THE STATE OF AUSTRALIA'S BIRDS 2007

Birds in a Changing Climate

Birds Australia
CONSERVATION THROUGH KNOWLEDGE

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The term climate change *is commonly used to refer to shifts in modern climate, including the rise in average surface temperature known as global warming or the enhanced greenhouse effect. We use it here to refer to anthropogenic climate change, under the presumption that it is overwhelmingly caused by humans and hence has potential to largely be stabilised or reversed.*

The State of Australia's Birds report series presents an overview of the status of the nation's birds, the major threats they face and the conservation actions needed. This fifth annual report focuses on climate change.

The climate is always changing and birds respond by adapting and evolving. However, at least since the very early 1900s the surface temperature of the earth has been warming at a rate unprecedented in human history, bringing with it shifts in local, regional and global weather systems. The vast majority of scientists agree that this is almost all attributable to the release of excessive amounts of greenhouse gases through human activity, particularly the use of fossil fuels and deforestation.

Australia has warmed by 0.9 °C since 1900, most rapidly since 1950, and is expected to warm a further 1 °C over the next two decades. Signs of this change are already reflected in the distribution and abundance of some of our birds and in the timing of their breeding and migration, in line with changes observed in other biota. Further shifts, both expansions and contractions, and extinctions have been predicted.

There will always be change, but the more we reduce greenhouse gas emissions and reconnect the natural world, affording nature some resilience and allowing birds to move across the landscape in response to climate change, the more certain the future will be for us and our birds. Overwhelmingly, we must stabilise and then reduce greenhouse gas emissions. There is nothing to be lost and everything to be gained by Australia acting now to reduce our dependence on fossil fuels and sequester (trap) carbon for the benefit of biodiversity.

At a desert waterhole a Crested Pigeon drinks deeply: a vision of the future? Photo by **Raoul Slater**

KEY POINTS

Climate change is bringing mixed news for Australia's birds. Some species will benefit, others will be disadvantaged over and above the other long-standing threats they face. We don't know how quickly birds can adapt to the changes, but we think that many will and we know that some won't. To facilitate adaptation, connectivity is the catch-cry: reconnecting natural landscapes and habitats and connecting biodiversity to carbon policies and procedures.

- Climate change is unequivocal: it is upon us and largely attributable to greenhouse gas emissions generated by the activities of humans—primarily the release of carbon dioxide from the burning of fossil fuels and deforestation.
- Average surface temperature in Australia has warmed by 0.9 °C over the last century. Because of the response-lag of temperature to atmospheric greenhouse gases, further warming is inevitable—considered with a high level of certainty to increase a further 1 °C in the next two decades—even if we manage to stabilise greenhouse emissions in the near future.
- Rainfall projections are less certain, but a decrease in the south is likely. Sea surface temperatures are rising, as are sea levels. An increase in the severity, and perhaps frequency, of extreme events, such as heat waves, drought, fire and flood, is also likely. All these changes have consequences for birds.
- Some of Australia's birds are showing changes consistent with climate change effects recorded elsewhere in the world; the most evident are range shifts southwards (and upwards); but there are also adjustments in the timing of events such as migration and breeding of land-birds, and both increases and decreases in the breeding success of various colonial seabirds. These changes are an indication that some species may have the potential to adapt and that others don't.
- Warming may be facilitating the spread of some species, both native and introduced, plant and animal, which has implications for the management of native species and the threat to them from pests.
- We are only just beginning to identify the life history characteristics of species most at risk. The prognosis is poor for species restricted to high altitudes and latitudes, to breeding islands that are low-lying or close to an affected food source, or to other small, disconnected islands of habitat. Wetland birds that are dependent on freshwater habitats starved of water or which will be inundated with salt water, will have limited means to adapt.
- It is difficult to separate the impacts of other threatening process, such as habitat loss, from the effects of climate change. Hence, impacts on populations are likely to be going undetected and the changes already detected may not be attributable to climate change alone.
- Federal, State and Local Governments and the public have generally recognised the advent of climate change and the need to reduce greenhouse gas emissions, make profound improvements in the efficiency of our energy and water use, and reduce overall consumption of energy and water and find more environmentally sustainable sources of both.
- To help birds and biota adapt to climate change, other environmental stresses, such as invasive species, must be reduced. For example, more funding should go into eradication of weeds in the early stages of establishment, and introduced, fire-promoting pasture grasses should be avoided. Habitat restoration should be employed to ease the impact of native invaders such as Noisy Miners.
- Species with a small range or limited ability to disperse may need extra assistance, including translocation.
- We lack rigorous long-term data on birds. Research and monitoring will need to address these issues to help us track and manage impacts and facilitate adaptation. Bird monitoring also has an important role to play in legitimising claims of biodiversity benefits from carbon offsets.
- The most important thing we can do for birds is to support projects aimed at increasing the connectivity and resilience of native vegetation, both within and between habitats, and between countries, so that birds can adapt and move across the landscape tracking shifts in climate.
- This ecological connectivity requires more than narrow corridors of native vegetation linking habitat patches; rather, a regionally scaled network of habitat patches that can be used variably over space and time.
- The significant value of fostering and restoring native vegetation as a means of sequestering carbon and slowing climate change is increasingly being recognised. It should be quantified through the development of compatible accounting systems for biodiversity and carbon.
- We urge governments to give serious consideration to the protection of biodiverse carbon (ie. carbon stored in ecosystems) in climate policies and procedures. The opportunity to achieve biodiversity conservation benefits through the carbon market and other mechanisms should not be lost.

