ levels:**

• C4 are grasses quite sensitive to grazing; also threatened herb species.

**Western peneplain woodlands and inland rocky hill woodlands (North Western region)**

These woodlands are at present already degraded by continuing drought conditions, with the loss of some tree species throughout areas of these woodlands observed as patch deaths of grey box (*Eucalyptus microcarpa*), bimble box (*Eucalyptus populnea* subsp. *bimbil*) and mid-ridge cypress trees. Along rocky ridges in the landscape, tree mortality rates of up to 85% have been observed and attributed to moisture stress. These communities span a gradient of changing rainfall patterns, with conditions under climate change predicted to be a lot drier in the south than will be experienced by woodlands in the north; as such, the impacts are likely to vary depending on geographic location. Changes in structure and composition are likely to occur in mosaics across the landscape, depending on the relief and topography, as well as on changes in grazing pressure and differential changes in rainfall and fire potential. The inland rocky hills woodlands occupy higher topography throughout the landscape and will therefore be subject to higher temperatures and increased moisture stress when compared with woodlands in the lower-lying areas.

Increased summer rainfall in the northern parts of the distribution of this community (e.g. to the north of Nyngan) may enhance the viability of cropping in the area and increase pressure for land clearing. Higher productivity throughout the ecosystem would also increase grazing pressure, with predicted increases in levels of goat and sheep farming. The combination of partial land clearing for cropping and overgrazing has already led to increased incidences of erosion and scalding throughout this community, as well as the proliferation of unpalatable shrubs (‘woody weeds’). Further rises in these practices would only serve to elevate the negative impacts of these disturbances, with consequences for the plant species composition and structure of these woodlands and flow-on effects on resource availability to fauna.

Northern occurrences of this community are also predicted to experience the same losses in soil crusts as the grassy subformation, with increased rainfall levels further increasing the risk of higher rates of erosion.

Areas experiencing higher annual rainfall in the north will experience increases in biomass production and accumulation; coupled with higher temperatures and more extreme drought conditions, this may serve to increase the fire risk in these areas. These effects may be tempered by increased grazing pressure on the ground, reducing fuel loads present in the community. In years of good rainfall, however, with increased productivity and grass growth, grass abundance may increase enough to sustain fire and increase the possibility of large, intense fires. Increased fire frequency would have negative impacts on cypress populations, with these trees requiring fairly long inter-fire periods for recruitment. It will also have negative implications for hollow-bearing trees, with the potential to destroy nesting/roosting resources for fauna species such as pink cockatoos (*Cacatua leadbeateri*). Loss of ground debris because of fire would remove habitat characteristics required by specialist species such as the bush stone-curlew and the kultarr (*Antechinomys laniger*), which are already heavily affected by continuing degradation of the ground layer by grazing. Fire is currently suppressed in these woodlands by the increased presence of more woody plants than were originally present in this ecosystem, with thick patches of growth occurring after germination events preventing the growth of grasses and decreasing fuel loads. As such, changes in the fire regime would lead to
marked alterations in the structure and species composition of these woodlands over the long term.

Winter-growing grasses, including speargrass, are important components of the ground layer of the peneplain and rocky hill woodlands in the southern parts of their range. Decreased winter rainfall in these southern areas would result in less growth of these species, reducing the fuel load able to carry fire. Lower annual rainfall would also increase the mortality of woody plants in these woodlands; combined with the loss of winter-growing plants, the effects of climate change are predicted to have marked impacts on the structure and composition of vegetation throughout this community, with flow-on effects on resource availability to fauna.

There are a number of flora species in this community already threatened by inappropriate fire regimes, overgrazing and land clearing. They include the coolabah bertya (*Bertya opponens*), the greenhood orchid (*Pterostylis cobarensis*) and the endangered fern, *Cheilanthes sieberi* subsp. *pseudovellea*. Increased moisture stress in drought years and the increased temperatures predicted as a result of climate change, as well as potential increases in fire frequency and changes in land use patterns, are likely to compound the vulnerability of these species, with the potential to decrease population numbers even further. Other species, such as the curly-bark wattle (*Acacia curranii*), are suffering from lack of fire throughout the system, because they require fire disturbance for suckering and seed establishment. An increase in fire frequency may favour this species, although inter-fire intervals that are too short may also be detrimental to recruitment.

Higher temperatures throughout the semi-arid zone are likely to have impacts on both flora and fauna, although the extent to which this may occur is unknown. Thermal limits exist in organisms beyond which normal physiological functions—such as reproduction and behaviour—may be impaired. The recruitment of species already on the western edge of their distributions (e.g. bimble box) may be adversely affected by increased temperatures, with potential changes in germination and establishment, as well as seed-setting and flowering. The potential effects of increased temperature on the organisms comprising these ecosystems, although unquantifiable, should not be discounted.

**Semi-arid sand plain woodlands (North Western and South Western regions)**

The Belah–Rosewood woodlands have already been heavily degraded by the impact of overgrazing and extended drought conditions. Both of these sources of disturbance have prevented sufficient regeneration of this community, which is unlikely to shift in geographic range owing to the edaphic restrictions on its constituent vegetation. This ecosystem is unlikely to persist as it is currently known, existing primarily in large remnants of senescent, poor-quality woodland. Die-offs of mature rosewood (*Alectryon oleifolius*) shrubs have already been observed, and with the recruitment of both this and belah (*Casuarina pauper*) suppressed by grazing by sheep and goats, these woodlands are likely to be replaced by chenopod shrublands containing unpalatable plants such as cannonball burr (*Dissoecarpus paradoxus*), cassias (*Senna* spp.) and hop-bushes (*Dodonaea* spp.), and other hardy shrubs. This will likely decrease the abundance of ground litter, with predicted increases in cryptogamic ground cover in its place. This is a disadvantage to threatened fauna species, such as the narrow-banded shovel-nosed snake (*Simoselaps fasciolatus*) and yellow-tailed plains slider (*Lerista xanthura*), that rely on litter for cover and food. These changes in the structure and species composition of this community will have marked impacts on the resident fauna utilising the resources of these woodlands. Species such as pink cockatoos nest in hollows in belah, whereas white-browed treecreepers (*Climacteris affinis*) are virtually restricted to this community in the west. Decreases in winter rainfall due to climate change are likely to cause further
decreases in productivity of the ground cover. The reduced abundance of winter-growing grasses and forbs will reduce the availability of resources for herbivorous and granivorous species and will affect insect abundance and species composition. A loss of termites would have marked impacts on insectivorous fauna, as well as on decomposition and nutrient cycling throughout the ecosystem. As such, it seems that the effects of climate change will serve to exacerbate the current decline in condition of the belah–rosewood woodlands.

**Sand plain mallee woodlands (North Western and South Western regions)**

Decreased winter rainfall will disadvantage winter-growing plants, including grasses such as speargrasses (*Aristida* spp.), forbs and subshrubs, as well as weeds [e.g. Ward’s weed (*Carrichtera annua*)]. The more resilient perennial species are likely to be favoured, with species such as saltbushes (*Rhagodia* spp.), daisy-bushes (*Olearia* spp.), cassias and cannonball burr likely to replace annuals, creating major changes in the species composition and structure of these woodlands. This will serve to decrease the species diversity of the community, with increased shrubbiness and decreased abundance of grasses in the understorey. This sparse ground cover is also less likely to carry fire, which would generally stimulate the emergence of a more diverse understorey. Some introduced species will be advantaged by a change in seasonality, with increased summer rainfall favouring some such as vervain (*Salvia verbenaca*), whereas others (e.g. medics, *Medicago* spp.) will be disadvantaged by the decrease in winter rainfall.

With this community already highly fragmented and degraded because of extensive landclearing and grazing, a trend towards lower productivity is predicted due to the loss of the grassy understorey and associated fauna, thus greatly simplifying the ecosystem. Tree and shrub cover will remain, but the changes in ground cover will have major impacts on reptile diversity because of changes in soil structure and resource availability. These latter factors will decrease the prevalence of termites, which are a major food resource for herpetofauna, including sand monitors (*Varanus gouldii*), geckos (e.g. *Diplodactylus* spp.) and skinks (e.g. *Ctenotus* spp., *Lerista* spp.), and other ground insectivores (and their associated predators). They will also affect decomposition and nutrient cycling throughout the ecosystem.

The endangered malleefowl will also be negatively affected by climate change, with the effects of lower levels of winter rainfall and moisture content on recruitment persisting for years beyond any good rainfall years. Certain moisture levels are required for the decomposition of leaf litter in mounds created by this species for heat production and egg incubation. Egg development may also be affected by increased ambient temperatures, with birds potentially spending less time tending their mounds because of the higher temperatures.

**Dune mallee woodlands (North Western and South Western regions)**

Hotter and drier conditions throughout the distribution of these spinifex-dominated woodlands, as well as increased storm frequency in summer, will increase fire risk throughout this community. This is likely to result in increased frequency of wildfires or hazard reduction burns, the latter being common land management tools for preventing large wildfires. In years of good rainfall, early successional species should be favoured by the increased frequency of fires. However, species requiring fairly long periods between fires will be at a significant disadvantage. This covers a large range of threatened fauna, including bats (e.g. greater long-eared bat), birds (e.g. southern scrub-robin (*Drymodes brunneopygia*), black-eared miner (*Manorina melanotis*), malleefowl), reptiles (e.g. jewelled gecko (*Strophurus elderi*), mallee blue-tongue lizard (*Cyclodomorphus melanops elongates*)) and mammals (e.g. southern ningau (*Ningaui yvonnae*)). This community is generally quite resilient to fire, as it is

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already a major driver of ecosystem processes and contains quite a few threatened plant species that require fire to regenerate [e.g. yellow swainson-pea (Swainsona pyrophila), narrow wattle (Acacia acanthoclada)]. Although short inter-fire intervals may advantage fire-ephemeral species such as spinifex (Triodia spp.), toothed Rasptwort (Haloragis odontocarpa), rough halgania (Halgania cyanea) and native poplar (Codonocarpus cotinifolius), they may cause extensive death of mallees, which regenerate from lignotubers, and cypress trees, which take a long time to accumulate their seed banks. The lignotubers, or underground storage organs, of mallee species are likely to be under increased stress from lower moisture levels. This, coupled with a number of fires in quick succession, will mean that these trees will have a decreased ability to regenerate, given insufficient time to restock their resources. Fire frequency will thus affect the structure and composition of this community, with species adapted to early succession favoured over secondary and longer successional species.

Decreases in overall annual rainfall throughout the areas occupied by these woodlands will see a loss of productivity in this community, with decreased ground cover of ephemeral tussock grasses and herbs, less flowering and seeding of spinifex, eucalypts and shrubs, and replacement of winter-breeding annuals with hardier, summer-growing perennial plants. This will have flow-on effects on resource availability for fauna species. The reduction in the abundance of flowering events will reduce nectar availability to insects and nectivorous bird species such as purple lorikeets (Glossopsitta porphyrocephala), and yellow-plumed (Lichenostomus ornatus), white-fronted (Phylidonyris albigans) and grey-fronted (Lichenostomus plumulus) honeyeaters.

Increases in pressure from agricultural practices, similar those pressures on other mallee communities, are likely to be experienced, with changes in land use practices (in conjunction with changes in fire regime) having the potential to influence the eventual condition of these woodlands. Much of the mallee is grazed by goats, sheep and rabbits, affecting the flora by the preferential removal of palatable grasses and seedlings of perennial plants, encouraging the growth of less-palatable species. The changes elicited by climate change will serve to compound the effects of these sources of disturbance.

Riverine sandhill woodlands (North Western and South Western regions)

This community has experienced previous heavy clearing to supply wood for farm infrastructure and for wheat cropping areas. This clearing, combined with the effects of current grazing by domestic livestock and rabbits, means that regeneration opportunities for this community are highly limited. Regeneration of white cypress pine (Callitris glaucophylla) in the overstorey generally occurs during wet years in association with La Niña periods, the occurrence of which have been limited recently. The effects of grazing, as well as competition with Mediterranean weeds such as barley grass and Paterson’s curse, have meant that this ecosystem has become highly degraded. It has therefore been listed as an Endangered Ecological Community. Few resources remain for native species. In the past such resources would have represented quality habitat for woodlands birds such as speckled warblers (Pyrhrholaemus saggitatus), but they have now have been invaded and taken over by unpalatable, weedy species such as African boxthorn.

The effects of climate change are likely to exacerbate the decline in quality of these woodlands, particularly if the interval between La Niña periods increases (although there is a large degree of uncertainty surrounding El Nino-Southern Oscillation patterns), along with the severity of drought, because of increases in temperature. Continued grazing is unlikely to allow the community to regenerate. As a consequence, these ecosystems are unlikely to persist as they are currently known.
Instead, they are likely to be replaced by species-poor, weedy grasslands, or alternatively reduced to nothing more than the sandhills the woodlands currently occupy. Decreased vegetative cover is likely to result in the erosion of these sandhills, which may fill nearby depressions. Examples of these woodlands used to occur around the Broken Hill district, but because of timber removal and subsequent grazing of the sites no evidence of them remains on the ground. These sandhills also have high cultural heritage value, historically having been used by indigenous people as burial sites. This community is already severely degraded, and the effects of climate change will further intensify its degradation. With maximum intervention it is likely to persist only in small areas.

**Subtropical semi-arid woodlands (North Western region)**

These woodlands are likely to experience impacts in the North Western region similar to those of the brigalow–gidgee woodlands (semi-arid woodlands – grassy subformation), although they are not currently as degraded. Situated on higher topography throughout the landscape, these woodlands are non-riverine and uninfluenced by floodplain dynamics. The soils supporting this ecosystem are not fertile enough to sustain cropping practices. Thus any increase in agricultural pressure will be likely to come from grazing, although this is likely be only minor because of the relative infertility of the soils. This community may not be as adversely affected by increased fire risk as the brigalow woodlands, as fire is already a major ecological process in this highly fire-prone system. The extent of this ecosystem in the North Western region represents the southern extremity of a primarily Queensland–based distribution; it is therefore likely that these woodlands will not be as negatively affected in this area as they may be in the more northern reaches of their distribution.

**North-west alluvial sand woodlands (North Western region)**

High levels of relatively recent land clearing have reduced the already restricted distribution of these woodlands even further, leading to the listing of carbeen open forest as an Endangered Ecological Community. This community is predicted to encounter the same issues as coolibah – black box (semi-arid woodlands – grassy subformation), with predicted changes in climate increasing pressure on the ecosystem in the future. Higher pressure from agriculture and river regulation will have direct impacts on vegetation structure and species composition, whereas increased local moisture levels are predicted to elevate feral rabbit problems. Some changes in structure and composition are expected with the projected effects of climate change. However, human land management of these woodlands—notably grazing and water regulation/dam expansion—will be the most important factor influencing the potential increase or decrease in condition of this community.

**Grasslands – North Western region**

This ecosystem has the potential to be favoured by predicted changes in weather and environmental conditions, with increased levels of annual rainfall causing higher levels of biomass and productivity. Latitudinal trends in potential impacts are predicted to occur across the range of this ecosystem, with lower overall annual rainfall predicted in the south-west of the range, transitioning to higher annual rainfall in the north-east. The impacts of climate change on the Mitchell Grasslands will depend ultimately on any changes in land use and management practices that occur. Agriculture plays a large role in the disturbance regime of the community, and changes in grazing and cropping practices due to increased annual rainfall and higher temperatures throughout the region will likely determine its eventual condition.
Major impacts

Increased summer rainfall:

- increased biomass accumulation of Mitchell grass:
  - change in species composition
  - potential decrease in plant species diversity
  - increased fire risk
- increased grazing pressure
- potentially favourable conditions for fauna:
  - depends on changes in land use
  - increased stocking levels and more frequent fires will negatively affect fauna
  - increased potential for feral mouse and locust plagues.

The dominant plant species in this community, Mitchell grass (*Astrebla lappacea*), is a summer-growing tussock grass able to tolerate dry conditions and moderate stocking levels. Given increased rainfall during its primary growth period, and higher temperatures potentially disadvantaging other plant species, Mitchell grass is likely to increase in biomass substantially, thickening and displacing forbs inhabiting inter-tussock spaces. This may serve to decrease plant species diversity in this community; increased growth of Mitchell grass may be offset, however, by potential increases in stocking levels and changes in fire regime. As inter-tussock spaces decline and competition increases, species such as the endangered creeping tick-foil (*Desmodium campylocaulon*) are likely to be disadvantaged, and any increases in grazing pressure due to higher productivity in the ecosystem would serve to further compound this decline.

An overall increase in annual rainfall, particularly in summer, will lead to greater biomass accumulation within this ecosystem, increasing the risk of fire. The vegetation also has the potential to thicken with elevated moisture levels and increased levels of CO₂, with potential invasion by woody shrubs such as mimosa bush (*Acacia farnesiana*). However, an increased incidence of fire throughout this ecosystem has the potential to offset this increased shrubbiness, and the overall structure of these grasslands is therefore unlikely to change. If grasses can maintain their cover, they will be able to compete, as the cracking soils will restrict the root growth of tree and shrubs.

Higher summer rainfall and the resulting increase in productivity and biomass are predicted to increase pressure from agricultural practices in terms of increased stocking levels and grazing regimes. This is likely to be an issue, particularly in the south of the region, which will receive proportionally less rainfall than the north, and grasslands contained within Travelling Stock Reserves may be heavily affected by increased grazing levels. Cropping in general is not at high levels in the areas occupied by these grasslands. However, intensification of agriculture in this system may be more likely to occur as a result of the decreased viability of agricultural practices farther south in the State in areas such as the Riverina, as the demand for produce increases.

The fauna supported by this ecosystem, including striped-faced dunnarts (*Sminthopsis macroura*), flock bronzewings (*Phaps histrionica*) and grass owls (*Tyto capensis*) will generally be favoured by increased moisture levels, as higher productivity and biomass in the grasslands will result in more resources (including foliage, seeds and invertebrates) being available. This, again, depends entirely on any changes in land use and management practices. Too frequent burning and
increased stocking levels would have detrimental impacts on most fauna species in this community. Higher moisture levels during summer breeding seasons will advantage burrowing frogs such as wide-mouthed frogs (*Cyclorana* spp.), the crucifix toad (*Notaden bennettii*) and the ornate burrowing frog (*Limnodynastes ornatus*). Many species (e.g. grass owls) use these grasslands as opportunistic resources during drier times farther south; the importance of this will increase under the predicted effects of climate change.

Increased productivity and seed production has the potential to influence feral house mouse (*Mus musculus*) population dynamics, with already high population numbers throughout these grasslands in the North Western region. Increases in mouse populations will increase competition with native rodents, such as long-haired rats (*Rattus villosissimus*). Increases in rainfall, however, may also have a positive effect on the abundance of the latter species, depending again on the grazing pressure, the fire regime, and competition with feral rabbits.

Wetter summers are likely to increase the biomass of summer-growing plants, leading to increased susceptibility of these areas to locust plagues. This has implications for other fauna species; the use of chemicals to control locusts is likely to cause inadvertent fauna deaths because of chemical non-specificity and increased potential for bioaccumulation throughout the food chain.

**Grasslands – South Western region**

Stocking rates on the riverine plain grasslands in the South Western panel region have already begun to decline over the past 15 years owing to increased periods of drought. Further decreases in rainfall predicted to occur with climate change will increase pressure from agriculture on these grasslands until pastoral practices become entirely unviable throughout the region. Major changes are predicted for this ecosystem, with particularly dire consequences because of the ecosystem’s high degree of endemism and biodiversity. A large proportion of the species composition and structure of this community is likely to be affected, with its entire geographic extent predicted to be affected past the point of no return.

**Major impacts**

**Decreased** moisture levels:
- increased pressure from grazing practices; areas of high species diversity are more likely to be targeted:
  - decrease in abundance of palatable species
  - species-diverse grasslands on lighter soils take longer to regenerate than those on heavier soils, even after de-stocking
- loss of lichen-dominant soil crusts:
  - increased soil erosion and changes in soil chemistry
- change in plant species composition and structure:
  - decrease in species diversity, with loss of winter-reproducing species
  - increased of abundance of the more arid-adapted, shrubby species and summer weeds
  - loss of endemic plant species
- changes in resource availability for fauna species:
  - changes in fauna species composition
  - effects on plains-wanderer (*Pedionomus torquatus*).
Increased levels of moisture stress will result in increased concentration of grazing patterns on areas of grasslands with high species diversity, owing to their higher content of palatable plants. These higher diversity grasslands are supported by lighter soils and take longer to regenerate after disturbance than the species-poor grasslands on heavier soils, owing to higher rates of erosion after disturbance. The structural nature of these soils also makes them more susceptible to invasion by weeds and rabbits, with lighter soils much easier to colonise and burrow in.