Birds to Watch: We are only just beginning to identify species suspected to be put at high risk by climate change. Examples include: Malleefowl; Herald Petrel; Blue Petrel; Australasian Bittern; Buff-banded Rail (Cocos-Keeling Islands subspecies); Painted Button-quail (Houtman Abrolhos subspecies); Latham's Snipe; Hooded Plover; Fairy Tern; Lesser Noddy (Australian subspecies); Orange-bellied Parrot; Lesser Sooty Owl; Albert's Lyrebird; Rufous and Noisy Scrub-birds; Noisy Scrub-bird; Mallee Emu-wren; Fernwren; Atherton Scrubwren; Mountain Thornbill; Bridled, Green-backed and Eungella Honeyeaters; Yellow Chat (Capricorn and Alligator Rivers subspecies); Chowchilla; Spotted Catbird; Golden and Toothed-billed Bowerbirds; Star Finch (Cape York subspecies) and Crimson Finch (white-bellied subspecies).

The Pheasant Coucal *(above)* is expanding its distribution southwards, perhaps in response to global warming. High altitude dwellers such as the uncommon Atherton Scrubwren *(left)* and the Chowchilla *(opposite page)*, here propped up on its tail as one leg sweeps the forest floor for insects, will have fewer options. Photos by **Ian Montgomery**

INTRODUCTION

The scientific evidence is now overwhelming: climate change is a serious global threat, and it demands an urgent global response.

Sir Nicholas Stern, 2006

Some of our businesses use more energy than others, but our strategy everywhere is the same… first, reduce our use of energy as much as possible. Then, switch to renewable sources of power where it makes economic sense. And, over time, as a last resort, offset the emissions we can't avoid.

Rupert Murdoch, 2007

SINCE 2003 BIRDS AUSTRALIA has produced an annual *State of Australia's Birds* (SOAB) report. The reports collate and disseminate information on trends in bird populations to inform Australians of the status of their birds and help bring about improved understanding and better management of the land for birds and other biota. They also provide feedback to the dedicated thousands who volunteer their time and skills to monitor birds. The first SOAB (2003) was an overview of the state of the nation's birds and the intention is to revisit those findings every five years to assess change. The 2008 overview will see the launch of the new national bird index, which will provide a concise summary of the status of a suite of Australia's birds. Interim reports address themes of national conservation importance.

SOAB 2006 dealt with invasive species and was widely distributed. Since then there has been some good news. The Federal and Tasmanian Governments have agreed on funding for a rabbit eradication program for Macquarie Island and the fox eradication program in Tasmania has received continued funding. 'Ecosystem degradation, habitat loss and species decline due to invasion of Northern Australia by Gamba Grass and other introduced grasses' is under consideration for listing as a Key Threatening Process under the Federal *Environmental Protection and Biodiversity Conservation Act* (EPBC Act). The Federal Government is also in the process of producing a Threat Abatement Plan (TAP) for the management of the impacts of exotic rodents on Australia's offshore islands. Disappointingly, the Victorian Government has again offered fox and wild dog bounties even though its last bounty program failed as have all such control campaigns throughout history. Evidence suggests that wild dogs/Dingoes may be better left in place to control foxes (and feral cats).