Extended periods of drought and higher grazing pressure on these grasslands will lead to decreased soil cover by forbs and lichen crusts, serving to exacerbate wind erosion and loss of topsoil and resulting in increased rates of scalding, in particular on lighter soils. The loss of well-developed lichen crusts through intense grazing will also lead to decreased levels of nitrogen fixation in the soil, with unknown but potentially dramatic effects on soil food webs, further degrading these communities. The loss of soil crusts will also potentially destabilise the soil and increase rates of erosion, as well as affecting the habitat of burrowing fauna such as dunnarts, lizards, frogs and termites.

The species composition of the grasslands of the South Western region are predicted to be altered significantly by reduced annual rainfall (in particular, the large reduction in winter rainfall). A large proportion of the plant species present throughout this system are winter-reproducing, including grasses [e.g. wallaby grasses (*Austrodanthonia* spp.)] and annual forb species, which are likely to be lost altogether, with ensuing decreases in species diversity throughout the community. Winter weeds (e.g. ryegrass), will also be disadvantaged by decreased levels of winter rainfall. A decline in then abundance of geophytic species such as lilies, irises and orchids (e.g. *Pterostylis* spp.) has already been observed, with drought conditions removing the winter rains required for shooting. Although these species possess underground storage organs, there is a limit to the length of time for which they can survive without rain. A drastic simplification in plant species diversity is likely to be observed in these grasslands, with anticipated invasion by the more woody, arid-adapted species such as booree and saltbush, as well as by unpalatable chenopods (e.g. Dillon bush) and weeds such as Paterson’s curse, crowfoot (*Erodium* spp.) and thistles, with resulting disastrous losses of endemic grassland plant species. This ecosystem has many more endemic plant species, such as peas (*Swainsona* spp.) and daisies (e.g. *Brachyscome* and *Leptorhynchos* spp.) than comparable areas of other ecosystems in the western half of the State. It therefore has a lot more to lose.

Increased levels of moisture stress, changes in plant species composition and increased grazing pressure will also have major flow-on effects on resource availability for fauna species. Extended drought periods will result in fewer seeds and fruits being produced, as well as reduced numbers of invertebrates. These ecosystems support a range of endemic grassland fauna species, such as curl snakes (*Suta suta*), which are likely to be adversely affected by losses in productivity, with the potential exclusion of these species and others such as Australian pipits (*Anthus australis*) and brown song larks (*Cincloramphus cruralis*) from these grasslands. Seasonal habitat users such as quail are also likely to make use of these ecosystems with changes in productivity and weather conditions. Instead, species such as banded lapwings (*Vanellus tricolor*), inland dotterels (*Peltohyas australis*) and Australian pratincoles (*Stiltia isabella*) may be favoured by drier, hotter weather conditions and a sparser vegetation structure.

The endangered plains-wanderer is currently under severe pressure of extinction from agriculture and feral predators, and the effects of climate change will compound the threatening processes this bird already faces. A grassland specialist, this species inhabits species-diverse grasslands on lighter soils. The habitat suitable for this
species is predicted to decline because of increased grazing pressure under the predicted impacts of climate change. This species is already heavily affected by continuing drought, with breeding events occurring in response to rainfall. During favourable conditions, breeding can be year-round, but in the last 6 or 7 years only one or two years have been wet enough to facilitate recruitment. Consequently, numbers have decreased by 90% in this time. Plains-wanderers require vegetation cover to a height of 30 cm (but no higher) to allow for both protection and predator detection. Increased grazing pressure, changes in grasslands species composition, and predicted increases in storm frequency and severity may change the habitat structure significantly enough to reduce the amount of suitable habitat available to this highly threatened species.

**Forested wetlands**

The forested wetlands were divided up by the origin of their water sources (northern-fed rivers or southern/centrally-sourced rivers), rather than by North Western and South Western panel regions, as the effect of climate change on river flow regimes was deemed to be the most important factor influencing the persistence and potential changes in the inland riverine forests.

Moisture stress from the combined effects of river regulation and drought, coupled with increasing rates of salinity, have seen the loss of more large, old-growth trees in this ecosystem in the last 10 years than in any other ecosystem in the State. Without serious intervention to provide these forests with sufficient environmental flows, there is little chance of regeneration. The effects of climate change will exacerbate the stresses already in place in this system, particularly as a reduction in rainfall throughout the southern parts of the region increases the need for water by irrigators. Significant effects on forest structure and composition are predicted, with considerable changes likely to occur throughout the ecosystem, and forests expected to retract right to the water’s edge. A continuing exponential decline in geographic extent and condition is projected from the extent of decline that has occurred in the past 10 years, with significant losses of this ecosystem by 2050. These forests may persist in remnants, especially in places with slightly higher rainfall. The predicted scale of biodiversity loss will be much bigger in forests fed by central- and southern-sourced rivers than in the north. The south-western area has much larger stands of forest under more intense pressure of degradation by human land-use practices such as forestry, irrigation and grazing. The northern-fed rivers have the potential to be advantaged by increased water flows; this will ultimately depend on levels of river regulation.

**Major impacts**

**Changes** in rainfall patterns:

- increased rainfall in northern-fed rivers; decreased rainfall in central- and southern-sourced rivers:
  - increased potential for water regulation for agriculture in northern systems; the net result will be to decrease water flow through rivers
  - large amount of water required to restore subsoil water levels
  - increased water stress in all rivers, with alteration of hydrological regimes due to regulation (in turn affecting the reproduction and recruitment of ephemeral species); loss of resources for fauna; changes in the structure and composition of vegetation to the better dryness-adapted species; increased rates of erosion; and potential for saline groundwater issues

- increase in extent of acid-sulfate soils
• degradation of the cultural heritage values of river red-gum communities

**Increased** temperatures:

• potential to exceed the physiological thermal limits of fauna and flora
• combined with decreased flows, will lead to increased occurrence of algal blooms
• decreased numbers of feral pigs and carp.

*Northern-sourced rivers (Namoi, MacIntyre, Darling, Gwydir, Culgoa, Paroo)*

Increased annual rainfall in the northern parts of the State are likely to increase the actual amount of water contained within the catchments of these rivers. However, as with the issues in the black box woodlands in the North Western region, this rainfall increase is also predicted to raise the level of flow regulation and water extraction for irrigation purposes within these rivers, resulting in fewer environmental water flows and fewer natural flooding regimes throughout these ecosystems. River regulation through weirs and dams, mainly for irrigated agriculture, has permanently inundated and killed some forests or severely altered the flooding regime, heightening the risk of further loss through water stress during drought periods. Significant areas of habitat, such as the Macquarie Marshes, are already particularly stressed, with increased moisture stress due to climate change predicted to heavily affect these communities because of their high levels of water dependence. Reductions in flows will reduce the abundance of overstorey vegetation—in particular river red gums—because of water stress and decreased chances for recruitment. The situation may be different in the forests supplied by the Paroo River, as it is presently unregulated.

These riverine forests currently represent corridors that enable western extensions of the more-easterly distributed species. Examples are quolls (*Dasyurus* spp.), koalas (*Phascolarctos cinereus*), parrots, frogs, water skinks, water dragons, rats, eastern strike-tits (*Falcunculus frontatus*), sacred kingfishers (*Halcyon sacra*), lace monitors (*Varanus varius*), pythons, turtles and bats [e.g. chocolate wattled bat (*Chalinolobus morio*)]. Any loss or change in structure will result in easterly range retractions for a number of these species. The loss of river red gums from this ecosystem will have dramatic impacts on all fauna in terms of the availability of resources, including food availability, shelter and shade for water (with resultant impacts on water temperature), as well as nesting/roosting sites for hollow-dependent species such as red-tailed black-cockatoos, powerful (*Ninox strenua*) and barking (*Ninox connivens*) owls, arboreal mammals such as brushtail possums (*Trichosurus vulpecula*), and many species of bats [e.g. Gould’s long-eared bat (*Nyctophilus gouldi*)].

A decrease in riparian vegetation because of moisture stress will facilitate increased rates of bank erosion, further compounding the effects of the vegetation loss, with topsoil removal lowering the possibility of recolonisation of bare ground patches. This loss of vegetation will not only reduce available habitat for aquatic fauna occupying these rivers; it will also reduce the amount of insulation provided from increasing temperatures through loss of shading. Reduced water flows and increased pooling will serve to increase nutrient and sediment concentration; combined with increased water temperatures, this may lead to increased occurrence of algal blooms, with resulting effects on water quality, not only for human use, but for fauna also. With decreased capacity for flushing, pools of water become uninhabitable, with highly saline and anoxic conditions also increasing the rate of tree decline.

An increase in the abundance of dryness-adapted plants (e.g. chenopods) is to be expected with the loss of riparian vegetation, with increases in the abundance of weedy species such as *Lippia*, castor oil plant (*Ricinus communis*) and Noogoora burr likely to further decrease the quality of these waterways and their forests.
The physiological impacts of increasing temperatures throughout the ecosystem are primarily unknown, and further research is required to quantify these effects. The potential exists, however, for marked and dramatic effects to occur, should the physiological thermal limits of fauna and flora species be exceeded. Apart from the direct impacts of increased daily minimum and maximum temperatures, indirect impacts will also be likely to contribute to stress, with a cascade of effects occurring because of decreases in the availability of resources. Loss of riparian vegetation because of moisture stress will compound the effects of increasing temperatures, with fauna species forced to make longer commutes to resources for foraging; it will also reduce the amount of shading on the ground layer of the ecosystem. As individuals experience increasing levels of stress, they are also more susceptible to disease and parasites, causing further decline in condition. The recruitment of flora species may also be adversely affected by increased temperatures, with potential changes in germination, establishment, seed-setting and flowering. The impending effects of increased temperature on the organisms comprising these ecosystems, although unquantified, should not be discounted.

Increased temperatures may allow expansion of the distributions of species, such as the noxious cane toad, that are currently limited by minimum temperatures. Other feral species (e.g. pigs) may be disadvantaged by higher temperatures and lower moisture levels, whereas carp may decline with decreasing water quality.

**Central- and southern-sourced rivers (Murray, Murrumbidgee, Lachlan)**

Already highly regulated and stressed through lack of moisture, these forests will be further affected by the increased moisture stress and temperatures expected with climate change. Southern-sourced rivers will experience much less rainfall than centrally sourced rivers, which in turn will experience much less rainfall than the northern-fed river systems. The forests supplied by these rivers will not experience the lack of water flows due to increased water regulation that will be experienced in the north; instead, they will experience reduced water flows due to reduced rainfall levels—in particular, reduced spring floods. The predicted scale of biodiversity loss will be much bigger in forests fed by the central- and southern-sourced rivers than in the north, with much larger stands of forest under more intense pressure of degradation by human land use practices such as forestry, irrigation, and grazing and resulting increases in salinity. The worst-affected areas will be the Lower Murray and the Lowbidgee floodplain.

These forests are likely to experience the same effects of moisture stress as in the forests fed by northern-sourced rivers, including loss of riparian vegetation and the resulting decreases in resource availability for fauna. There are large numbers of already threatened fauna that rely on resources supplied by river red gum habitat, including the regent (*Polytelis anthopeplis*) and superb parrots, squirrel gliders, large-footed myotis (*Myotis macropus*) and powerful and barking owls. Reductions in flow will reduce the numbers of breeding events of colonial nesting birds, thus reducing the numbers of rookeries constructed by species such as egrets, herons, ibis and spoonbills and reducing the availability of habitat for other taxonomic groups such as fish, crayfish, and frogs, including the endangered southern bell frog. Populations of fish will decline as water quality decreases, with flow-on effects on food resource availability for birds. Loss of nocturnal insectivores such as bats and other insectivorous fauna such as birds because of habitat loss will result in increased potential for mosquito populations to flourish, especially with more pooling of water due to lack of significant flow in rivers; this will result in increased potential for the spread of diseases such as Murray River encephalitis and Ross River fever.
Increased pooling and temperatures may lead to higher tadpole mortality rates, with consequential effects on recruitment to amphibian populations. Responses may differ among different wetland types, with river red gum forests responding better to summer flows than freshwater (black box – lignum) wetlands. However, studies comparing primary productivities on river red gum wetlands flooded at different times of year found that spring flooding produced higher diversity and productivity than summer flooding (Robertson et al. 2001). Amphibian populations—particularly those of the southern bell frog—are at high risk of extinction owing to their high level of sensitivity to reduced frequency of flooding and extended dry periods. Local extinctions of southern bell frog populations have already been recorded as a result of reduced flooding frequency. The change in seasonality of water availability because of climate change will have an enormous impact on these wetlands.

The threatened flora in this community also requires flooding, and decreases in the intensity, duration and frequency of flooding events will have negative impacts on the growing conditions of species such as the small scurf-pea (Cullen parvum) and river swamp wallaby-grass (Amphibromus fluitans), as well as decreasing their capacity for dispersal and recruitment. Species that require regular flooding will be replaced by the more arid-adapted species and salt-tolerant plants, such as chenopods and samphire (Halosarcia spp.), as well as by introduced weeds and grasses, further reducing the quality of this habitat.

Decreased river flows have already resulted in higher prevalence of acid-sulfate soils throughout these river systems, most notably in tributaries of the Murray River. Once exposed to air, these soils release sulfuric acid into the ground water and surface water. Acidic water can dramatically alter the ecological character of wetlands and estuaries, cause fish kills, reduce farm productivity, release heavy metals from contaminated sediments, pollute water, affect human and animal health, and damage infrastructure such as bridges.

**Freshwater wetlands – North Western region**

Freshwater wetlands are immensely important areas of high productivity in the landscape, providing food and habitat resources for a high diversity of fauna species—in particular, wetland birds and aquatic species such as invertebrates, frogs, fish and turtles. They are important sites of highly productive refugia in relatively poorly productive landscapes. Many wetlands have been drained as a result of continuing intense pressure from agriculture and development. Profound and ongoing degradation of existing wetlands from direct water extraction and/or alteration of natural water regimes by diversion, impoundment (dams/weirs) and regulation of river flows (mainly for irrigated agriculture) has been compounded by recent drought and is likely to be exacerbated by the predicted impacts of climate change.

The impacts of predicted climate change on these freshwater wetlands will depend ultimately on a number of factors, including changes to river regulation levels and possible changes in evaporation rates. The potential exists for increased flooding frequency in wetlands fed by northern-sourced rivers; this depends entirely on predicted increases in agriculture in the region causing increased pressure for irrigation and water extraction or flow regulation, as well as on the duration of floods being shortened by possible increases in evaporation (although this latter point is uncertain). Wetlands located more in the west and the south of the region will experience less rainfall and their condition is likely to be reduced considerably. Large changes in the species composition and structure of the ecosystem are predicted to occur, along with major decreases in geographic extent.
**Major impacts**

**Changes** in rainfall patterns:

- increased rainfall in northern areas:
  - increased potential for water regulation for agriculture in northern systems; the net result will be to decrease water flow through rivers and into wetlands, although some rivers will remain unregulated
  - a large amount of water will be required to restore subsoil water levels

- decreased rainfall in the more southern and western areas:
  - increased pressure for groundwater extraction

- increased water stress in all rivers:
  - altered hydrological regimes owing to increased regulation, decreased rainfall and increased groundwater extraction, with effects on reproduction and recruitment of water-dependent and ephemeral species
  - loss of resources for fauna
  - change in the structure and composition of vegetation to the better dryness-adapted species

- increased pressure for wetland draining with changes in hydrological regime; highly productive systems will be attractive to agriculture for cropping

- change in seasonality of moisture availability from the traditional spring flooding:
  - effects on recruitment success of waterbirds and amphibians (especially winter- and spring-breeding species)

**Higher** temperatures, the effects of which will depend on changes in evaporation:

- potential to exceed the physiological thermal limits of fauna and flora:
  - potential increase in tadpole mortality

- decreased numbers of feral pigs.

The freshwater wetlands are fed by the same rivers as the forested wetlands, and they will experience much the same effects of reduced moisture availability throughout the region owing to both increased flow regulation (in the north) and decreased rainfall (more in the south). The mound springs of the Darling and Paroo river systems, in areas such as the Nocoleche and Macquarie Marshes nature reserves, support a suite of endemic or threatened species (e.g. *Nitella partita* and *Goodenia nocoleche*), which are likely to be negatively affected by increased moisture stress. Reduced flooding will remove suitable growing conditions, reduce riverine connectivity, increase fragmentation and affect recruitment in a system with already restricted dispersal capacity.

The expansion of agriculture because of increased rainfall levels in the region, with the resulting need for irrigation, is likely to reduce flows into wetlands, and the length of inter-flood periods is likely to increase significantly. Wetlands relying on ephemeral flooding events may still receive some water eventually, but those reliant on local rainfall, particularly in the west, may suffer considerably more water stress. The predicted increase in storm events may be offset by longer inter-flood periods, with ephemeral species only able to survive certain lengths of time without water. These ephemeral lakes may also dry quicker when floods actually do occur; this will depend primarily on changes in evaporation rates, which were unable to be predicted by the current climate change model. (The interplay of increased temperatures, changes in wind patterns and changes in rainfall patterns and humidity means that the...
directionality of evaporation changes cannot be quantified.) Changed hydrological regimes are also likely to increase the potential suitability for these highly productive areas to be drained and used for lake-bed cropping, further increasing the pressure on these wetlands.

Changes in the seasonality, frequency and duration of flooding patterns will have significant impacts on the species composition of the vegetation of this community, with resulting impacts on resource availability for the fauna utilizing this ecosystem. Lignum (*Muehlenbeckia florulenta*) is a signature species of the floodplain shrublands and one of the most important habitat components for many fauna species that utilise these inland wetlands, such as the threatened grey grasswren (*Amytornis barbatus*). Changes in flooding regime will have dramatic impacts on lignum survival in these systems, with both prolonged drought and prolonged flooding having negative impacts on the survival and reproductive capacity of these plants. These impacts will be wide-ranging: these habitats support a massive diversity of waterbirds, some of which migrate from their breeding grounds overseas to make use of the resources found in these wetlands.

Some burrowing frog species are tolerant to dry periods and, being opportunistic breeders, are less likely to be sensitive to the shift to summer rainfall. However, other species such as the crucifix toad are winter breeders and may have reduced breeding opportunities and local extinctions.

The impacts of increased temperatures on wetland ecology are difficult to predict and depend ultimately upon changes in evaporation rates. Increased temperatures caused by climate change will decrease the levels of water oxygenation in these wetlands, with the potential for increased aquatic fauna die-offs, or earlier die-offs with quicker drying (depending again on the unknown direction of changes in evaporation). Although rates of tadpole metamorphosis increase with higher temperatures, high evaporation rates may reduce the hydroperiods of rain-fed wetlands to an extent where mass mortalities of tadpoles are more common. Feral pigs are already a threat in wetland areas; increased temperatures and lower water availability throughout these communities may actually serve to reduce habitat suitability for pigs; this, again, depends on the duration of the flooding events that do occur, which is influenced primarily by rates of evaporation.

**Freshwater wetlands – South Western region**

The impacts of climate change on freshwater wetlands in the South Western panel region are similar to those in the North Western region and will be heavily influenced by any changes in evaporation rates affecting the duration of flooding events. The wetlands in this system, however, are likely to experience much lower levels of rainfall than those in the north. The wetlands in this region are already reliant on human intervention to receive water flows because of the high level of regulation of the river systems; with further predicted decreases in rainfall, the opportunities for environmental flows throughout this system will be significantly reduced. For ecosystems that are already struggling to survive, the effects of climate change are likely to have significant negative impacts.

The impacts of predicted climate change on these freshwater wetlands will depend ultimately on a number of factors, including changes to river regulation levels and potential changes in evaporation rates. Wetlands located in this region will experience much less rainfall and are likely to be reduced in condition considerably. Changes in most of the species composition and structure are predicted to occur, with the loss of the entire geographic extent possible. The wetlands of the South Western panel region were deemed to be at a higher level of risk than those in the North Western panel region.
**Major impacts**

**Increased** moisture stress during winter, spring and autumn:
- all wetlands likely to have reduced periods of inundation
- changes in seasonality of flooding events
- lower water volumes entering system, thus decreasing the hydroperiod of the wetlands
- increased pressures from agriculture because of decreased viability in other areas, possibly leading to the draining of wetlands and the cropping of highly fertile lake beds
- changes in the species composition of vegetation (especially decreased lignum survival):
  - impacts on resource availability for fauna (especially fauna relying on lignum)
  - decreased frequency of large breeding events, with population dynamics issues for affected species
  - loss of water-dependent species (e.g. non-burrowing frogs and fish and invertebrates)
  - change to the better dryness-adapted plant species
- fewer recreational visitors; human impact and disturbance will be reduced, but the system will be degraded anyway.

There are three key issues that need to be emphasised in relation to wetland hydrology: seasonality, frequency and hydroperiod. A shift in the timing of inundation of seasonally flooded and ephemeral wetlands is likely to significantly alter recruitment success of waterbirds and amphibians, particularly within black box – lignum systems. These water bodies traditionally flood in early spring through a combination of snow melt and tributary inflows higher in the Murray-Darling Basin. During the environmental flooding of 2007–08, wetlands were flooded in late December (summer) for operational reasons. Although the initial vegetation response and frog breeding was very good, plant condition declined rapidly and by March was poor, with subsequent declines in water quality. Despite initially promising calling responses from resident frogs, including the southern bell frog, actual recruitment was much lower than had been observed during spring flooding in previous years. No bird breeding was observed; had it occurred it is unlikely to have been completed because of declining productivity. This indicates that spring flooding is required for successful recruitment events in these wetlands in the South Western region, and that changes in flooding regimes due to climate change will have significant negative impacts.

A dramatic reduction in the volume of winter rain will exacerbate the already heavily degraded areas of freshwater wetlands in the South Western region. Even wetlands still supplied with water by irrigation are likely to be significantly affected owing to predicted changes in the irrigation patterns. The viability of agriculture is likely to decrease throughout the region, with less annual rainfall and increased temperatures, and competition for water resources will thus be markedly increased. The reduced frequency of flooding events and overall moisture availability in these wetlands will lead to a considerable overall decrease in the abundance of lignum, one of the most important sources of fauna habitat in the dry interior. The loss of lignum habitat will affect waterbirds in particular, with threatened species such as Australasian bitterns (*Botaurus poiciloptilus*), painted snipe (*Rostratula*...
benghalensis), brolgas (Grus rubicundus) and freckled ducks (Stictonetta naevosa) losing important breeding sites. The loss of winter rain for spring breeding events, combined with the loss of breeding sites, will see marked effects on the population dynamics of many wetland birds. The frequency of large breeding events will decrease, and the length of time between these events may actually exceed the life spans of some species, resulting in the loss of entire generations of birds. Declines in numbers of species such as egrets, spoonbills, ibis and crakes have already been observed since the 1980s, and the impacts of climate change are likely to intensify this decline. There have already been significant reductions in the flooding frequency of black box-lignum wetlands as a result of flow regulation. These pose a serious threat to many amphibians, which typically have short life spans. The southern bell frog appears to be particularly sensitive to altered flooding frequency and increased dry periods (e.g. the formerly robust populations that occurred at Avalon swamp within the Lowbidgee system went locally extinct because the wetland was dry for a 5-month period in 2006).

As noted in the North Western region discussion, reductions in the volume of water entering the floodplain, coupled with increased evaporation rates and infiltration because of a lack of subsurface water, are likely to reduce wetland hydroperiods. Although many amphibians are relatively plastic in terms of development times, individuals that undergo rapid metamorphosis are typically smaller and may have reduced fitness/survivorship, so extinction risk will increase overall.

Decreases in moisture availability will have major impacts on the flora species composition and structure of these wetlands, with species reliant on water likely to be replaced by ephemeral dryland species such as unpalatable chenopods, copperburrs, pigface, samphire and halophytes. The drier areas to the west are predicted to be dominated by low saltbushes and copperburrs, as well as by dillon bush and African boxthorn, whereas communities in the east are likely to be weedier, with species such as Noogoora burr, Paterson’s curse and grasses able to proliferate. This will result in massive reductions in productivity and loss of resources throughout the ecosystem.

Saline wetlands

The inland saline lakes are restricted to small patches in the landscape and were not mapped as occupying any area within either the North Western or South Western panel region owing to the coarse scale of mapping. No prior information was therefore supplied to panel members regarding this formation. The panel, however, decided that this community warranted discussion, and it acknowledged the potential for change throughout this system, although the direction of change could not be predicted owing to a lack of knowledge of changes in groundwater availability. Almost no changes in species composition and community structure are expected, but there may be some changes in geographic extent.

As saline open water or dry salt pans surrounded by open succulent herbfields, these ecosystems have been largely unaffected by land clearing and are less affected by grazing than other communities of the arid zone. The principal threats to these lakes include damage to the soil and vegetation by feral pigs, and from gypsum and sand mining.

Potential for impact due to climate change exists if groundwater extraction from underground basins increases in the area as a result of a decrease in local rainfall. Decreases in local rainfall may also cause surrounding lunettes to become unstable and erode, causing lake depressions to be filled.

The extreme conditions in saline lakes support a highly specialised flora and fauna endemic to these ecosystems. The constituent flora and fauna of these lakes show a
high degree of endemism and have highly restricted distributions. The *Halosarcia lylei* low, open shrubland is an endangered ecological community known only from the saline lakes. This high level of endemism gives this community a lot to lose if any degradation occurs as a result of sand mining, trampling by grazing herbivores, or climate change.

With the predicted impacts of climate change, the potential exists for freshwater wetlands to resemble these saline lakes in structure, but they will not be equivalent floristically or ecologically. Instead, they will be species poor and will have a very simplified structure.

**Arid shrublands (acacia subformation) – North Western region**

This ecosystem has a very widespread distribution across Australia, and it has a seemingly high level of resilience in the face of a variety of climatic conditions and disturbance impacts. Despite this appearance, many of the acacia shrublands are extensively grazed by domestic stock, feral animals (especially rabbits, goats and pigs) and native herbivores. Recruitment of their constituent vegetation is limited as a result, although in some communities recruitment is sufficient to have produced mixed cohorts of plants. This formation also consists of certain communities that are extremely widespread, whereas others occupy only small patches and have quite restricted distributions. These smaller communities are comprised mainly of a few dominant species and display low levels of species diversity, usually because of the effects of grazing on the ground cover [e.g. purple-wood wattle (*Acacia carneorum*) shrublands and nelia (*Acacia loderi*) shrublands]. As a result, climate change is likely to have varying levels of impact in different areas, depending in part on the amounts of other sources of disturbance in the particular community.

Changes in human land use patterns due to agriculture will have important consequences for this system, in particular because of changes in the fire regime with changes in grazing patterns and fuel availability, as well as a reduction in recruitment capacity. The canopy trees in these ecosystems are already senescent, and although the trees are long-lived and highly resilient, continued suppression of recruitment by grazing is creating an aging population. Without active intervention and removal of recruitment suppression through reduction in grazing levels, the impacts in this system are likely to be more pronounced post-2050, with the potential loss of mulga (*Acacia aneura*). Within the 2050 time frame, however, small changes in structure and species composition were predicted, with the loss of some geographic extent. The eastern edge of the arid shrublands’ distribution may suffer encroachment by eucalypt woodlands in areas of increased rainfall. Ultimately, the unknown effects of increased temperature due to climate change and the heavy influence of changing human land use patterns precluded a definitive assessment.

**Major impacts**

**Changes** in moisture availability, with the majority of region likely to experience increases in summer rainfall and decreases in winter rainfall and the south-west of the region receiving overall less annual rainfall:

- mulga recruitment currently limited by rainfall:
  - potential for recruitment enhanced in the northern areas, depending on the grazing levels
  - recruitment limited in areas receiving less rainfall
  - impacts on mulga specialist fauna species
- change in grazing pressure with changes in rainfall and temperature that may increase the perceived viability of land for pastoral uses
• changes in seasonality of rainfall:
  — increase in the abundance of summer-growing plants over winter-growing ones, with flow-on effects to seasonal fauna resource availability

**Increased** temperatures:

• potential for increased frequency of fire weather:
  — combined with increased summer rainfall may increase fuel loads and lead to increased fire frequency, with negative impacts on mulga recruitment
  — depends on fuel levels (grazing may reduce fuel availability)

• physiological thermal limits of small diurnal fauna may be exceeded:
  — changes in behavioural patterns (e.g. daily foraging patterns)

• change in the timing of flowering events (acacia and understorey species).

The acacia shublands are dominated by mulga, which flowers opportunistically when adequate soil moisture is available, with fruiting generally occurring in late winter or early summer (Williams 2002). Major recruitment events of mulga occur very infrequently; conditions have to be extremely favourable, with large amounts of rainfall and no grazing pressure (from, in particular, rabbits). Thus an increase in summer rainfall throughout most of the region may favour the fruiting and recruitment of mulga, provided that levels of grazing are not so high as to prevent seedling survival, as the more palatable species are susceptible to grazing in their juvenile forms. Areas receiving overall less annual rainfall, however, in the south-west of the region, will have reduced capacity for flowering and seeding, with resulting impacts on resource availability for resident and nomadic fauna. Mulga specialists such as Hall’s babbler (*Pomatostomus halli*) and the chestnut-breasted quail-thrush (*Cinclosoma castaneothorax*) will be the most heavily affected. The nelia shrublands are an Endangered Ecological Community in a similar state of decline as the rosewood–belah woodlands, with recruitment suppressed by grazing and compounded by extended periods of drought. Increasing moisture stress from climate change in the area occupied by this community will exacerbate this decline. Without active intervention and removal of grazing, the potential exists for the entire extent to be lost.

Changes in rainfall patterns throughout the northern areas of the region may increase the perceived viability of grazing in areas occupied by these communities. This may lead to an increase in stocking rates, which will increase the pressure on these shrublands considerably, especially in times of drought; practices such as lopping mulga for fodder have negative impacts on recruitment and resource availability for fauna. However, the changes in land use due to agriculture—particularly in areas receiving considerably less rainfall than at present—are difficult to predict, and they remain a contentious source of disturbance in this community. Climate change is likely to cause changes in human land use patterns in these areas, but the direction and extent remain unknown.

Increased levels of summer rainfall have the potential to increase fuel loads within, and in the areas surrounding, the arid shrublands, whereas hotter temperatures may increase fire risk, particularly in areas with high concentrations of buffel grass (*Cenchrus ciliarus*) and spinifex. An increase in fire frequency in these communities would have major negative impacts on mulga reproduction and recruitment, with the potential to affect the species composition and structure of the shrublands and consequently the resource availability for fauna. Mulga can take anywhere between 5 and 15 years (or more) to set seed after fire (Williams 2002), and too frequent fires would substantially suppress recruitment and may increase the abundance of the more fire-resilient species and of grassy species. Increased fire
frequency would also serve to reduce the amount of mistletoe present in the mulga, diminishing a resource important to many birds present in this ecosystem, including threatened species such as the pied honeyeater (Certhionyx variegatus). The frequency of fire will ultimately depend on the levels of grazing throughout the ecosystem; increased grass growth and subsequent productivity due to increased summer rainfall may result in higher grazing pressure and a subsequent reduction in fuel levels. As mentioned earlier, the direction of change in grazing pressure is difficult to predict, and any flow-on effects are likely to be debatable too. Thus the direction of change in fire frequency is also difficult to predict, but it will likely play a major role in shaping the eventual condition of this community.

This community is already arid adapted, it would seem that increases in temperature may have less of an effect on the organisms here than elsewhere. It must be emphasised, however, that temperature has just as much capability to affect the functioning of this ecosystem as any others, with the potential for physiological thermal limits to be exceeded for many species (in particular small, diurnal organisms). Increased minimum and maximum temperatures may affect daily foraging patterns, with diurnal organisms (e.g. small honeyeaters and thornbills) unable to be active for longer periods during the day, thus decreasing the amount of time available for collecting resources. Even ectothermic species are unable to be active during the hottest parts of the day, and they will need to gather more food in shorter periods of time, thus increasing the pressure in an already unpredictable environment. A lot of constituent species in these ecosystems occur farther north and in hotter conditions, and they may be able to survive the predicted changes. However, knowing species responses to higher temperatures is difficult without further research, so caution must be exercised in drawing any conclusions.

Increased temperatures may also influence the flowering patterns of plants within these communities, with implications for pollinators and flow-on effects on insectivorous species. Changes in the timing of resource availability of constituent species such as wattles, as well as understorey species such as emu bushes (Eremophila spp.), will have more direct impacts on nomadic species [e.g. black (Certhionyx niger), pied and white-fronted honeyeaters] than on sedentary resident species such as chats (Epthianura spp.). Periods of resource availability will potentially become asynchronous with migration patterns.

Arid shrublands (Chenopod subformation) – North Western region

The impacts of climate change on the chenopod shrublands in the North Western region were considered to be quite similar to those in the acacia shrublands, i.e. difficult to predict. There is potential for some of the communities within this formation to be favoured, whereas others will be disadvantaged, depending on the differential responses to localised rainfall. There will also be variations in the levels of human impact owing to unpredictable fluctuations in grazing pressure and the unquantified effects of increased temperature. The general level of resilience of these shrublands seems to be high, considering the harsh environmental conditions to which they have already become adapted. The riverine and aeolian chenopod shrublands have already been heavily modified by overgrazing and show an increased prevalence of unpalatable species because of preferential removal of the more palatable plants; this impact is predicted to continue, and any increases in grazing levels due to climate change (if they occur) will further exacerbate the degradation of these unique communities. Ultimately, the unknown effects of increased temperature due to climate change and the heavy influence of changing human land use patterns precluded a definitive assessment.
**Major impacts**

Seasonal **change** in moisture availability, although overall annual rainfall will remain similar:

- increase in summer rainfall and decrease in winter rain:
  - change in species composition from winter- to summer-growing plants
  - favouring of generalist, unpalatable species by impacts of grazing
  - potential for increased grazing pressure during drought (difficult to predict because of the human element)

**Increased temperature:**

- combined with no real overall change in annual rainfall will lead to decreased productivity:
  - fewer grasses, with implications for fauna
  - decreases in termite abundance, leading to possible soil food web effects (particularly reduced nutrient cycling).

Saltbushes are perennial plants that are sources of fodder during drought, and increased temperatures with no real change in annual rainfall levels are likely to exacerbate drought conditions throughout the region, potentially increasing grazing pressure in this community. The more palatable chenopods in these shrublands [e.g. old man (Atriplex nummularia) and bladder (Atriplex vesicaria) saltbushes] are sensitive to even low levels of continuous grazing and may be replaced by more unpalatable species, such as copperburrs and bluebushes (Maireana spp). Increased summer rainfall could lead to increased recruitment of bladder saltbush, but this may be offset by changes in grazing pressure or extended periods of drought. (This species drops its leaves during exceptionally dry years.) Once approximately 20% foliage is reached, these plants can defoliate entirely, with potentially big losses of plants resulting in increased erosion of foothills where these saltbush regularly occur.

Recruitment in these communities is generally restricted to the higher rainfall years, with long-lived species such as saltbush tolerating the dry conditions in between. Short-lived ephemeral species such as bulbs, lilies and daisies, however, have short-lived seeds. Increasing drought conditions and inter-rain periods, as well as decreased winter rainfall, may see a decline in these species, because it is unknown how long they can survive between wet periods. For this same reason, a decrease in winter weed abundance may also occur.

As mentioned in the discussion on the acacia shrublands, these ecosystems are already adapted to quite high temperatures; predicted increases in temperature may still exceed the physiological thermal limits of some organisms, with potential consequences on the species composition of the community. The fact that the effects of temperature increases on individual organisms have not been quantified leaves room for speculation as to the magnitude of the impacts these elevated temperatures will have at the ecosystem level. These impacts should not be dismissed as irrelevant.

These ecosystems display high levels of endemism, especially in regards to fauna, supporting birds such as gibberbirds (Ashbyia lovensis), redthroats (Pyrhrolaemus bruneus), white-winged fairy-wrens (Malurus leucoterus) and inland dotterels, small mammals such as the fat-tailed dunnart (Sminthopsis crassicaudata), and reptiles such as the oriental ctenotus (Ctenotus orientalis) and the tesselated gecko (Diplodactylus tessellatus). Although these species are restricted to habitats such as these arid shrublands, their geographic ranges extend a long way north, into hotter conditions. We can therefore expect that these organisms are already adapted to
survival under the conditions that may eventuate under climate change. However, the effects of increased temperature have not been quantified and must not be discounted as non-existent, especially in light of the level of endemism within the community that may be affected.

Increased temperatures and potentially changes in rates of evaporation are likely to decrease the productivity of these communities, eventuating in possible losses of grass cover, decreases in termite numbers, and reduced nutrient cycling within the soil. Microscale effects such as these have the capacity to result in much larger impacts on the ecosystem, but their magnitudes are difficult to predict given the unquantifiable effects of increased temperature and changes in the rates of evaporation.

In general, an increase in hotter, drier, less productive conditions is likely to favour more generalist species such as chenopods, especially in areas where other communities (e.g. floodplain woodlands) contract because of climate change. These species may benefit from these changing conditions; however, the structure and composition of the communities likely to replace those in the retracting ecosystems will be highly simplified, with an overall reduction in diversity and productivity. It is more likely that the changes will occur as in situ species replacements, rather than by range expansions of chenopod shrublands.

**Arid shrublands (chenopod subformation) – South Western region**

Much of the assessment of the situation of chenopod shrublands in the North Western region also applies to that in the South Western region, but with the additional pressure of greatly reduced moisture availability. As in the North Western region, chenopod shrublands are likely to continue to undergo changes in the availability of palatable plants because of continued grazing impacts, with hotter, drier conditions compounding the effects of grazing in suppressing recruitment of the more palatable species. Marked changes in species composition and community structure are expected, with some potential changes in geographic extent. The chenopod shrublands of the South Western region are at higher risk of negative impacts from projected climate change than are those in the North Western region.

**Major impacts**

**Decreased** moisture availability:
- less winter rainfall:
  - loss of winter annuals and grasses
  - decrease in species diversity
  - decrease in productivity
  - increase in abundance of shrubs

**Increased** temperature:
- effects unknown, but is likely to have an impact.

A major decrease in moisture availability throughout this ecosystem in the South Western region will see major changes in species composition, with harder species favoured that are more drought tolerant and resilient to higher temperatures. Black bluebush (*Maireana pyramidata*) will have a competitive advantage over other species such as pearl bluebush (*Maireana sedifolia*), as it recruits easier and is more resilient to both heat and the impacts of grazing. Plants such as grasses, and herbs and forbs [e.g. everlasting daisies (*Chrysocephalum* spp.)] occupying inter-tussock spaces will suffer considerable moisture stress with the loss of winter rain, with
reductions in cover of winter-growing species such as spear grasses and increases in the cover of the more arid-tolerant species. This will result in a loss of species diversity, as well as a reduction in productivity. The reduction in grass cover will lead to less invertebrate activity and the associated impacts of lowered levels of decomposition and nutrient cycling throughout the system, as well as to changes to resource availability for fauna. The loss of palatable grasses and forbs will have major impacts on all fauna species, with flow-on effects throughout the entire food web. Herbivores and granivores such as Bolam’s mouse (Pseudomys bolami), blue-winged parrots (Neophema chrysostoma), white-winged wrens, finches, chats and invertebrates will be directly affected by the removal of primary food resources. The rest of the community [e.g. ground-dwelling insectivores such as fat-tailed dunnarts, and skinks (Morethia adelaidensis, Ctenotus uber)] will suffer indirect flow-on effects from the reductions in productivity. The loss of groundcover species is also likely to result in elevated levels of erosion throughout the chenopod shrublands.

The overall structure of the community is predicted to change, with colonization by woodier shrubs likely because of the decreased rainfall. Species such as hopbush and bluebush may proliferate in concert with the reduction in grass and herb coverage, with a resulting decrease in species diversity. Grazing will continue to affect species composition in these shrublands, with the more palatable plants preferentially grazed, leading to a proliferation of the less palatable plants such as cotton bush.

Impacts on large proportions of the fauna in this region are difficult to predict, as their biology and ecology are poorly known (e.g. it is not known how long burrowing frogs can survive while buried). Impacts are likely to be due to changes in the frequency and intensity of rain events, which are difficult to predict. As these rain events are often localised, local extinctions may be patchy across the region rather than having range shifts.

As with other formations of the arid zone, the effects of increased temperature were difficult to assess, given the potential unknown changes in agricultural land uses and the potential problems with thermal limits in constituent species within the ecosystem. However, an increase in temperature is likely to result in fewer incidences of frost, which may have implications for the germination of currently frost-limited species.
7 Alps and Southern Tablelands regions

7.1 Description of the regions

The Alps and Tablelands region covers the tablelands and mountains of the Great Dividing Range and Snowy Mountains. The region extends along the plateaus and tablelands of the Great Dividing Range south of the Liverpool Range to the Victorian Border, edged to the east by the coastal escarpment and to the west by the South Western Slopes (see the unshaded area in Figure 7). The region is defined by the tablelands and mountains cool temperate climatic regions in the winter and mixed rainfall zones. The region closely corresponds to the South-eastern Highlands and Australian Alps bioregions of NSW.

The reporting regions for this study are based on the regions used in the NSW State Plan. The Alps and Tablelands form part of the South-eastern NSW, Western NSW and Riverina State Plan regions. However, the Alps and Tablelands have been separated from the other State Plan regions because their climate is vastly different.

![Figure 7 The Alps/Tablelands region](image-url)
7.2 Climate projections presented to the panel

- The weather will be warmer:
  The minimum and the maximum temperatures will be between 1.5 and 2.5 °C warmer. Daytime maxima will be generally 2 to 2.5 °C warmer, whereas overnight minima will be 1 to 2.5 °C warmer.

- Summer rainfall will increase substantially:
  Most of the region will receive a 20% to 50% increase in summer rainfall. This will be at the upper end of the observed variability in the Central Tablelands (the 1960–89 period also had wetter summers) and well beyond the observed variability in the Southern Tablelands, Alps and Monaro.

- Winter rainfall (and snow) will decrease substantially:
  There will be a 10% to 50% decrease in precipitation during winter, with the intensity of deficit increasing with increasing latitude. This will be below to well below the observed variability in winter rainfall in the 20th Century, particularly in the Alps and Southern Ranges.

- Spring and autumn will be slightly wetter than, or close to, average in the Central Tablelands and 5% to 20% drier in the south:
  Compared with the long-term seasonal variability, rainfall in spring and autumn are generally within the ranges observed in the 1900 to 2000 period. Autumn is generally at the drier end of the observed range and spring is at the moderate to wetter end (Table 4).

Table 12 Temperature and rainfall summary for the Alps and Southern and Central Tablelands of NSW (2050 A2 Scenario)

<table>
<thead>
<tr>
<th>Season</th>
<th>Minimum Temperature</th>
<th>Maximum Temperature</th>
<th>Precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>1.5–2.5°C warmer (warmer in the east)</td>
<td>2–2.5°C warmer</td>
<td>5–20% increase in the Central and Southern Tablelands. No change in the ACT Region. 5%–20% decline in the Alps and Monaro.</td>
</tr>
<tr>
<td>Summer</td>
<td>1.5–2°C warmer</td>
<td>1.5–2°C warmer</td>
<td>20–50% increase in summer rainfall.</td>
</tr>
<tr>
<td>Autumn</td>
<td>1–2.5°C warmer (warmer in the east)</td>
<td>2 –2.5°C warmer</td>
<td>No change in the Central and Southern Tablelands. 5–20% decrease from the ACT south, including in the Alps and Monaro.</td>
</tr>
<tr>
<td>Winter</td>
<td>1–2.5°C warmer</td>
<td>2–2.5°C warmer</td>
<td>10–20% decrease in Central Tablelands and eastern Monaro. 20%–50% decrease in Southern Tablelands, Alps and Monaro.</td>
</tr>
</tbody>
</table>
### Tabel 13 Summary of impacts by ecosystem: Alps and Southern Tablelands regions

<table>
<thead>
<tr>
<th>Ecosystem</th>
<th>Community</th>
<th>Main reasons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet sclerophyll forest</td>
<td>Southern Tablelands and escarpment</td>
<td>Major impacts likely from increased fire frequency.</td>
</tr>
<tr>
<td>Grassy woodlands</td>
<td>Subalpine, grassy woodlands, tableland clay</td>
<td>Impacts will vary depending on the community. Major impacts will be as a result of predicted changes in seasonality of rainfall and increased fire frequency.</td>
</tr>
<tr>
<td>Dry sclerophyll forests</td>
<td></td>
<td>Major impacts from increased aridity and decreased annual rainfall likely.</td>
</tr>
<tr>
<td>Heathlands</td>
<td>Sydney montane, southern montane</td>
<td>Major impacts predicted from increased fire frequency.</td>
</tr>
<tr>
<td>Grasslands</td>
<td></td>
<td>Predicted changes in rainfall seasonality will impact on productivity and threatened species.</td>
</tr>
<tr>
<td>Alpine complex</td>
<td>Grasslands above 1110m altitude</td>
<td>Likely to be highly changed in terms of species composition and ecological function due to decreased annual precipitation.</td>
</tr>
<tr>
<td>Freshwater wetlands</td>
<td>Montane lakes, bogs and fens</td>
<td>Decreases in productivity and changes in species composition are expected due to projected decreased moisture availability.</td>
</tr>
<tr>
<td>Forested wetlands</td>
<td></td>
<td>Decreased annual rainfall is likely to affect flood events resulting in reduced productivity and recruitment of some species.</td>
</tr>
</tbody>
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### 7.3 Assessment of impacts on each ecosystem

**Wet sclerophyll forest (WSF) (grassy and shrubby subformation combined)**

*p.Southern Tablelands WSF; southern escarpment WSF; montane WSF*

The majority of Southern Tablelands forests in the north of their range have been cleared for pasture or pine plantations, with little area protected in reserves, whereas in the south substantial areas remain on steeper terrain in Kosciusko National Park. Montane forests are relatively unaffected by clearing; the main source of disturbance in these communities is the alternation of forest grazing and burning for green pick, which results in lower plant diversity and decreased abundance of shrub species. Large stands of southern escarpment west sclerophyll forests remain in the south of the region, although all but the most inaccessible have been at least slightly modified
by logging by removal of the larger trees. These forests are protected in reserves throughout their range, although some of the reserves (e.g. Kanangra-Boyd National Park) were logged heavily before reservation.

The montane forests are dominated by the presence of a single species, alpine ash (Eucalyptus delegatensis) and thus have great capacity for loss if the effects of climate change negatively affect this species. Fire is a major ecological process in these habitats, and predicted increases in fire frequency are likely to have a significant impact on the species composition and structure of these forests, including the availability of resources such as tree hollows for nesting/roosting habitat, food and light. There are wide-ranging implications for fire management in the alpine ash forests; survival of this community depends on total fire exclusion.

Changes in extent of the wet sclerophyll forests at the less viable extremes of their physiological ranges and sensitivities may lead to gradual shifts or losses in their relative distribution. Forests in the west of the region may contract gradually with increasing temperatures and decreasing annual rainfall. These ecosystems will be susceptible to potentially very abrupt changes, depending on the differences in disturbance regimes. The montane wet sclerophyll forests have the potential to undergo catastrophic changes in species composition and structure with increased fire frequency, to the stage where they would not persist as they are currently known, with consequent major reductions in geographic range. The Southern Tablelands and escarpment forests are at less risk of impact than other ecosystems in this region because they are less likely to suffer extreme changes in weather patterns, and the potential also exists for the climatic effects on escarpment forests to be moderated by coastal weather influences. Changes in species composition and structure are still expected, primarily as a result of increasing fire frequency, with heavier impacts predicted in the Tablelands forests.

**Major impacts**

**Increased fire frequency:**
- increased fuel load in wetter years because of increased summer rainfall:
  - increased fire risk in drier years
- alpine ash communities are highly sensitive to fire:
  - change in species composition and structure
  - increased shrubbiness; loss of alpine ash
  - fire-resistant species favoured
- increased potential for hazard-reduction burns in Southern Tablelands forests
- loss of refugia in southern escarpment forests
- implications for hollow-bearing trees and resource availability for fauna

**Increased temperatures:**
- may increase the length of the growth season
- may exceed the temperatures required for seed germination
- alpine ash are potentially buffered by their location on south-facing slopes

**Shift in seasonality of moisture availability, with increased summer rainfall and less winter rainfall:**
- potentially advantageous, as the forests are currently winter-growth limited.
The risk of fire may decrease in years of good rainfall with increased moisture availability in summer; however, fuel loads will also be increased because of higher rainfall levels during the peak growth season of these communities, resulting in increased fire risk in drier periods following this growth. The 2003 fires were the result of summer storms in areas that had been previously drought affected; the predicted increase in frequency and intensity of storms because of climate change is thus likely to elevate the potential fire risk in these forests.

The montane wet sclerophyll forests (alpine ash and related communities) are extremely fire sensitive; alpine ash is killed by fire and requires an inter-fire period of more than 20 years to reach a stage of maturity where it is able to set seed. Between 30 and 40,000 hectares (approximately 50%) of this community was burned during the bushfires of 2003. Any fires of the same magnitude within the immediate future will be devastating for the survival of this ecosystem as it currently occurs. An increase in fire frequency as a result of projected climate change will see decreases in alpine ash populations by 2050, leading to a more patchy distribution; alpine ash were lost from the Cabramurra area after the 1986 fires and were replaced by leguminous shrubs. A decrease in leaf litter provided by alpine ash would lead to increased rates of erosion in these areas, especially in the post-fire period.

Increased fire frequency will also lead to changes in species composition and structure of the montane forests, with the potential to affect large areas of forest over short time periods. Loss of mature-age and potentially hollow-bearing trees and an increase in shrubbiness in the understory will lead to a reduction in nesting and roosting habitat for hollow-dependent fauna such as the yellow-bellied glider (*Petaurus australis*) and changes in the availability of resources such as leaf litter for ground-dwelling fauna (e.g. small mammals, arthropods). There is also the potential for the more fire-resistant species [e.g. ribbon gum (*Eucalyptus viminalis*)] to replace alpine ash; such species may be able to occupy higher elevations with the predicted increases in temperature.

Southern escarpment wet sclerophyll forests support a large variety of endemic species, with a mix of both coastal and tableland distributed flora and fauna. Occupying climatically buffered areas, these forests are full of micro-endemic species such as Monga tea-tree (*Leptospermum thompsonii*), a mallee-form of *Eucalyptus fastigata*, and many others (e.g. rare snow gums and grevilleas). They also support small pockets of refugia dominated by rainforest species, such as eastern leatherwood (*Eucryphia moorei*) and black sassafras (*Atherosperma moschatum*). The potential increases in fire frequency due to climate change will render these...
forests extremely susceptible to losses of rare and unique flora and fauna. Increases in fire frequency will change the species composition and structure of these forests, with impacts on resource availability to fauna. These communities support a number of threatened fauna species, including the spotted-tailed quoll (*Dasyurus maculatus*), sooty owl (*Tyto tenebricosa*) and eastern false pipistrelle (*Falisistrellus tasmaniensis*), which will be negatively affected by a reduction in resources such as tree hollows and by changing habitat structure.

The endangered smoky mouse (*Pseudomys fumeus*) occupies wet sclerophyll forests in south-eastern NSW and the ACT. It feeds mainly on seeds and fruits in the summer and on underground fungi (truffles) in winter. The key features of almost all the habitats of the smoky mouse seem to be connected to its specialist dietary requirements. Flowers and legumes that provide seeds and epacrids that bear berries are typical food resources of this species, but such assemblages may not develop until 10 years or more following fire. Drier soils and increased fire frequency will also decrease truffle growth. Increases in fire frequency and changes to the species composition of the wet sclerophyll forests in this region are likely to have negative impacts on food availability for this vulnerable species and for other ground-dwelling fauna relying on these and similar resources.

The growth of high-altitude communities is restricted in the winter months by the cold temperatures, and the main growth seasons are presently spring, summer and autumn. Increased temperatures may serve to lengthen the growth season and allow growth in months in which growth is presently restricted. Certain environmental conditions are required for the seeds of tree species in these communities before they are able to germinate; Alpine ash requires cold, moist conditions for 6 weeks during winter and spring for regeneration, and snow gums (*Eucalyptus niphophila*) require these same conditions for 3 weeks. Thus, elevations in winter and spring temperatures—particularly at low elevations and in less sheltered positions—are likely to result in conditions beyond the range of those required. The projected decreases in average annual rainfall, coupled with increased temperatures, are likely to result in conditions beyond those required for recruitment in these species. Range retractions of these species may occur, into refugia that provide optimal microclimates. Dry-tolerant species such as brown barrel (*Eucalyptus fastigata*), ribbon gum (*Eucalyptus viminalis*) and mountain gum (*Eucalyptus dalrympleana*) may encroach on stands of alpine ash, especially at lower elevations.

Potential exists for the impacts of climate change to remain latent in these communities and for ‘ecological debts’ to develop over time. An example of this would be the reduced regenerative capacity of alpine ash as a result of the temperature and moisture changes described above, and the subsequent occurrence of an intense, extensive wildfire that kills all the mature trees. It may appear as though the fire was the trigger for the loss of this species from the area; however, if regeneration capacity had not been reduced, then recruitment would have been able to occur. It is therefore important to recognise sources of degradation and to realise that although this community may look healthy and intact, resilience may be lowered and ecological functions can in fact be disrupted.

A large proportion of species occupying the montane zone have narrow temperature occupancy ranges that could be exceeded under projected changes in climatic conditions. Changes in canopy cover due to disturbance and increasing fire frequency have the potential to decrease the resilience of many species of flora and fauna. Longer-lived plant species are more likely to be negatively affected by fire rather than by increases in temperature; impacts may therefore not be seen by 2050, but may manifest in the longer term. Decreased regeneration rates after the 2003 fires may indicate that warmer temperatures and decreased rainfall due to climate change are already suppressing recruitment in these communities.
There is potential for alpine ash communities to be protected from the effects of increased temperatures and increased fire frequency and levels of solar radiation. This is because of their location on south-facing slopes, where they are more effectively buffered from the effects of climate change than are other communities within this formation. The importance of these forests as areas of refuge for rainforest elements such as native mulberry (*Hedycarya angustifolia*) and other wet-adapted species is still likely to be reduced with decreased annual rainfall levels, with consequential implications for other species utilising these refugia.

Warmer, damper summers may make eucalypt seedlings more susceptible to fungal infections, particularly with plants already experiencing increased stress from other sources of disturbance. The dispersal of weed species such as briar rose (*Rosa rubiginosa*) and blackberries (*Rubus fruticosus* agg.) along moist drainage lines may be advantaged by increased summer rains, coupled with the effects of decreased canopy cover due to increased fire and increased dieback from moisture stress. Scotch broom (*Cytisus scoparius*) may be able to establish itself in drier forests.

**Grassy woodlands**

*Subalpine woodlands; Southern Tablelands grassy woodlands; tableland clay grassy woodlands.*

The impacts of climate change are likely to be displayed much sooner, and to a much greater extent, on the grassy woodlands of the Tablelands than on subalpine woodlands, because the latter have higher levels of connectivity through the landscape. The Tablelands woodlands are already less resilient because they have suffered more fragmentation over longer periods of time, resulting in more depauperate seedbanks and ensuing low levels of recruitment. In addition, isolated remnants have reduced buffering capacity against extreme weather events such as storms, which are predicted to increase in frequency with climate change. This will be compounded, in particular, by decreased moisture availability throughout the region, resulting in significant changes in species composition and decreasing the overall diversity and condition of the community, as well as causing eventual severe retraction of geographic extent. These woodlands are already among Australia’s most threatened ecosystems because of clearing and habitat modification for agriculture. The impacts of climate change are likely to aggravate their degradation, with negative impacts on a range of Endangered Ecological Communities.

The subalpine woodlands are likely to suffer more from increased habitation by invasive species because of increased temperatures. Changes in species composition and habitat structure are predicted in these communities, with increased grazing levels and competition with native species. Because of their contiguous distribution, these woodlands will be better buffered against potential climatic impacts than the Tablelands woodlands, which will be heavily degraded into the future unless there are changes in management regimes to allow regeneration. Drier conditions are likely to result in reduced stocking capacity in the lowland woodlands, with potentially increased opportunities to manage these lands for conservation.

**Major impacts**

**Change** in seasonality of rainfall/moisture availability, with increased summer rainfall and decreased winter rainfall:

- impacts on plant species composition (grasses and weeds)
  - C4 plants favoured over C3 plants
- less spring growth, with loss of geophytic species
• increased shrubbiness:
  — change in habitat suitability for fauna species
  — decreased species diversity
• change in timing of flowering events:
  — affects resource availability (insects, pollen/nectar)
• change in the timing of breeding cycles of autumn- winter- and spring-breeding fauna

**Decreased** annual rainfall:
• decreased recruitment and increased patch deaths of trees because of drought:
  — increased susceptibility to disease and insect attack
• possible decreases in grazing viability
• increased salinity

**Increased** fire frequency:
• impacts in subalpine rather than lowland woodlands

**Increased** temperatures:
• increase in abundance of species currently limited by cold:
  — more weed/feral species
• increase in grazing in colder areas.

The change in seasonality of moisture availability will have profound impacts on the species composition of these communities. C4 plants, such as kangaroo grass (*Themeda australis*) are summer growing and will thus be favoured by increased summer rainfall over C3 plants (e.g. *Poa* spp.), spring annuals and perennial geophytic species (orchids, daisies and herbs), which require winter rain for growth. This effect is likely to be less of an issue in subalpine woodlands, with the abundance of winter-growing species currently limited by the cold temperatures. Shrub growth will be promoted by an increase in the areas of bare patches throughout the ground cover as a result of decreased productivity of grasses in spring. These communities are predicted to experience an increase in shrubbiness, with a corresponding decrease in plant species diversity—an impact that has already begun to be observed in subalpine woodlands.

Changes in the abundance of groundcover plant species—in particular a reduction in the cover of grasses—will have major negative impacts on the productivity of the ecosystem and on resource availability for fauna in this community. The vulnerable broad-toothed rat (*Mastacomys fuscus*) is likely to be heavily threatened by the impacts of climate change, as it relies heavily on the grassy ground cover in subalpine woodlands as a primary food source, as well as for nesting and cover while foraging.

Patch deaths of large numbers of trees are already occurring throughout these ecosystems at very high rates because of the occurrence of sequential drought periods, which are predicted to be exacerbated by further decreases in annual moisture in the region. The potential exists for increased susceptibility to insect attack in constituent species such as Blakely’s red gum (*Eucalyptus blakelyi*), which is more vulnerable than other eucalypts to moisture stress and potential psyllid insect attack. Yellow box (*Eucalyptus melliodora*), on the other hand, is quite drought tolerant, although the effects of drying may be latent within these ecosystems because of the deeper soils it inhabits. Snow gum (*Eucalyptus niphophila*) woodlands have also
suffered widespread tree deaths, attributable to continuing drought conditions, a phenomenon that will continue to occur with decreasing moisture availability. Losses of overstorey trees will have dramatic effects on the overall structure and function of these woodlands. The recruitment of new trees is currently suppressed by grazing; continued suppression of recruitment will thus lead to an increase in openness in these habitats and a decrease in the numbers of hollow-bearing trees, with implications for fauna dependent on the resources provided by these trees.

Because they have specific breeding habitat requirements, specialist woodland fauna species such as the hooded robin (*Melanodryas cucullata*) and the diamond firetail (*Stagonopleura guttata*) will be heavily affected by changes in the structure and composition of these woodlands. The loss of habitat heterogeneity and structural layers throughout these communities has already resulted in a decline in insectivorous woodlands birds. Further habitat simplification and loss of productivity owing to the predicted impacts of climate change will exacerbate this decline and will also affect species such as possums (e.g. sugar gliders, *Petaurus breviceps*) and ground-dwelling mammals (e.g. antechinus). Predicted decreases in grazing viability in these habitats may actually favour re-establishment of these fauna. However, in some cases, other fauna such as the invasive non-native common myna (*Acridotheres tristis*), or the native but competitive noisy miner (*Manorina melanocephala*), may exclude some species.

Species generally known to occupy the more westerly-distributed habitats have already begun to frequent these woodlands more often, with the presence of bird species such as white-browed woodswallows (*Artamus superciliosus*), redbacked kingfishers (*Todiramphus pyrrhopygia*), redcapped robins (*Petroica goodenovii*) and black honeyeaters (*Certhionyx niger*) reflecting the drying of the environment farther west. Species such as galahs (*Cacatua roseicapilla*) and crested pigeons (*Ocyphaps lophotes*) are becoming more and more common in these environments, indicating similarities between the Tablelands woodlands and those farther west that are normally inhabited by such species. The capacity for these woodlands to act as refugia for western species will be reduced with further decreases in average annual moisture levels, with negative implications for fauna species seeking sanctuary from more hostile conditions.

Altitudinal migrants in the Alps region, such as the gang-gang cockatoo (*Callocephalon fimbriatum*), eastern spinebill (*Acanthorhynchus tenuirostris*), white-eared honeyeater (*Lichenostomus leucotis*) and various robin species shift their distribution to lower altitudes seasonally. During winter, colder temperatures and lower resource availability cause these species to move from subalpine woodlands to more suitable habitat, most notably the grassy woodlands on the Tablelands. Decreased productivity in both of these communities will have negative effects on these migratory species, with declines in gang-gang cockatoo populations already being observed. Other species such as the rainbow bee-eater (*Merops ornatus*), dollarbird (*Eurystomus orientalis*) and white-winged triller (*Lalage sueurii*) migrate from north to south, utilising the abundance of resources available in these habitats in spring. Decreased winter rainfall, and hence a lack of productivity and resources during the spring breeding season, will have wide-ranging impacts on the ecology of migrational species, with the effects of climate change predicted to compound declines already evident because of drought and habitat modification.

The predicted change in seasonality of moisture availability in these woodlands will affect the timing of the breeding cycle of many species of fauna because of changes in the flushes of resource availability. Decreased winter rainfall will result in lower nectar yields of winter- and spring-flowering eucalypts (e.g. yellow box), with fewer resources available for nectivorous species such as the endangered regent honeyeater (*Xanthomyza phrygia*) and superb parrot (*Polytelis swainsonii*). Changes
in the timing of flowering events may change the species pollinating these flowers, with implications for pollination efficiency. Decreased nectar and pollen availability will result in lower insect activity, with associated effects on insectivorous species, including the suite of declining insectivorous woodland birds. Changes in the timing and amount of seasonal rainfall have the potential to cause asynchrony between availability of resources and the arrival of migratory species. There also may be asynchrony between the arrival of migratory species, with some species responding to day length cues for migration, whereas others respond to temperature cues. The latter species may begin migration earlier in the year than usual, in response to warmer temperatures. Apart from changes in the timing of food resource availability, any species that breed in autumn or winter, such as the common toadlet (Crinia signifera) and Bibron’s toadlet (Pseudophryne bibroni) will be negatively affected by reduced winter moisture levels. All of these changes in resource availability to fauna, including a deficiency of nesting and roosting habitat as a result of the loss of hollow-bearing trees, will result in major reductions in the species diversity present in these communities.

At least slight decreases in average annual moisture availability will result in decreased recharge potential for the watertable in the woodlands at low elevations. Combined with potential increases in evaporation and compounded by declines in tree numbers, this is likely to result in elevation of the watertable, with increased occurrence of salinity throughout the region. This will exacerbate the effects of decreased annual rainfall on the viability of grazing in these ecosystems, with a possible reduction in grazing pressure, and increased potential for managing lands for conservation purposes.

Growth is currently restricted in these ecosystems during the colder months because of low temperatures; increased temperatures may serve to lengthen the growth season, although concurrent decreases in winter rainfall may offset any potential gains. Elevated temperatures are likely to result in decreased frost events, allowing increased eucalypt recruitment into cleared areas, although eucalypt recruitment is currently suppressed in the tableland woodlands because of grazing of palatable seedlings by stock and native herbivores. The management of grazing levels in these woodlands will have major effects on the ability of these ecosystems to persist under the predicted impacts of climate change.

Summit effects such as cold temperatures, winds and frosts are likely remain hostile enough to prevent the establishment of subalpine woodlands in the alpine zone. It is more likely that a thickening of trees will occur at the upper tree line, rather than a direct increase in altitudinal occupancy. At higher elevations, the area inhabited by snow gum woodland/forest is liable to increase, especially into areas cleared for grazing over 50 years ago and into cold air drainages from which they would currently be excluded by cooler temperatures. This potential encroachment by subalpine woodlands will have negative impacts on the alpine communities currently occupying these lower altitude drainage basins.

Elevated temperatures will increase habitat suitability for many species currently limited by the cold and will increase the number of fauna species able to over-winter in the subalpine woodlands. This will increase competition between new species and resident species, with potentially negative impacts on a range of threatened fauna. The broad-toothed rat requires the insulation provided by the snow layer to allow it to be active during the cold winter months, and it will be heavily affected by decreased snow cover, as well as by increased predation risk, in winter. In addition, increased temperatures will allow non-native species such as rabbits (Oryctolagus cuniculus), deer (Cervus spp.) and hares (Lepus europaeus) to over-winter in these habitats, increasing competition for the broad-toothed rat. Grazing by stock, rabbits and hares may eliminate grass cover, and trampling by stock can destroy nests. Rabbits also
attract predators to areas of habitat. In addition to this, decreased snow cover will increase exposure to feral predators such as cats (*Felis catus*) by increasing habitat suitability for this, and other, currently snow and cold-restricted species.

An increase in the abundance of non-native herbivore species in these habitats will introduce grazing impacts into areas not presently affected by this disturbance. This will result in a reduction in the abundance of inter-tussock herbs, as well as a decrease in the amount of palatable vegetation, with subsequent increases in the abundance of less palatable species such as snowgrass (*Poa labillardieri*) and reductions in productivity throughout the community. Predicted changes in climate will favour non-native invasive plant species such as scotch broom (*Cytisus scoparius*), blackberry (*Rubus fruticosus*), serrated tussock (*Nassella trichotoma*) and St. John’s wort (*Hypericum perforatum*). Scotch broom has the ability to invade bare ground easily, and once established, it shades out other species, has a long-lived seed and grows very densely, giving it the capacity to destroy this ecosystem if it has the chance to become established. Examples of this have already been documented in these ecosystems in the Barrington Tops National Park.

Fire has been largely absent from the Tablelands woodlands in the past because of their fragmented nature, and for the same reason they are unlikely to experience the major adverse affects associated with predicted increases in fire frequency. Subalpine woodlands, however, are largely contiguous throughout the landscape, and fire is likely to be a much larger factor in shaping the structural changes in this community. Increasing temperatures and drier conditions, as well as increased prevalence and intensity of summer storms, will increase the fire frequency in these woodlands, with the potential for large structural and species compositional changes throughout.

The climatic conditions currently experienced by subalpine woodlands would have served to prevent wildfires in the past, thus preventing adaptation to more fire-resistant survival strategies. Although fire was once an artificial source of disturbance in these woodlands because of burning for green-pick by graziers, grazing was excluded from these habitats in the mid-20th Century, and the fire frequency has consequently reduced dramatically. Increases in fire frequency have the potential to greatly alter the dynamics of these woodlands. Burning by graziers resulted in thickening of tree and shrub density in these ecosystems, with increased fires and clearing for grazing resulting in mallee-like regeneration of eucalypts from tubers. These changes are likely to be continued and worsened if fire frequency increases in these woodlands, with consequential reductions in productivity and changes in species composition.

**Dry sclerophyll forests (shrub/grass and shrubby subformation combined)**

The presence of extensive areas of rugged terrain such as ridgetops and hill slopes, together with low soil fertility, has rendered large areas of this ecosystem unattractive to agriculture. These communities have therefore remained largely unmodified and protected in reserves. However, dry sclerophyll forests occupying the more gentle topography and areas adjoining those of higher fertility have been cleared for forestry and agricultural practices.

These communities are potentially at less risk than others within the Alps/Tablelands region, as they exhibit high resilience and are encountered across a wide range of climatic conditions. Some changes in species composition and community structure may occur because of the predicted effects of climate change—primarily as a result increasing aridity due to a decrease in annual rainfall levels and an increase in temperatures. Extreme drought or fire events have the potential to have large impacts on these forests, but the formation itself is likely to persist as it is currently
known. More likely to manifest will be negative impacts on fauna due to a decrease in the productivity of the vegetation, with the loss of dasyurids throughout these communities already notable. Biotic interactions in this formation are likely to be more important than abiotic changes, but the effects of these cannot be predicted owing to the uncertain direction of the changes and the feedback effects between different species.

This is an extremely variable formation, and the effects of climate change were difficult to predict because of a lack of information on ecosystem functioning. However, general responses to current drought conditions show that further drying due to climate change will likely result in more stunted growth of trees and a more open structured forest, with primarily the same species persisting in a smaller growth habitat. The effects of grazing are also likely to be exacerbated by increasing aridity, and some losses in geographic extent were therefore predicted.

**Major impacts**

**Increasing** aridity, with decreased annual rainfall and increasing temperatures:
- shift in vegetation structure and perhaps species composition, overstorey and ground cover:
  - increased shrubbiness due to increased moisture stress on grasses
  - decreased productivity, with loss of diversity
  - effects on the fauna present
- reduced frequency, extent and duration of flowering events:
  - flow-on to resource availability to fauna
  - reduced winter rainfall affecting winter- and spring-breeding species
  - increased summer rainfall, possibly leading to increased disease prevalence

**Increased** fire frequency and intensity:
- adds to changes in understorey composition and structure from increasing aridity
- potential for increased hazard-reduction burning, with consequent loss of productivity.

Because of the nature of the topography occupied by the majority of the forests in this formation (exposed hill slopes and ridge tops) this community is exposed to quite high levels of solar radiation when compared with other communities. The net effect of this temperature increase and a decrease in annual rainfall levels throughout the region will be an increase in aridity within these ecosystems. This will serve to increase the shrubbiness of these dry forests, with grasses being unable to be supported by lower moisture levels, leading to major structural changes at the ground level and negative impacts on productivity. A decrease in the abundance of grasses will have consequences for resource availability for fauna, directly affecting granivorous species, as well as invertebrates. There will be more indirect effects of decreased invertebrate activity on insectivorous species and on nutrient cycling throughout the forests. Browsing pressure is likely to increase from native herbivores—both resident and from surrounding areas—because of continuing drought conditions. A decrease in grass cover will lead to a shift in grazing patterns, resulting in palatable shrubs being eaten; this may lead to proliferation of the less palatable species.

Decreases in moisture availability and increasing temperatures have the potential to change the structure of the understorey in these dry sclerophyll forests. A decrease in grassy ground cover and increased shrubbiness throughout these forests may lead
to a thickening of the ground layer, depending on the plants species present. Species such as kunzeas can do quite well with limited resources; in communities that are currently depauperate in ground fauna (e.g. *Eucalyptus mannifera* forests), a thickening of ground cover would certainly serve to increase habitat suitability and refuge for small mammals and birds. The direction of these changes, however, will depend on the current state of each forest remnant, because those with an already degraded understorey will react differently from those with an understorey that is intact. It will also ultimately depend on changes in fire frequency, with increased instances of low-intensity hazard-reduction burns leading to a decrease in understorey cover.

Decreased moisture availability will also lead to decreases in the density of these forests, with reductions in the numbers of canopy trees likely to occur through continuing moisture stress. Patch deaths of old-growth scribbly gums (*Eucalyptus rossii*) have already been observed in forests around Tumut, and if recruitment levels are reduced by increased moisture stress it is likely that some changes in habitat structure will result. With large amounts of forest (about 90%) occurring as regrowth, trees in these ecosystems are subject to high levels of competition for limited resources, and they are therefore more vulnerable to ongoing moisture stress. Losses of overstorey trees in these forests—particularly old-growth trees—will result in decreased hollow abundance and food resource availability for fauna, including the squirrel glider (*Petaurus norfolcensis*) and other possums, and various species of parrots, cockatoos and bats. In addition, lower moisture levels will also lead to more stunted growth in the trees that do manage to survive. Yellow box trees (*Eucalyptus melliodora*) have already been observed to be struggling in many areas because of moisture stress, and they are likely to be heavily disadvantaged by further decreases in annual rainfall throughout the region. Eucalypts may be replaced in some areas by more arid-adapted species such as wattles (*Acacia* spp.), whereas species requiring higher moisture levels may retreat into the more mesic gullies in steep topographies.

Increased aridity will result in greatly reduced flowering frequency in plants (especially eucalypts), with fewer resources available for nectivorous species such as the endangered regent honeyeater (*Xanthomyza phrygia*) and superb parrot (*Polytelis swainsonii*). A decrease in the frequency of flowering events will result in reduced nectar and pollen availability and consequentially less insect activity and lerp availability, with associated effects on insectivorous species such as mammals, bats and birds, including the suite of declining woodland birds. Changes in the timing of moisture availability may lead to changes in the timing of flowering events of certain plant species, with the potential to disrupt resource availability for fauna during their synchronised breeding seasons. In particular, decreases in winter rainfall will have major effects on winter- and spring-flowering plants, including white box (*Eucalyptus albens*) and mugga ironbark (*Eucalyptus sideroxylon*), with consequences for spring breeding fauna—especially resident nectivorous species. Other winter-breeding fauna, such as dasyurids (*Antechinus* and *Sminthopsis* spp.), will experience major decreases in rainfall and resource availability at the most crucial time of year; declines in these species have already been observed.

An increase in summer rainfall levels may lead to increased termite activity, with the potential to increase productivity at this time of year. Termites are currently limited by cold temperatures and may therefore be advantaged by the increased temperatures under predicted climate change.

The possibility exists for an increase in disease prevalence on the Tablelands because of changes in rainfall patterns. An increase in summer rainfall, as well as higher temperatures, could advantage the spread of fungal infections by *Fusarium* spp. and cinnamon fungus (*Phytophthora cinnamoni*), the occurrence of which has increased at Wee Jasper recently.
Increased aridity and more frequent and intense storm events will lead to increased fire frequency, either through wildfires or by an escalation of hazard reduction burns, particularly in areas surrounding urban and semi-rural development. This elevation in fire frequency will result in changes to the structure and species composition of these forests; the endpoints reached will vary because of the variability in the current understorey compositions. Dry sclerophyll forests are resource-poor ecosystems, and increased fire frequency may not necessarily advantage shrubs (as would normally be expected) if nutrients are lacking within the ecosystem. Any increases in fire frequency will cause definite reductions in the number of hollow-bearing trees, with resulting decreases in nesting and roosting habitat for hollow-dependent fauna species such as bats, arboreal mammals and birds. Increased fire frequency will also result in simplification of the ground layer, with losses of structural features such as logs and leaf litter. Structural simplification of the ground layer will result in decreased diversity of small mammals, as it provides less refuge and foraging habitat and increases exposure to feral predators such as cats and foxes, the effects of which have already been noted in the ACT.

Some of these communities develop very dense stands of cypress (Callitris spp.) seedlings following disturbance from clearing, grazing or logging. Thick regrowth of cypress leads to slow growth rates and suppresses plant growth in the understorey, which is unlikely to carry fire; these thickets are therefore currently locked into the landscape. Predicted increases in fire frequency may serve to open these areas up, with resulting increases in species diversity within the community. However, fires that occur too frequently will eliminate cypress in these woodlands by killing young trees before they have reached maturity and set seed.

Increased occurrence of hazard-reduction burns or otherwise low-intensity fires will have wide-ranging impacts on the vegetation present within this ecosystem, as well as on ecosystem functioning. Low-intensity fire can decrease seed production of brown stringybark (Eucalyptus baxteri) for up to 10 years, with flow-on effects of lowered levels of resource availability to fauna species such as gang-gang cockatoos (Callocephalon fimbriatum); so although the community can look healthy and intact, with trees appearing to be in good physical shape, their ecological functions can in fact be disrupted.

Heathlands

*Sydney montane heaths; southern montane heaths*

The distribution of these heathlands is constrained by geographic features; they are located primarily on highly elevated exposed sandstone cliffs, ridges and upper slopes. Changes in these communities will therefore need to occur *in situ*, as dispersal capacity is extremely limited and recolonisation is not readily facilitated after local extinction events. Some losses in geographic extent are therefore expected. Because of their infertile, skeletal soils, these ecosystems are relatively unaffected by clearing. The main source of disturbance in these ecosystems is fire, and expected increases in fire frequency due to climate change are likely to lead to some changes in species composition and possibly decreases in diversity in these habitats. Judicious management of fire regimes will be required to preserve the rare and often endemic flora and fauna supported by these communities, especially in regards to fire frequency and intensity. A range of fire regimes is required to promote a mosaic of vegetation age classes and species composition and to protect species diversity.

Major impacts

*Increased fire frequency:*
- inter-fire frequency affects colonization by fauna species:
  - a longer frequency is required by eastern bristlebirds (Dasyornis brachypterus)
  - a mosaic of fire regime is required for maximum species diversity
- effect on species composition (obligate seeders versus resprouters)
  - species that require fire for regeneration may prosper

**Decreased** overall moisture availability:
- physiological tolerances may be exceeded:
  - moisture-dependent species may decline
- possible decreases in diversity.

Fire is currently the most important ecological driver of species composition within these communities. As such, predicted decreases in annual rainfall and increases in temperature, with subsequent increases in fire frequency, may have marked impacts on species such as the eastern bristlebird and the eastern ground parrot. Although ground parrots can colonise burnt habitat 1 or 2 years after fire, maximum densities of this species and the eastern bristlebird are not reached until 15 to 20 years after fire. This lag is likely due to the density of vegetation required by these two primarily ground-dwelling birds as refuge from predators. Plants that respond to fire by germinating from seed in these habitats will also be disadvantaged by shorter inter-fire intervals, with fire recurring in some cases before plants reach maturity and set seed; those that resprout after fire will be advantaged. Inappropriate fire regimes may also have an impact on the flowering of shrubs contained within these heathlands, such as banksias, grevilleas and hakeas, with flow-on impacts on resource availability for fauna species such as the eastern pygmy possum (Cercartetus nanus). Repeated fires may adversely affect fire-sensitive species, although the topography and the abundance of rock will minimise this threat somewhat by creating heterogeneity in the landscape through which fire can burn.

Other species (e.g. the endangered shrub Dampiera fusca) prefer shorter inter-fire intervals, and some fauna species colonise quickly after fire (e.g. bandicoots (Isoodon and Perameles spp.)) and may therefore be favoured by increased fire frequency. In order to retain the high degree of endemism and diversity present within these ecosystems, a range of fire regimes are required throughout the heathlands to produce a mosaic of vegetation types and to allow different fauna species to co-exist. An increase in fire management of these communities increases the risk of introducing and dispersing root rot caused by cinnamon fungus (Phytophthora cinnamoni), which would be extremely detrimental to a variety of plant species in these communities.

Regular rainfall events are required by this community because of the skeletal soil depths on these primarily rock-based formations. Decreased annual rainfall levels may exceed the physiological tolerances of moisture-dependent species supported by seepages and surface-water collections, including endemic species such as the Budawangs cliff-heath (Budawangia gnidioides). The abundance of species occupying moist niches may be decreased; these include a suite of orchids such as the Tallong midge orchid (Genoplesium plumosum) and Eriochilus species. These have already been noted to be suffering the effects of extended drought periods, having not recovered even after two good years of rainfall, and they are still exhibiting greatly reduced flowering. Further prolonged drought periods due to climate change will have negative effects on these species, with potential losses of
some rare and unique species, particularly in the Sydney montane heaths and southern montane heaths in Wadbilliga National Park.

Winter- and spring-flowering species will be negatively affected by the decrease in winter rainfall predicted across the region, with fewer flowering events, or potentially less pollen, produced by dominant species such as *Allocasuarina nana* and *Banksia ericifolia*. This will have major impacts on resource availability for a wide range of fauna species present in these ecosystems, including honeyeaters, small mammals (e.g. eastern pygmy possum) and invertebrates.

**Grasslands**
This section excludes alpine grasslands (all above 1100 m), which are discussed under *Alpine complex* below.

Heavily modified throughout their range for agricultural use through grazing, cultivation and pasture improvement, the vegetation species present in these grasslands currently depend on grazing pressure, with reduced occurrence of palatable grasses and herbs and an abundance of introduced pasture grasses and weeds. The Monaro grasslands are already sitting at the edge of their climatic range in the rainshadow of the Alps, and they have been drying since the 1960s. The best examples of these grasslands exist in areas with low to intermediate grazing levels, unaffected by pasture improvement—primarily in Travelling Stock Reserves and cemeteries. Overgrazing and fragmentation serve to lower the resilience of these ecosystems, rendering them less able to deal with the impending impacts of climate change.

The Alps and Tablelands region is expected to undergo a major change in rainfall seasonality, with considerably less winter and spring rainfall and more summer rainfall. The temperate montane grasslands are predicted to experience major decreases in productivity owing to loss of grass cover and changes in species composition, as well as a proliferation of weeds. There will be major impacts on a suite of already threatened specialist grassland fauna species, such as the grassland earless dragon (*Tympanocryptis pinguicolla*). Along with increased pressure from agricultural land uses, substantial contractions in geographic extent are predicted, with notable losses of *Poa labillardieri* grasslands and possible conversion of other areas to poor-quality agricultural land that may not necessarily be representative of this ecosystem.

**Major impacts**

**Decreased** annual rainfall and change in the seasonality of moisture availability—in particular, with drier winters and springs and wetter summers

- general decrease in productivity
- decrease in spring annual growth, especially in the south of the region (both exotic and native species affected)
- short-term changes in species composition, with a shift from winter-growing C3 grasses to summer-growing C4 grasses:
  - increase in abundance of summer weeds
  - management implications (grazing regimes, use of fertilisers)
- likely heavy impacts on already threatened specialist grassland fauna:
  - decreased cover, leading to increased predation
  - reduced productivity: less invertebrate activity because of dry conditions
— change in species composition, with implications for resource availability

- increased erosion
- loss of snowgrass (Poa labillardieri) grasslands along drainage lines:
  - definite decline in productivity
  - increased weed invasion
- the drier environment may favour the spread of calicivirus in European rabbits (Oryctolagus cuniculus) and disfavour the spread of myxomatosis
- possible conversion to agricultural land and grasslands not representative of this community

**Increased** temperatures:

- increased length of the growing season
- if combined with increased CO₂ levels, may lead to increased shrubbiness.

Drier winter and spring periods across the region (particularly in the southern reaches) will occur at times of the years when rainfall is normally highest. This will result in major reductions in spring annual growth of both native and exotic plants, with significant decreases in the productivity in these communities. The grasslands on the basalt soil from Cooma to Bombala depend primarily on spring rainfall for their primary growth season, and not on retained soil moisture; they will therefore experience less spring growth. In the short term, an increase in summer rainfall is likely to favour C4 grass species, which are primarily summer-growing [e.g. kangaroo grass (Themeda australis) and red grass (Bothriochloa macra)] over winter-growing C3 species such as Poa. In the long-term, however, the cumulative effect of repeated, extended drought periods and increasing temperatures will result in decreased cover of native grasses and annual forbs, with increasing potential for colonisation by weeds such as Chilean needlegrass (Nassella neesiana), serrated tussock, and African lovegrass (Eragrostis curvula), the latter two of which are well adapted to very dry conditions. These weeds are highly invasive, even into undisturbed grasslands, and are likely to invade inter-tussock spaces. This will have major implications for management of these grasslands (grazing regimes and fertilisation protocols) to prevent the proliferation of weeds.

Increasing temperatures will also have negative effects on the diversity within these ecosystems, especially for spring wildflowers stimulated by day length. *Prasophyllum* orchids have recently been noted to emerge, but unseasonably high temperatures have resulted in the flowers becoming unviable before seeding could occur.

Decreased productivity due to drought in this ecosystem will be exacerbated by the effects of climate change, with dire implications for the persistence of an already threatened suite of specialist grassland species. Recent surveys in the grasslands of the Cooma Nature Reserve recorded only one grassland earless dragon. This paucity was attributed to a drop in invertebrate numbers because of decreased spring forb and new grass growth due to the drought. Other species of concern include the striped legless lizard (*Delma impar*). Decreased grass cover will also increase the susceptibility of grassland fauna species to predation by birds such as kookaburras (*Dacelo novaeguineae*) and raptors such as the brown falcon (*Falco berigora*), as well as feral carnivores such as foxes and cats. The golden sun moth, or mouthless moth, occurs in temperate grasslands dominated by wallaby grasses (*Austrodanthonia* spp.). Females lay their eggs at the bases of wallaby grass tussocks, and the larvae are thought to feed exclusively on the roots. The inter-tussock spaces in these grasslands provide important microhabitat for this species, as these spaces are typically where females display to attract males. Changes in the
dynamics of these grasslands, including loss of productivity, shifts in species composition, and invasion of inter-tussock spaces by weeds, will have dramatic impacts on this already endangered species.

Overgrazing and fragmentation serve to lower the resilience of these ecosystems, rendering them less able to deal with the impending impacts of climate change. The less mobile species, including invertebrates and reptiles, are more vulnerable to localised ecosystem changes, whereas the more mobile species such as the brown falcon may have the opportunity to seek resources elsewhere.

Changes in the seasonality of moisture availability will lead to increased pressure on this community in drier times across winter. Recovery during high rainfall times in summer is likely to be slowed by the degree of drying over winter and spring, with gradual decreases in ground cover. This will then lead to higher rates of erosion, particularly during intense summer rainfall events, which are predicted to occur at higher frequencies under projected climate change. Runoff has been predicted to increase by between 9% and 12% in the Tablelands, but higher summer rainfall levels are not likely to provide much reprieve from drier conditions at all other times of year. Levels of grazing by eastern grey kangaroos (*Macropus giganteus*) have intensified in the last few years in the more northerly grasslands; in addition to the conditions predicted with climate change, expansion of kangaroo populations due to increases in the numbers of surface water storages (dams and urban lakes) will serve to add to winter degradation in these grasslands. Overgrazing by both native herbivores and stock will open up the inter-tussock spaces because of decreased forb coverage. This may leave room for trees and shrubs such as burgan (*Kunzea ericoides*) to become established and perhaps take over within a few years. Decrease incidences of frost due to climate change means that grazing intensity will have structural impacts in quite a short period of time.

The dampest habitats within these grasslands occur along drainage lines. They support swards of *Poa labillardieri*, of which only approximately 2% remain intact because of conversion to exotic pastures. The continual drying predicted to occur under climate change will result in the loss of these areas through greater susceptibility to weed invasion by species such as sweet vernal grass (*Anthoxanthum odoratum*), spear thistle (*Cirsium vulgare*) and Yorkshire fog (*Holcus lanatus*). The loss of these grassy communities will result in major decreases in productivity, with effects on fauna species requiring wetter environments, such as the endangered green and golden bell frog at Carwoola/Captains Flat with historical records in the Monaro and Murrumbateman areas.

An increase in the length of the growing season because of increased temperatures, in addition to increased CO₂ levels, may promote the establishment of shrubs, including both native and exotic species, across grassland regions.

The overall effect of climate change, in combination with ongoing land use pressures, will see major changes in the dynamics of these grasslands, including an increase in weed abundance, decreases in productivity, and changes in the species composition of both flora and fauna. Because of the decline in ecosystem functioning, these impacts will cause contraction of these ecosystems to a point where the value of the community is lost and it is replaced by agricultural land, exotic pastures, or weedy paddocks.

### Alpine complex

This formation includes montane grasslands above 1100 m altitude.

The alpine complex is a composite formation of treeless communities at altitudes above 1100 m, which are related by their structural characteristics rather than by their species composition. A range of endpoints are expected to be reached by the
different communities encompassed by this formation, with some being favoured by the impacts of climate change and others being completely lost. The alpine complex as a formation itself will continue to exist after 2050, but it will be highly changed in terms of species composition, ecological function, and the proportions in which individual classes exist. A change in the actual extent of the alpine complex is not expected to occur, as trees are currently limited not only by temperatures, but also by frost and glazing events that will continue to occur under the modelled climate change scenario. After 2050, however, this scenario may change, and trees may begin to encroach on the upper tree line; prior to this, vegetation on the upper tree line is predicted to thicken. In the short term, drier periods have the potential to cause more marked changes, whereas in the long term increased temperatures will drive ecological change.

Faunal diversity in the alpine zone may actually increase under climate change; a number of species currently limited by cold temperatures and snow may be able to persist because of temperature elevations and decreases in snow cover. However, this also increases the impacts of grazing and trampling on these sensitive communities. Specialist fauna species (in particular, the mountain pygmy-possum) are unlikely to persist without active intervention under the predicted changes in climate. Increased temperatures, decreased moisture and snow cover and increased fire prevalence will all serve to affect the resources available to this threatened species, with definite potential for localised extinctions.

Some distinct components of the alpine complex, including the snow-patch communities (alpine fjaeldmarks) and groundwater communities such as the short alpine herbfields and bogs and fens, may be lost all together with the predicted impacts of climate change, principally because of increased temperatures and reduced precipitation (snow cover). The alpine fjaeldmarks are a highly specialised ecosystem because of their long period of snow coverage, and they are highly likely to be overtaken by the surrounding, more generalist shrubs and grassland communities. The short alpine herbfields, as well as the bogs and fens, are complex ecosystems in which soil, moisture and plant relationships are very sensitive and ultimately depend on groundwater storage. On the other hand, the alpine heaths may be unaffected or even favoured, and they may infringe on other classes within the alpine zone, depending on the degree of increase in fire frequency. Overall, the alpine complex will be simplified, with increased prevalence of generalist shrublands and heathlands and fewer specialist cold-dependent communities. Further research is required in a variety of disciplines to assess the best methods for managing and conserving these ecosystems in a changing climate.

**Major impacts**

**Decreased** annual precipitation (in particular, winter snow cover):

- loss of the insulation properties of snow over winter and exposure to more extreme temperatures and frosts:
  - frost-kills in plants
  - exposure of over-wintering fauna (e.g. mountain pygmy-possum (Burramys parvus) to temperatures below physiological thresholds
  - increase in exposure to feral predators (currently limited by the presence of snow) (e.g. cats)
- increase in abundance of fauna currently limited by snow
- increased erosion through frost exposure:
increased soil temperatures caused by a reduction in snow cover combined with warmer temperatures
changes in invertebrate activity and nutrient cycling, with loss of organic matter in soils

loss or simplification of water-dependent communities (short alpine herbfields, alpine fjældmarks, bogs and fens):
  - southern corroboree frogs (Pseudophryne corroboree) require winter precipitation in sphagnum bogs for egg survival
  - loss of organic matter from humic soils through combined effects of decreased moisture and increased temperatures
  - flow-on effects to downstream plant communities

**Increased** temperatures:
animals may be able to reach higher altitudes that are currently cold-limited:
  - increase in fauna diversity
  - increase in number of species able to over-winter
  - increased grazing pressure from native and feral herbivores [e.g. deer, pigs (Sus scrofa), kangaroos]
  - reduced species diversity and endemism
  - increased weed invasion
decreased summer germination of herbaceous seeds
increased shrubbiness due to combination of increased temperatures with drier conditions
vegetation thickening at the upper treeline (but this may still be restricted by extreme events such as frosts)
change in migration patterns of Bogong moths (Agrotis infusa):
  - effect on resource availability to fauna (e.g. mountain pygmy possum, foxes)
  - shift in predation focus if moths are not available
  - altitudinal change
impacts on sphagnum (bleaching/crisping)
  - a component of the ecosystem very important for water regulation and fauna habitat
shortened spring breeding season for fauna
increased potential for plant and animal pathogen dispersal
**Increased** fire frequency because of the drier, warmer environment:
fire is currently only an infrequent component of the ecosystem, so some major changes are expected
increased peat and organic soil fires
changes in species composition:

- fewer obligate seeders (e.g. *Sphagnum spp.*)
- some species may flourish after fire, but they are still used to only infrequent fires
- consequences for broad-toothed rat and mountain pygmy-possum.

The predicted decrease in annual precipitation—in particular, the major decrease in snow cover over winter—will have major negative impacts on the functioning of this ecosystem. Decrease in snow cover actually serves to lower minimum soil temperatures, rather than increase them, as snow acts to insulate everything beneath it from the effects of below-freezing temperatures and frosts. Without snow cover flora and over-wintering fauna may be exposed to the effects of frost, and temperatures may drop below physiological thresholds. Exposure to frosts freezes plants, and although some plants are frost tolerant others may be killed by repeated frosts, and the flowers of some plants may be destroyed by frost. The majority of plants bud in autumn and retain the buds under the snow to flower in spring. The loss of snow cover, and thus the loss of insulation from frosts, will lead to the loss of flowers and consequently reduce the reproductive potential of plants. Snow also serves to retain water in the ecosystem for longer periods of time, and quicker snow melts with increased temperatures mean that water is lost through the ecosystem more quickly than it would be normally, reducing the amount of time it is available to flora and fauna. Some specialist plant species, particularly in the alpine herbfields, such as the alpine marsh-marigold (*Psychrophila introloba*), frequently reside in the meltwaters of semi-permanent snowpatches and would therefore be adversely affected by reduced snow cover. Most species will be affected by decreased water availability in the alpine complex, with decreased production of seed predicted for species such as the mountain plum-pine, which is a vital food resource for fattening mountain pygmy-possums in preparation for their winter hibernation.

Any fauna (including the endangered mountain pygmy-possum) that is normally active under the snow or requires snow cover for insulation will be negatively affected by decreased snow coverage. Mountain pygmy-possums hibernate for between 5 and 7 months over the coldest months of the year, in insulated refuges created in boulder piles under the snow, which buffer temperature extremes. Air temperature has a strong effect on the efficiency of hibernation and energy expenditure: if temperatures drop too low, metabolism is increased in the hibernating possum, resulting in increased expenditure of vital fat reserves, reducing survivorship and recruitment. Earlier snow-melt times will lead to arousal from hibernation in advance of the availability of resources—in particular, the arrival of the Bogong moths from their over-wintering grounds. Consequently, decreased snow coverage during winter as a result of decreased precipitation and increased temperatures is likely to have dramatic effects on this already extremely vulnerable species. Exposure of fauna to feral predators such as cats is also likely to increase, as predators may be able to increase their activity with decreased snow coverage. Other species at risk include endemic alpine skinks and frogs, as well as the broad-toothed rat and the echidna (*Tachyglossus aculeatus*).

The distributions of some plants and animals are restricted by snow, and decreased snow coverage will result in an increase in the number of species able to persist in high-altitude alpine areas from which they may be currently excluded. This includes both native and non-native vertebrates and invertebrates, with wide-ranging impacts on ecosystem functioning, depending on the inter-species interactions. Of particular threat to the alpine communities is the likelihood of increased grazing pressure from both native and introduced herbivores, including deer, pigs, kangaroos/wallabies, hares and horses (*Equus caballus*). Increased erosion in alpine ecosystems will
result from the increased summer rains predicted with climate change, exposure of bare ground beneath disappearing snowpatches, loss of alpine plants through fire, impacts of grazing by hard-hoofed feral animals, pig rooting and increased pressure from tourism. Australia's highest lake, Lake Cootapatamba, currently suffers from increasing siltation, which will only be exacerbated by the conditions resulting from climate change. Increased rates of erosion will lead to sediment infill in areas of critical refuge habitat for fauna, such as the boulder fields required by mountain pygmy possums. Increased feral herbivore activity in the alpine zone will also increase the rate of trampling in sensitive areas of vegetation, including montane peatlands and swamps, as well as soil disturbance due to foraging activity.

More frosts, combined with the impacts of grazing, will serve to alter the vegetation structure of these communities, as an increase in the area of bare ground will favour the establishment of shrubs. Increased summer temperatures will reduce the germination of herbaceous seeds, and when this is combined with the increase in area of bare ground the net result will be increased shrubbiness throughout the alpine complex. The prevalence of shrub species such as *Grevillea australis*, *Phebalium* spp., *Kunzea* spp. and *Orites* spp. has been observed to be increasing since the 1970s, independent of the effects of fire and grazing. This is evidence of the sensitivity of this formation to the impacts of climate change. Increased temperatures will lead to changes in the soil, with nutrient cycling by invertebrates and soil fauna likely to be significantly affected by continually higher temperatures.

Predicted increases in temperature are likely to result in vegetation thickening at higher altitudes, with more tree growth occurring around the treeline, rather than the upward altitudinal movement predicted by the gradual distribution shift model. The treeline is defined as the altitudinal level at which the energy resources available limit the growth of trees: around the world this altitudinal position is at the 10 ºC mean maximum summer temperature level. Increases in global warming will raise this altitudinal level and increase the potential for the treeline to rise. However, the response of the snow gums (*Eucalyptus niphophila*) will be very slow because of the extreme weather conditions that prevail against recruitment at the treeline. These extreme events include frosts and glazing storms, which will persist under climate change. Hence the upward altitudinal movement of the treeline will not be readily evident by 2050. Identifiable changes in the treeline as a response would not be expected for up to 100 years or more.

The extent of changes in the distribution of plant species and communities will, predictably, be indirectly influenced by reduced snow cover. This is expected to cause an increase in diurnal freezing and thawing of the alpine humus soils, with increased ‘frost-heave’ action in areas with exposed soils. A flow-on effect will be a decrease in organic matter decomposition rates and a resulting depletion of soil nutrients within the nutrient-cycling regime of the alpine humus soils. This could greatly affect high-biomass-producing plant communities, such as tall alpine herbfields and heaths, leading to a reduction in their area of distribution. The alpine humus soils are low in nutrients and are able to support high biomass production only through rapid growth, biomass accumulation, decomposition, and nutrient release to growing plants. Important components of soil organic matter decomposition are the soil micro-fauna and invertebrate populations, which will similarly be reduced in number and activity if soil temperatures are reduced in the autumn and spring and increased in summer.

Increased temperatures may result in earlier flowering times of annual plants and shrubs, potentially disturbing the synchronicity of resource availability with the arrival of migratory bird species. The spring breeding seasons of bird species such as the flame robin (*Petroica phoenicea*), pink robin (*Petroica rodinogaster*), Richard’s pipit (*Anthus novaeseelandiae*) and various species of honeyeaters, as well as other
spring-breeding fauna, are likely to be altered. Evidence suggests the breeding season could be shortened under climate change because of increased temperatures and changes in resource availability, or conversely lengthened due to decreases in snow cover and increases in temperature allowing for multiple breeding attempts.

Potential also exists for increased temperatures to cause changes to the ecology of Bogong moths. Although this species has a fairly broad thermal range, it aestivates in cool rock crevices among boulderfields at high elevations. Increases in temperature throughout the alpine zone may lead the moths to move upward in altitude for their aestivation period, potentially affecting their availability as a food resource for species such as the mountain pygmy-possum. Without this source of autumn fattening food, it is likely that most local populations of mountain pygmy-possums at high elevations in the Kosciusko area would become extinct (NPWS 2002).

Within the complex there will be winners and losers under the projected changes in climate. Although generalist alpine heaths and shrublands will persist, and may actually increase in extent, specialist wet and snow-dependent communities such as the short herbfields may disappear all together, resulting in redistribution and overall ecosystem simplification of communities.

The short herbfields are restricted to depositional zones below semi-permanent snow patches where cold water drips out, and they will be negatively affected by a reduction in cold water availability through decreases in snow coverage and increased temperatures. Increased exposure to disturbances such as frost exposure and grazing will place the persistence of this community under considerable threat from the predicted impacts of climate change. Predicted increases in grazing by introduced and native herbivores because of increased habitat suitability will have marked effects on the species composition of the alpine herbfields. Highly palatable species such as the anemone buttercup (Ranunculus anemoneus), mountain celery (Aciphylla glacialis) and robust wallaby grass (Chionochloa frigida), which were grazed to near extinction in the past under livestock grazing regimes, will again decrease in abundance with increased grazing levels, whereas the less palatable species are likely to proliferate. This will result in reduced species diversity in the alpine zone, with the loss of some endemic species as the palatable inter-tussock herbs are preferentially removed by herbivores.

The changes in climate predicted by the present modelling indicate that climate in the alpine zone is becoming less of a barrier to invasive species. The spread of environmental weeds such as yarrow (Achillea millefolium), tansyleaf milfoil (Achillea distans) and orange hawkweed (Hieracium aurantiacum ssp. carpathicola) may lead to localised extinctions of native plants, with infestations of hawkweed species having already occurred in montane regions in New Zealand. Other species also likely to do well in alpine herbfields with the predicted changes in climate are Thistles, cats ear (Hypochaeris radicata) and dandelion (Taraxacum officinale).

The alpine bogs and fens depend on both ground water and localised precipitation patterns and are expected to suffer quite severely under the predicted change in precipitation regime. Reduced water flows will dry out these wetlands, leading to decreased coverage with water-dependent plants and sphagnum moss, as well as increased erosivity and channelling during high-intensity rainfall events. Extreme-temperature days are already having an effect on sphagnum recruitment and survival, with the moss showing signs of bleaching and crisping after hot days. These extreme temperature days are predicted to increase in magnitude and severity under climate change. Coupled with decreased precipitation throughout the alpine zone, they will definitely have a negative impact on the functioning of the alpine bogs if the cover of sphagnum moss is reduced. Disturbances such as fire and grazing, which
have negatively affected these communities in the past, are also predicted to increase with climate change and will compound the effects of drying. Sphagnum areas have retreated over the past 50 years because of grazing and drought, turning into sedgelands and grassland, and fire caused the loss of approximately 15% of the alpine bogs in 2003. The impacts of grazing will be increased in the next 40 years as the temperature limitations of grazing species are reduced. The effects of climate change will directly threaten the survival of the endangered southern corroboree frog, in particular because of changes in the alpine bogs resulting from decreased precipitation levels. The species has an extremely limited range, being restricted to sub-alpine areas within Kosciusko National Park, and it utilises the sphagnum bogs as breeding habitat. Females lay their eggs in a terrestrial nest, and the eggs hatch following substantial autumn or winter rains. The adults move into the surrounding heath and subalpine woodland, but the tadpoles remain in the pools of the alpine bogs to over-winter. Predicted reductions in water flow through these communities will result in decreased recruitment of the corroboree frog, whereas increased radiation and temperatures, in addition to decreased moisture levels throughout the formation, will lead to decreased adult survivorship. The alpine bogs and fens not only provide habitat for a number of endemic species such as the corroboree frog; they also influence the survival of communities downstream, which will also be negatively affected by flow reductions through these wetlands. Core areas of bogs may survive with the help of subterranean water supplies. However, with the added pressures of grazing and trampling, in particular by horses, this community will be subject to climate-change-related disturbance that may see it disappear altogether.

The general drying of the alpine region under the predicted changes in climate is likely to lead to increased fire frequency, with more widespread and intense fires. Fire has only ever been an infrequent part of the ecosystem functioning of the alpine zone, with only a handful of events since the late 18th Century; much greater frequency will lead to changes in the species composition and vegetation structure in a number of communities. Alpine vegetation is comparatively fire sensitive. It is slow to regenerate and contains many more obligate seeders than other communities. In particular, communities located on organic soils, such as the sphagnum bogs and the alpine herbfields, comprise mostly plants that have not evolved alongside the effects of fire, and the alpine heaths are comprised of extremely flammable plant species. The mountain plum-pine, one of the major food resources of the mountain pygmy-possum, is particularly flammable and sensitive to fire. Another fire before the current cohort of *Podocarpus* seedlings has matured could be catastrophic for the species and the community in which it is dominant. Increased fire frequency must be viewed as a threat to the persistence of the pygmy-possum.

Other species, although better-adapted to fire, would exhibit risky regeneration strategies if fire frequency were to increase beyond a certain threshold. The 2003 fires burned 90% of the alpine complex, and because of the drought effects present before the fires the organic soils burnt for weeks. Epacrid species present in the fjeldmarks regenerated sufficiently after the fire, but even 5 years on they are still only very small. Candle heath (*Richea continentis*) in the alpine bogs did not germinate until 3 years post-fire; another fire in that time would have wiped out this population. Increasing fire frequency is likely to disadvantage even those species that are well adapted to fire.

Regeneration, germination and recruitment of some plant species are facilitated by fire, leading to dramatic increases in abundance [e.g. of wild parsnip (*Trachymene composita*) and prickly starwort (*Stellaria pungens*)]. The alpine stork's-bill (*Pelargonium helmsii*) and papery goosefoot (*Chenopodium erosum*) were encountered after the 2003 fires, but they had not been recorded in the area previously, with papery goosefoot being significant as the first chenopod ever to be
located in the alpine zone. These species however, are still adapted to only infrequent occurrences of fire, and the impacts of marked increases in fire frequency on these species are unknown.

The effect of increased fire frequency on resource availability to fauna species will vary with the resources being utilised. Species such as the mountain pygmy-possum will be heavily affected by the predicted losses of mountain plum-pine, whereas the broad-toothed rat relies on grasses that resprout quite quickly after fire and may not be as vulnerable. All species will be threatened by the lack of cover present immediately post-fire, through increased exposure to predators such as cats and foxes.

**Freshwater wetlands**

*Montane lakes; montane bogs and fens (classes dealt with separately)*

Examples of montane bogs and fens (or escarpment bogs) include Nunnock, Wingecarribee and Bega swamps. These swamps are floristically similar to alpine bogs and fens, apart from containing a restionaceous (rush-like) component absent from the alpine bogs. These ecosystems are ground water dependent and are rich sources of peat formed upon organic soils. Significant changes in species composition of these communities are predicted to occur, as increased fire frequency will favour the proliferation of shrubs. Retractions in geographic range are likely, as are losses of these communities, particularly in the west and south of their distribution. The western communities, such as those present in Micalong Swamp and in Bago and Maragle state forests, will experience drier conditions and higher fire frequency, which will be compounded by human impacts such as grazing and hazard-reduction burning. Swamps with more easterly distribution are less likely to be affected by climate change within the next 40 years, but they are more likely to suffer degradation through human disturbance. These ecosystems are naturally isolated and are thus susceptible to human disturbances, which are likely to be irreversible. The impacts of climate change—including drying and increased fire frequency due to decreased average annual rainfall and increased weed invasion and erosion—will compound the effects of human disturbance on already degraded communities. Changes to the water regime and the condition of these ecosystems will also have major impacts on the communities downstream.

The montane lakes in the Alps and Tablelands region consist of ephemeral lakes, including Lake George and Lake Bathurst, as well as lakes in small deflation hollows, such as Llangothlin Lagoon (permanent glacial lakes such as Blue Lake were discussed above as part of the Alpine complex). These lakes have already undergone considerable drying, which is likely to be exacerbated by the overall decreases in annual rainfall predicted because of climate change. These lakes and depressions are predominant features in the landscape and are unlikely to change in geographic extent; however, they may be reduced in functionality by the loss of ecosystem values through multiple-source impacts from agricultural disturbance. Although the changes to these communities will be based on human disturbance, the impacts of climate change will exacerbate these changes. Increased dryness throughout the region will reduce the ability of this community to resist weed invasion and to recover once inundation occurs. Degradation of the montane lakes is likely to continue throughout their range, as there is little opportunity to mitigate the disturbance through management by conservation reserves.
**Major impacts**

**Decreased** annual moisture availability, with a major decrease in winter rainfall and slight increase in summer rainfall:

- decreased productivity and species diversity
- loss of resources for fauna:
  - loss of winter rainfall will be detrimental to winter- and spring-breeding fauna species
- changes in species composition:
  - incursions by plant species less able to tolerate wet conditions
  - loss of endemic wet-adapted plants
- gradient of less annual rainfall to more annual rainfall from west to east
  - western bogs and fens will be more heavily affected by drying than eastern ones
- possible increases in fire frequency with drier conditions
- increase in weed abundance
- increased erosion.

The montane bogs and fens are already heavily affected by human disturbance. Communities such as the Micalong and Wingecarribee swamps, although supposedly protected by their locations within flora reserves, are presently affected by cattle-grazing practices and show signs of degradation through heavy incisions, trampling and burning. Some swamps—especially those located in the Southern Highlands, are surrounded by pine (*Pinus radiata*) plantations, the harvesting of which increases erosion and silt deposition in the swamps. Commercial peat mining occurs throughout the range of these bogs and fens; mine subsidence in the Blue Mountains has already led to the draining and drying of swamps in the area, including Long Swamp. The worst example of degradation was manifested at Wingecarribee Swamp. After being mined for approximately 25 years, this swamp collapsed structurally, leading to drying, erosion, and subsequent shrub and weed invasion. Wingecarribee Swamp was once a habitat of international significance for species such as Latham’s snipe (*Gallinago hardwickii*) and the giant dragonfly (*Petalura gigantea*). Its collapse resulted in dramatic changes to the soil and vegetation that may take hundreds of years to fully rehabilitate. These ecosystems are exceedingly vulnerable to changes in climatic conditions, with decreased annual rainfall throughout the region compounding their already degraded state.

Because of their depositional nature, these swamps are areas of high availability of resources such as water and nutrients, as well as providing a diversity of habitats for the breeding, feeding and refuge of many native birds, frogs [including the northern corroboree frog (*Pseudophryne pengilleyi*)], skinks, snakes, tortoises and invertebrates such as insects and endemic crayfish (*Euastacus* and *Engaeus* spp.). As well as this, because of their high productivity they support an abundance of mammals, including the vulnerable broad-toothed rat, and concentrations of wombats and other native herbivores. Changes in habitat quality due to drying and draining of swamps, and/or changes in species composition, will therefore have wide-ranging impacts on resource availability for fauna in important areas of current refugia. Autumn and winter-breeding frog species such as Bibron’s toadlet (*Pseudophryne bibroni*) and the southern toadlet (*Pseudophryne dendyi*) will be adversely affected by reductions in winter rainfall, with subsequent increases in the mortality rates of both tadpoles and adults.
These swamps also support a number of rare, endemic plants, including the swamp gentian (*Gentiana wingecarribiensis*), leek orchid (*Prasophyllum uroglossum*) and yellow loosestrife (*Lysimachia vulgaris* var. *davurica*). As drying occurs with climate change, wet-adapted species will decline. There will be subsequent incursions by surrounding vegetation, including the more marginal wetland taxa [e.g. coral ferns (*Gleichenia* spp.) and tea-trees (*Leptospermum* spp.)]. The risk of invasion by exotic species also increases, as plants normally excluded by higher water levels will be able to colonise the extremely fertile soil. Increased potential exists for invasion by weeds, including blackberry (*Rubus fruticosus* agg.), willows (*Salix* spp.) and pasture grasses.

The spongy surfaces of these communities are particularly susceptible to trampling by hoofed animals such as livestock and to disturbance by feral pigs and horses, which uproot plants and wallow in the mud. The impacts of introduced herbivores on these swamps will increase with the predicted decrease in moisture availability. They will become a source of green feed, invertebrates and rhizomes in times of low resource availability in the surrounding landscape. As drying continues, the impacts of human use will also be exacerbated, with the continual use of vehicles through sensitive areas for activities such as hunting leading to entrenchment and degradation.

Montane bogs and fens throughout the region will undergo a general drying due to decreases in overall annual rainfall levels; however, those in the west of the region are at increased risk of drying because the annual rainfall is lower than in the east of the region. The western swamps are also more commonly located on private lands and in State Forests, so there are fewer opportunities to manage them for conservation purposes. All swamps are at increased risk of peat fires and of collapse through drainage, and there is decreased potential for recovery. As these soils dry out, they reach a stage where they are almost hydrophobic, and significant amounts of peat deposits may oxidise and decompose.

The ephemeral montane lakes, such as lakes George and Bathurst have been undergoing a period of decline in species diversity for quite some time. These lakes have been drying out, and with source taxa likely to be ephemeral in nature, lack of more frequent, substantial rainfall may prevent the recruitment and regeneration of some species, with many species now no longer existing where they once did. The faunal assemblages in these ecosystems are not well known; however, a decline in winter rainfall will affect winter- and spring–breeding species such as the eastern banjo frog (*Limnodynastes dumerilii*). Pastoral development of these nutrient-rich areas and the surrounding grasslands began hundreds of years ago, with heavy grazing causing local extinctions and resulting in the replacement of many native plant species by introduced ones. Species such as the endemic *Pelargonium* are unlikely to persist, as continual drying due to climate change will compound the effects of sustained grazing.

Small ephemeral lakes will fill with one good rainfall, whereas larger ones, such as Lake George, may take years of good rainfall to fill. The effects of drying are likely to be displayed along a gradient, with the larger, local-catchment lakes taking years of consistently higher rainfall levels to recover, although recovery is less likely to happen under the predicted climate scenario. None of these lakes is protected within conservation reserves; most of them are under long-term Crown lease agreements and are managed in accordance with local farming conditions.

The montane lakes are currently in a general state of severe degradation; because of lack of water and the effects of agricultural practices they are not much more than simplified aquatic communities. An influx of diverse plant species would normally occur when these lakes are flooded, but increased length of drought periods has led
to decreases in condition and resilience. At present, these lakes are drier for longer periods than they are wet. Periods of inundation that would normally decrease weed cover are reduced in frequency, with drying occurring quickly once inundation actually occurs; this effect is predicted to intensify under climate change. Continual heavy grazing pressure further compounds this degradation.

Reduced annual rainfall levels and increased temperatures will lead to prolonged periods of drought and are likely to cause further degradation of these ecosystems so that they cease to exist as they are currently known. Invasion by exotic species such as thistles, Paterson’s curse, pasture weeds and serrated tussock (*Nassella trichotoma*), as well as structural changes to the vegetation caused by more permanent drying, will lead to simplification throughout the system, with the risk of these areas becoming indistinguishable from the surrounding agricultural lands or (once they are actually inundated) from even more simplified wetlands. Wetlands are also at higher risk of salinisation with increased drying. Lakes George and Bathurst periodically contain fresh water overlying saline deposits at depth, as reflected by the presence of existence of salt marsh plants. Prolonged drought periods will potentially raise these saline deposits, leading to increased salinity throughout the area and increased prevalence of salt-tolerant plants.

The geographical extents of the montane lakes will remain the same; whether the community structure remains discernable from those on agricultural land will determine the change in distribution of these ecosystems. In terms of retaining distinct flora and fauna, this community is predicted to decline severely independently of the impacts of climate change, which will only serve to exacerbate the decline.

**Forested wetlands**

Both the eastern riverine (river oak – *Casuarina cunninghamiana*) and the inland riverine (river red gum – *Eucalyptus camaluldensis*) forests are presently heavily affected by human sources of disturbance, including land clearing as a by-product of agricultural development on adjacent land, nutrient enrichment, weed invasion and livestock grazing. The effects of these threats will be exacerbated by the impacts of climate change—in particular, by reduced flows due to decreased average annual rainfall throughout the region, as well as increased temperatures. The impacts will be manifested more strongly in communities affected by water regulation and surrounded by agricultural lands. Although some of these riverine forests are buffered in areas such as the Kowmung and the Shoalhaven rivers and are presently less affected by human impacts, they are still likely to be affected by climate change. Changes in geographical extent are unlikely to occur, but alterations in the structure and composition of these communities are likely to follow a geographical trend, with minor impacts on the northern and eastern edges of the region and major impacts to the west and south (the tablelands) in areas of agricultural development, such as the Murrumbidgee. Losses of overstorey trees due to the combined effects of continual drying, recruitment suppression by grazing and weed invasion will have major impacts on the quality of habitat for fauna, with losses in resources, productivity and biodiversity expected. Because these ecosystems generally occur on unreserved or private lands, the potential for their conservation is greatly reduced. It is therefore imperative that environmental water flows are maintained throughout the region to allow these communities the chance to regenerate and persist as they are currently known.

**Major impacts**

**Decreased** annual rainfall, with a gradient of more rainfall to less rainfall from north to south:
• decreased snow cover and thus decreased melt flows
• fewer flooding events owing to river regulation and water extraction, with a loss of ephemeral nature:
  — decreased casuarina and river red gum recruitment
  — increased tree death from water stress
  — decreased shrub component
• decreased productivity:
  — decline in riparian vegetation (thinner riparian band)
  — decline in resource availability for fauna in major dispersal corridor networks
• decreased water quality
• changes in flow paths due to loss of riverbank vegetation (stream widening and changes in course):
  — increased erosivity

**Increased** temperatures:
• warmer water temperatures, with lower oxygen levels
• impacts on aquatic fauna
• increased potential for algal blooms

**Changes** in seasonality of rainfall (decreased winter rainfall and increased summer rainfall):
• increased invasion potential for summer-growing weed species [e.g. willows (*Salix* spp.), blackberries (*Rubus* spp.), aided by decreased shading because of loss of overstorey through moisture stress.

Although the decrease in average annual rainfall throughout the region will result in a general drying of the environment, flow regimes in the rivers supporting these forests are ultimately affected by human water regulation. Continual drying under predicted climate change, in addition to water storage in dams and extraction for agriculture, has negative effects on river oak and river red gum recruitment, as well as increasing moisture stress on already established trees. This is already being displayed in forests along the Deua River, with the removal of water for orchard production resulting in the deaths of river oaks in the area from continued water stress. Recruitment suppression of this species is also occurring, as a result of drying and the effects of grazing. Further water stress due to climate change is likely to result in the loss of established river oaks and river red gums. Water flows upstream of these communities are also likely to decrease, particularly in the Snowy River, with the predicted reductions in snowfall and the resulting spring snowmelt flows. Changes in the structure of this community can be expected to occur, with growth in the riparian band narrowing; vegetation will survive close to the mean water’s edge, but not farther outwards, because of restricted recruitment. Flooding provides the main stimulant for regeneration of these communities, and with increasing flow regulation and decreasing flows upstream the ability of this community to persist is greatly threatened. Loss of riparian vegetation will result in stream widening because of decreased stabilisation and increased erosivity of soils, with increased siltation downstream and resultant decreases in water quality.

These forests are currently very weedy, highly disturbed environments because they are located along waterways, which provide an easy dispersal mechanism for invasive species such as willows. These weed species are predicted to be favoured
by climate change with the change in seasonality of rainfall, with decreased winter rainfall and an increase in rainfall in summer during their growth period. Willows compete with native trees for water and with trees already stressed by decreased moisture. With river oak recruitment suppressed by decreased winter rainfall, the decrease in shading by native overstorey trees will also favour weed establishment. Willows are among the worst weeds in Australia because of their invasiveness, potential for spread, and economic and environmental impacts. Unlike most other vegetation, willows spread their roots into the bed of a watercourse, slowing the flow of water and reducing aeration. They form thickets that divert water outside the main watercourse or channel, causing flooding and erosion where the creek banks are vulnerable. Willow leaves create a flush of organic matter when they drop in autumn, reducing water quality and available oxygen and directly threatening aquatic plants and animals, such as the threatened Booroolong frog (*Litoria booroolongensis*). This, together with the amount of water willows use, damages stream health. The replacement of native vegetation (e.g. river red gums) by willows reduces habitat (e.g. nesting hollows, snags) for both land and aquatic animals. Potential increases in the abundance of weed species such as willows because of climate change will have major negative impacts on these already degraded ecosystems.

The understory of these communities on the Tablelands is currently affected by riparian grazing practices, further increasing invasion potential for weed species. Native shrubs such as bossiaeas, leptospermums and the threatened pale pomaderris (*Pomaderris pallida*) have been greatly reduced in range, particularly along the Murrumbidgee River, increasing the potential for the establishment of understory weeds such as briar rose (*Rosa rubiginosa*), blackberries and hemlock (*Conium maculatum*); this in turn reduces the recruitment and re-establishment potential of native plants. The removal of native vegetation cover by fire also favours weed establishment, and with drier conditions and increased temperatures under climate change, fire frequency may increase throughout the region.

The riparian stream-bank communities provide productive corridors for fauna dispersal. They contain resources such as tree hollows for nesting and roosting, as well as food resources such as seeds, nectar and pollen and insects. Threatened species such as the regent honeyeater rely on the flowers and fruit of mistletoe present in casuarina and river red gum forests, as well as on the foliage for nesting material. Superb parrots use riverine red gum corridors farther to the west. Any changes in forest structure that result in a decrease in the abundance of overstorey trees and tree hollows, mistletoe, and other resources will have negative effects on fauna species, including arboreal mammals, hollow-nesting birds and bats (e.g. large-footed myotis, *Myotis macropus*). Aquatic species such as the platypus (*Ornithorhynchus anatinus*), water rat (*Hydromys chrysogaster*) and Macquarie Perch (*Macquaria australasica*) require riparian vegetation to provide structural stability to stream banks, shading from sunlight, and underwater habitat for invertebrate prey species. Changes to the species composition and structure of riparian vegetation, through the loss of overstorey species, will have wide-ranging impacts on aquatic ecology.

An increase in temperature, combined with potential loss of shading from overstorey trees, will serve to increase water temperatures within the rivers supporting these ecosystems. This will have implications for the fauna and flora species within these riverine forests and for the rivers themselves, with lower oxygen levels present in warmer waters. Invertebrate reproduction is likely to be affected; mayflies (*Ephemoptera*) and stoneflies (*Plecoptera*) both prefer cool, fast-flowing water, as it has higher levels of dissolved oxygen. A decrease in invertebrate numbers and diversity will have significant negative impacts on insectivorous species, including native fish, bats and birds, as well as on nutrient cycling throughout the ecosystem.
Warmer waters combined with an increased occurrence of water pooling due to decreased flows and local rainfall, and the resulting increased nutrient concentrations, will increase the potential for algal blooms, with detrimental effects on water quality for fauna, as well as for human use.
8 References

Adlem L and Timms BV (2000) Biogeography of the Freshwater Peracarida (Crustacea) from Barrington Tops, NSW. *Proceedings of the Linnean Society of New South Wales* 122, 131–141


Appendix 1  Workshop participants

North Coast, Tablelands and Hunter regions workshop, 8 and 9 May 2008

Conveners
Joanna Muldoon and Tim Thomcraft, Project Officers, Information and Assessment Section, North East Branch, DECC.

Participants
Travis Peak Umwelt (Australia) Pty Limited
Steven Bell Eastcoast Flora Survey
Lachland Copeland DECC
Peter Richards Eco Logical Australia Pty Ltd
David Milledge Landmark Ecological Services
Robert Kooyman Royal Botanic Gardens and Domain Trust
Lucas Grenadier DECC
David Scotts DECC

Not present but providing additional input:
Bruce Chessman Principal Research Scientist, Catchment and Environment Protection Sciences Branch, DECC
Neil Saintilin

North West Slopes to Darling Riverine Plains (part of the New England – North West State Plan region) workshop, 14 and 15 May 2008

Conveners
Joanna Muldoon and Tim Thomcraft, Project Officers, Information and Assessment Section, North East Branch, DECC.

Participants
Murray Ellis DECC
Doug Binns State Forests NSW
Greg Steenbeeke Inverell Catchment Management Authority
Phil Spark
Mick Andren (day 1 only) DECC
John T. Hunter J.A. Hunter Pty Ltd
David Milledge Landmark Ecological Services
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Not present but providing additional input:
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Sydney region workshop, 15 and 16 May 2008

Conveners
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Participants:
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Martin Schulz Fauna Consultant, Information and Assessment Section, Metropolitan Branch, DECC

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South Coast region workshop, 7 and 8 May 2008

Conveners
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Participants:
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Phil Craven Project Officer, Environmentally Sustainable Forest Management, South Coast Region, DECC
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Dr Michael Dunlop Land, Water and Biodiversity Analyst, CSIRO Sustainable Ecosystems
Jackie Miles Naturalist, ngh environmental Pty Ltd
Dimitri Young Threatened Species Coordinator, Biodiversity Conservation Section, South Branch, DECC
North Western – South Western regions workshop, 7 to 9 May 2008

Conveners
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Else Foster Operations, Northwest Branch, Lower Murray-Darling CMA, Buronga
Miranda Kerr Parks and Wildlife Western, DECC, Dubbo
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David Parker Regional Biodiversity Conservation Officer, DECC, Griffith
James Val Scientific Services, DECC, Buronga
Mike Maher Wetlands and Rivers, Riverbank, DECC

Not present but providing additional input:
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A/Prof. Ian Lunt Charles Sturt University, Wagga Wagga

Alps – Tablelands regions workshop, 13 and 14 May 2008

Conveners
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Participants
John Briggs Senior Threatened Species Officer, DECC, Queanbeyan
Dr Linda Broome Senior Threatened Species Officer, DECC, Queanbeyan
Matt Cameron Regional Biodiversity Conservation Officer, DECC, Albury
Roger Good Good Environmental Systems; former DECC ecologist
Prof. Geoff Hope Australian National University, Canberra
Alison Mathews Charles Sturt University, Albury
Dr Keith McDougall Senior Threatened Species Officer, DECC, Queanbeyan
Geoff Robertson Flora Ecologist, DECC, Queanbeyan
Julian Seddon CSIRO Sustainable Ecosystems, Canberra
Not present but providing additional input:

Dr Ken Green  Alpine Ecologist, NSW Parks and Wildlife, DECC, Snowy Mountains
A/Prof. Ian Lunt  Charles Sturt University, Albury
Dr Damon Oliver  Senior Threatened Species Officer, DECC, Queanbeyan
Rainer Rehwinkel  Senior Threatened Species Officer, DECC, Queanbeyan
## Appendix 2  Significant species of the North West Slopes to Darling riverine plains study region

Prepared by Phil Spark

<table>
<thead>
<tr>
<th>Community</th>
<th>Significant fauna</th>
<th>Significant flora</th>
<th>Threats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semi-arid floodplain grasslands – black soil plains west of Moree</td>
<td>Five-clawed worm-skink (<em>Anomalopus mackayi</em>)</td>
<td>Myall EEC</td>
<td>African boxthorn Mimosa</td>
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<td></td>
<td>Stripe-faced Dunnart</td>
<td>Coolibah – black box EEC</td>
<td>Lippia</td>
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<td>Bustard</td>
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<td>Brolga</td>
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<td><strong>Refer to list of fauna species at eastern and southern limits (Appendix 3)</strong></td>
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<tr>
<td>Western Slopes grasslands – alluvial plains and weathered basalt slopes on the Western Slopes</td>
<td>Significant for grassland birds and mammals, many at eastern limit on Liverpool plains, e.g.</td>
<td>Plains grass grasslands EEC</td>
<td>African lovegrass Chickory</td>
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<tr>
<td></td>
<td>Bustard</td>
<td>Liverpool Plains EEC</td>
<td>Wild turnip Mimosa</td>
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<td></td>
<td>Brolga</td>
<td>Myall EEC</td>
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<td></td>
<td><strong>Refer to list of fauna species at eastern limit (Appendix 3)</strong></td>
<td>Fuzzy box EEC</td>
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<td></td>
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<td>Finger panic grass (<em>Digitaria porrecta</em>)</td>
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<td>Community</td>
<td>Significant fauna</td>
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| Yetman DSF siliceous sand (e.g. Bebo and Arakoola NR sandstone) | Eastern cave bat  
Large-eared pied bat  
Greater long-eared bat  
Little pied bat  
Yellow-bellied sheathtail-bat  
Grey-headed flying-fox  
Hairy-nosed freetail bat  
Koala  
Black-striped wallaby  
Squirrel glider  
Delicate mouse  
Spotted-tailed quoll  
Square-tailed kite  
Barking owl  
Hooded robin  
Speckled warbler  
Grey-crowned babbler  
Diamond firetail  
Brown treecreeper  
Turquoise parrot  
Black-chinned honeyeater  
Glossy black cockatoo  
Dunmall’s snake  
Border thick-tailed gecko  
Endangered population of brush turkey  
**Refer to list of fauna species at western and southern limits (Appendix 3)** | Stuart’s bush pea (*Pultenaea stuartiana*) | African lovegrass and Coolatai grass are major problems and have already invaded Arakoola NR |


<table>
<thead>
<tr>
<th>Community</th>
<th>Significant fauna</th>
<th>Significant flora</th>
<th>Threats</th>
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<tbody>
<tr>
<td>Western Slopes DSF Sandy infertile soil (e.g. Pilliga NR) Mugga ironbark, cypress, tumbledown red gum Many endemic species</td>
<td>Square-tailed kite Barking owl Hooded robin Diamond firetail Brown treecreeper Turquoise parrot Black-chinned honeyeater Speckled warbler Grey-crowned babbler Regent honeyeater Glossy black cockatoo Eastern cave bat Large-eared pied bat Greater long-eared bat Little pied bat Yellow-bellied sheathtail-bat Grey-headed flying-fox Spotted-tailed quoll Squirrel glider Koala Pilliga mouse Eastern pygmy possum Refer to list of fauna species at western limit – (Appendix 3)</td>
<td>MacBarron’s goodenia (<em>Goodenia macbarronii</em>) <em>Pomaderris queenslandica</em> <em>Diuris tricolor</em></td>
<td>African lovegrass and Coolatai grass are major problems and have already invaded much of the Coonabarabran locality</td>
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<td>Community</td>
<td>Significant fauna</td>
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<td>Threats</td>
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<tr>
<td>Northern Tablelands DSF community</td>
<td>Square-tailed kite</td>
<td>Rod’s star hair (Astroticha roddii)</td>
<td>Coolatai grass and African lovegrass have begun to invade</td>
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<td>Black pine, Caley’s ironbark, orange gum, tumbledown red gum</td>
<td>Barking owl</td>
<td>Ovenden’s ironbark (Eucalyptus caleyi subsp. Ovendenii)</td>
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<td>Infertile rocky ridges in Emmaville–Bonshaw area</td>
<td>Glossy black-cockatoo</td>
<td>Stuart’s bush pea (Pultenaea stuartiana)</td>
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<td>Turquoise parrot</td>
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<td>Regent honeyeater</td>
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<td>Hooded robin</td>
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<td>Diamond firetail</td>
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<td>Brown treecreeper</td>
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<td>Black-chinned honeyeater</td>
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<td>Speckled warbler</td>
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<td>Koala</td>
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<td>Spotted-tailed quoll</td>
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<td>Eastern bentwing bat</td>
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<td>Eastern cave bat</td>
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<td>Large-eared pied bat</td>
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<td>Greater long-eared bat</td>
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<td>Refer to list of fauna species at western limit (Appendix 3)</td>
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<td>Serpentinite ridges</td>
<td>Square-tailed kite</td>
<td>Rupp’s boronia ((\text{Boronia ruppii}))</td>
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<td>Barking owl</td>
<td>Woodsreef stringybark ((\text{Eucalyptus sp.}))</td>
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| North West Slopes DSW: moderately fertile soils on Western Slopes, silver-leaf ironbark – white cypress – white box | Square-tailed kite  
Spotted-tailed quoll  
Greater long-eared bat  
Little pied bat  
Yellow-bellied sheathtail-bat  
Grey-headed flying-fox  
Border thick-tailed gecko  
Koala  
Squirrel glider  
Barking owl  
Swift parrot  
Hooded robin  
Speckled warbler  
Grey-crowned babbler  
Diamond firetail  
Brown treecreeper  
Turquoise parrot  
Black-chinned honeyeater  
Regent honeyeater  
Painted honeyeater  
**Refer to list of fauna species at western limit (Appendix 3)** | Lake Keepit hakea (*Hakea pulvinifera*)  
EEC  
White box – yellow box – Blakely’s red gum (also listed as a critically EEC) | Coolatai grass and African lovegrass are invading |
<table>
<thead>
<tr>
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<th>Significant flora</th>
<th>Threats</th>
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<td>Northern Tablelands DSF granitic soil</td>
<td>Square-tailed kite</td>
<td>Howell shrublands EEC</td>
<td>Coolatai grass, African lovegrass and whisky grass have begun to invade</td>
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<tr>
<td>(e.g. Warrabah NP, Watson’s Creek NR,</td>
<td>Barking owl</td>
<td>McKie’s stringybark/Blackbutt open forest EEC</td>
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<td>Ironbark NR)</td>
<td>Glossy black-cockatoo</td>
<td>McKie’s stringybark <em>(Eucalyptus mckieana)</em></td>
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<td>Turquoise parrot</td>
<td>Narrow-leaved peppermint <em>(Eucalyptus nicholii)</em></td>
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<td>Regent honeyeater</td>
<td>Velvet wattle <em>(Acacia pubifolia)</em></td>
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<td>Hooded robin</td>
<td><em>Rutidosis heterogama</em></td>
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<td>Diamond firetail</td>
<td>MacBarron’s goodenia <em>(Goodenia macbarronii)</em></td>
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<td>Brown treecreeper</td>
<td>Austral toadflax <em>(Thesium austral)</em></td>
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<td>Pilliga outwash</td>
<td>Black-striped wallaby</td>
<td>Western grey box EEC</td>
<td>Buffel grass</td>
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<td>DSF</td>
<td>Glossy black-cockatoo</td>
<td>Fuzzy box EEC</td>
<td>Coolatai grass</td>
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<td>Edge of fertile plains</td>
<td>Square-tailed kite</td>
<td>EEC of white box, yellow box and Blakely’s red gum</td>
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<td><strong>Overlap zone between fauna at their eastern and western limits (Appendix 3)</strong></td>
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<td>Dry rainforest</td>
<td>Endangered population of brush turkey</td>
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<td><strong>Refer to list of fauna species at western limit (Appendix 3)</strong></td>
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<td>Western vine thicket</td>
<td>Brush-tailed rock wallaby</td>
<td>Ooline (<em>Cadellia pentastylis</em>) (also an EEC)</td>
<td>Semi-evergreen vine thicket EEC</td>
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<td>Grey-headed flying fox</td>
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<td>Endangered population of brush turkey</td>
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<td><strong>Refer to list of fauna species at western limit (Appendix 3)</strong></td>
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<td>Western Slopes grassy box woodland</td>
<td>Squirrel glider</td>
<td>Austral toadflax <em>(Thesium austral)</em></td>
<td>Serious infestation of Coolatai grass and African lovegrass</td>
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<td>Koala</td>
<td>Bluegrass <em>(Dichanthium setosum)</em></td>
<td>Feathertop rhodes grass</td>
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<td>Five-clawed worm skink</td>
<td>Myall creek wattle <em>(Acacia atrox)</em></td>
<td>Whisky grass</td>
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<td>Hooded robin</td>
<td>EEC of white box, yellow box and Blakely's red gum (also listed as a critically EEC)</td>
<td>Saffron thistle</td>
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<td></td>
<td>Diamond firetail</td>
<td>Plains grass grasslands EEC</td>
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<td>Turquoise parrot</td>
<td>Fuzzy box EEC</td>
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<td>Swift parrot</td>
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<td>Black-chinned honeyeater</td>
<td>Inland grey box EEC</td>
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<td>Floodplain Transition grassy box Woodland</td>
<td>Squirrel glider Hooded robin Grey-crowned babbler Diamond firetail Brown treecreeper Turquoise parrot Black-chinned honeyeater Koala Greater long-eared bat Little pied bat Yellow-bellied sheathtail-bat Bush stone curlew Bustard Barking owl Glossy black-cockatoo Square-tailed kite Overlap zone between fauna species at eastern, western and southern limits (Appendix 3)</td>
<td>Western grey box EEC Fuzzy box EEC</td>
<td>Mimosa</td>
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<tr>
<td>Inland floodplain swamps – Gingham</td>
<td>Wetland bird breeding blue-billed duck Freckled duck Pink-eared duck Australasian bittern Black-necked stork Painted snipe Giant dragonfly Five-clawed worm skink Stripe-faced dunnart Little pied bat Yellow-bellied sheathtail-bat Bush stone curlew Brolga Bustard Grey-crowned babbler Refer to list of fauna species at eastern and southern limits (Appendix 3)</td>
<td>EEC listed under Fisheries Management Act Coolibah EEC Ramsar, JAMBA, CAMBA significance</td>
<td>Lippia Water hyacinth Box thorn Pigs</td>
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<td>Montane bogs and fens</td>
<td>Refer to list of fauna species at western limit (Appendix 3)</td>
<td>EEC upland wetlands of the drainage divide of the New England Tablelands</td>
<td></td>
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<tr>
<td>Inland Floodplain shrublands – lignum watercourses</td>
<td>Wetland bird breeding Blue-billed duck Freckled duck Pink-eared duck Australasian bittern Black-necked stork Painted snipe Giant dragonfly Five-clawed worm skink Stripe-faced dunnart Little pied bat Yellow-bellied sheathtail-bat Bush stone curlew Bustard Brolga Grey-crowned babbler Refer to list of fauna species at eastern and southern limits (Appendix 3)</td>
<td>EEC listed in FM Act Lippia Water hyacinth Box thorn Pigs Noogoora burr</td>
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<tr>
<td>Inland riverine red gum</td>
<td>Pale-headed snake</td>
<td>EEC listed in FM Act</td>
<td>Lippia</td>
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<td>forest</td>
<td>Koala</td>
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<td>Water hyacinth</td>
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<td>Barking owl</td>
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<td>Bush stone curlew</td>
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<td>Refer to list of fauna species at eastern and southern limits (Appendix 3)</td>
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<tr>
<td>Coast and tablelands riverine forest</td>
<td>Booroolong frog&lt;br&gt;Davies tree frog&lt;br&gt;Bell's turtle&lt;br&gt;Olive perchlet&lt;br&gt;Purple spotted gudgeon&lt;br&gt;Silver perch&lt;br&gt;Square-tailed kite&lt;br&gt;Squirrel glider&lt;br&gt;Koala&lt;br&gt;Hooded robin&lt;br&gt;Diamond firetail&lt;br&gt;Brown treecreeper&lt;br&gt;Turquoise parrot&lt;br&gt;Swift parrot&lt;br&gt;Black-chinned honeyeater&lt;br&gt;Regent honeyeater&lt;br&gt;Painted honeyeater&lt;br&gt;Barking owl&lt;br&gt;Spotted-tailed quoll&lt;br&gt;Eastern bentwing bat&lt;br&gt;Greater broad-nosed bat&lt;br&gt;Yellow-bellied sheath-tail-bat&lt;br&gt;Grey-headed flying-fox&lt;br&gt;<strong>Refer to list of fauna species at western limit (Appendix 3)</strong></td>
<td>EEC listed in FM Act&lt;br&gt;**Casuarina dieback&lt;br&gt;Plague minnow&lt;br&gt;Redfin perch&lt;br&gt;Trout&lt;br&gt;Blackberry&lt;br&gt;Madeira vine&lt;br&gt;Willows&lt;br&gt;Privet&lt;br&gt;Noogoora burr&lt;br&gt;Wild turnip</td>
<td><strong>High rate of endemism</strong></td>
</tr>
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</table>

<p>| Northern montane heath – Kaputar       | <strong>Possibly adjunct populations at western limit – refer to list of fauna species at western limit (Appendix 3)</strong> | <strong>High rate of endemism</strong> | <strong>High rate of endemism</strong> |</p>
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| Western peneplain woodland – shrubby bimble box – cypress | Pale-headed snake  
Yellow-bellied sheathtail bat  
Koala  
Square-tailed kite  
Pale-headed snake  
Barking owl  
Major Mitchell cockatoo  
Stripe-faced dunnart  
Little pied bat  
Yellow-bellied sheathtail-bat  
Bush stone curlew  
Grey-crowned babbler  
Painted honeyeater  
Black-chinned honeyeater | **Refer to list of fauna species at eastern and southern limits (Appendix 3)** | Buffel grass  
African boxthorn |
| Moist open Forest – Nundle and Kaputar | Yellow-bellied glider  
Davies tree frog  
Eastern false pipistrelle  
Greater broad-nosed bat  
Powerful owl  
Masked owl  
Glossy black cockatoo  
Swift parrot  
Spotted-tailed quoll  
Grey-headed flying fox  
Eastern bentwing-bat | **Refer to list of fauna species at western limit (Appendix 3)**  
Small-fruited mountain gum (*Eucalyptus orestbia*)  
Sphagnum moss cool temperate rainforest EEC  
Ribbon gum – mountain gum – snow gum EEC | Blackberry  
Scotch broom |
Appendix 3  Species at the limits of their range in the North West Slopes to Darling riverine plains study region

Prepared by Phil Spark

The following tables list those species whose distribution areas are at the southern, eastern or western limit within the North West Slopes and Plains and that are therefore at increased risk of impact by climate change. They have been classified into ‘Highly Significant’, ‘Significant’ and ‘Common’ on the basis of their abundance and the extent of their occurrence within the region.

Key to symbols used:
NE  Nationally Endangered (Environment Protection and Biodiversity Conservation Act 1999)
NV  Nationally Vulnerable (Environment Protection and Biodiversity Conservation Act 1999)
E   Endangered (NSW Threatened Species Conservation Act 1995)
V   Vulnerable (NSW Threatened Species Conservation Act 1995)
RS  Regionally significant
AL  Common, widespread species at the limit of its distribution area
### Regionally significant species at their western limit on the North West Slopes and Plains

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### Regionally significant species at their eastern limit in this region

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<td>Gehyra variegata</td>
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<td>Prickly gecko</td>
<td>Heteronotia binoei</td>
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<td>Narrow-nosed planigale</td>
<td><em>Planigale tenuirostris</em></td>
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<td>Fat-tailed dunnart</td>
<td><em>Sminthopsis crassicaudata</em></td>
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<td>Stripe-faced dunnart</td>
<td><em>Sminthopsis macroura</em></td>
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<tr>
<td><strong>BATS</strong></td>
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<tr>
<td>Inland freetail-bat</td>
<td><em>Mormopterus sp.</em> (spf)</td>
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<tr>
<td>Southern freetail-bat</td>
<td><em>Mormopterus sp.</em> (lpf)</td>
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<tr>
<td>Little pied bat</td>
<td><em>Chalinolobus picatus</em></td>
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<td>Greater long-eared bat</td>
<td><em>Nyctophilus timoriensis</em></td>
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<td>Inland broad-nosed bat</td>
<td><em>Scotorepens balstoni</em></td>
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<td>Black-tailed native-hen</td>
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<td>Australian bustard</td>
<td>Ardeotis australis</td>
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<td>Red-necked avocet</td>
<td>Recurvirostra novaehollandiae</td>
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<td>Australian pratincole</td>
<td>Stiltia isabella</td>
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<td>Red-tailed black cockatoo</td>
<td>Calyptorhynchus banksii</td>
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<td>Major Mitchell cockatoo</td>
<td>Cacatua leadbeateri</td>
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<td>Mulga parrot</td>
<td>Psephotus varius</td>
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<td>Little corella</td>
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<td>Cockatiel</td>
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<td>Red-winged parrot</td>
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<td>Mallee ringneck</td>
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<td>Northiella haematogaster</td>
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<td>Black-eared cuckoo</td>
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<td>White-winged fairy-wren</td>
<td>Malurus leucopepterus</td>
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<td>Western warbler</td>
<td>Gerygone fusca</td>
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<td>Inland thornbill</td>
<td>Acanthiza apicalis</td>
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<td>Chestnut-rumped thornbill</td>
<td>Acanthiza uropygialis</td>
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<td>Southern whiteface</td>
<td><em>Aphelocephala leucopsis</em></td>
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<td>Spiny-cheeked honeyeater</td>
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<td>Yellow-throated miner</td>
<td><em>Manorina flavigula</em></td>
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<td>Singing honeyeater</td>
<td><em>Lichenostomus virescens</em></td>
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<td>Black honeyeater</td>
<td><em>Certhionyx niger</em></td>
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<td>Crimson chat</td>
<td><em>Epthianura tricolor</em></td>
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<td>White-fronted chat</td>
<td><em>Epthianura albifrons</em></td>
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<td>Red-capped robin</td>
<td><em>Petroica goodenovii</em></td>
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<td>White-browed babbler</td>
<td><em>Pomatostomus superciliosus</em></td>
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<td>Crested bellbird</td>
<td><em>Oreoica gutturalis</em></td>
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<td>Little raven</td>
<td><em>Corvus mellori</em></td>
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<td>Little crow</td>
<td><em>Corvus bennetti</em></td>
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<td>Apostlebird</td>
<td><em>Struthidea cinerea</em></td>
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<td>Spotted bowerbird</td>
<td><em>Chlamydera maculata</em></td>
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<tr>
<td>Barking owl</td>
<td><em>Ninox connivens</em></td>
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<tr>
<td>Spotted nightjar</td>
<td><em>Eurostopodus argus</em></td>
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Regionally significant species at their southern limit on the North West Slopes and Plains

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<td><strong>FROGS</strong></td>
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<td>Short-footed water-holding frog</td>
<td>Cyclorana brevipes</td>
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<td>New Holland water-holding frog</td>
<td>Cyclorana novaehollandiae</td>
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<td><strong>GECKO</strong></td>
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<td>Northern velvet gecko</td>
<td>Oedura rhombifer</td>
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<td><strong>SNAKES</strong></td>
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<td>Spotted python</td>
<td>Antaresia maculosa</td>
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<td>Dunmall’s snake</td>
<td>Furina dunmalli</td>
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<td>Eastern two-lined dragon</td>
<td>Diporiphora australis</td>
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<td>Freckled monitor</td>
<td>Varanus tristis orientalis</td>
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<td>Ctenotus ingrami</td>
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<td><strong>SMALL GROUND MAMMALS</strong></td>
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<td>Delicate mouse</td>
<td>Pseudomys delicatulus</td>
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<td>Black-striped wallaby</td>
<td>Macropus dorsalis</td>
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<td><strong>BATS</strong></td>
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<tr>
<td>Beccari’s freetail</td>
<td>Mormopterus beccari</td>
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<tr>
<td>Hairy-nosed freetail-bat (at its south-east limit)</td>
<td>Mormopterus sp.</td>
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<td>Flock bronzewing</td>
<td>Phaps histrionica</td>
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<td>Squatter pigeon</td>
<td>Geophas scripta</td>
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<td>Bush stone-curlew (formerly occurred farther south)</td>
<td>Burhinus grallarius</td>
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<td>Grass owl</td>
<td>Tyto capensis</td>
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<tr>
<td>Wandering whistling-duck (occurs farther south during wet years)</td>
<td>Dendrocygna arcuata</td>
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