The theme of this year's SOAB is climate change. Along with the rest of the planet, Australia's climate has undergone recent shifts (Table 1; Figure 1 & 2) ascribed to a build-up of greenhouse gases released by human activities in the past 150 years. There has been a consistent warming trend, both on land and at sea (Figures 1 & 2), which will continue even if greenhouse emissions are stabilised, and the rate change is expected to be greater than in the past. Simulations by global climate models point to a further rise averaging 1 °C by 2030 across much of Australia, and even hotter inland. By 2070, temperatures are expected to average 2–5 °C higher than in 1990, with the largest increases in summer. To put these changes in perspective, a further 1 °C rise in average temperature will make Melbourne's climate like that currently experienced at Wagga Wagga in southern New South Wales. Changes in rainfall are spatially and seasonally variable (Figure 3), but projections are for less water and run-off in nearly all catchments by 2030 and a 30% decrease in rainfall across southern Australia.

Even with the relatively modest level of warming already reached, measurable changes have occurred to bird populations and the systems that support them, and others are predicted (see Table 2). Climate change is affecting the behaviour, population dynamics and ranges of birds. Changes to bird habitat over the last 50 years include: encroachment of eucalypt into rainforest and of woody weeds into semi-arid and arid areas; intrusion of mangroves landward into freshwater systems and salt marshes; 40% reduction in spring snow depth and spread of trees into the alpine meadows zone; and glacial retreat in the sub-Antarctic and Antarctic—all of which may have a global warming component and impact on birds. The changes to bird populations described in the first sections of this report are only a few among the early signs of potentially profound changes that we are only just beginning to understand.

Many Australian birds have evolved to cope with high year-to-year variability in climate, adjusting the timing of life-history events and migrations accordingly. The observed changes in phenology in response to climate change described in Section I of this report do not appear as consistent or strong as those recorded in the Northern Hemisphere, where advances in breeding dates of 2–5 days per decade since the 1970s have been recorded for many species. However, long-term breeding and migration data is generally poor for Australian species. Range shifts, however, appear to be more evident here. The transition zone between tropical and temperate seabirds has moved south. The latitudinal range shifts of landbirds mapped in Section 1 are as much as 2–3 degrees or 200–300 km over two decades; a rate of roughly 100–150 km per decade. This is more rapid than the 6 km/decade northward movement reported across a range of North Hemisphere taxa, but consistent with that predicted by a change in mean annual temperature of 1 °C (which corresponds to a shift in climatic zones of approximately 100–130 km in latitude in temperate areas). While these southward movements are range expansions, they should not necessarily be viewed as beneficial except that they may indicate a capacity for the species to adapt by moving with its climatic zone. Most are probably coupled with decreases at the northern end of the species' ranges (as illustrated in Figure 11). Phenotypic changes (e.g. in body size) have been reported in birds elsewhere but have not yet been investigated in Australia.

Whereas Section I reports on some of the observed changes in Australian birds, Section II covers the further changes predicted for birds. Adaptable species with broad climatic ranges and a strong ability to disperse will most likely be advantaged, invasive pest species amongst them (see article, p. 18). Conversely, species with narrow climatic ranges, small populations and specific habitat requirements will most likely be disadvantaged. These include high altitude and far southern species and birds of Wet Tropical rainforest. Wetland birds are also likely to suffer. Declines in rainfall and surface water flow will continue to place significant stress on rivers and riparian environments. Reduced water flow into wetlands and marshes that are important bird habitat areas could result in less frequent breeding events. Risks to wetlands from climate change include salt-water intrusion from rising sea levels. If sea levels rise significantly, the vast low-lying floodplains of northern Australia, including Kakadu, are at risk from saltwater inundation. Intercontinental migrants, particularly shorebirds, may be affected by disruptions to the synchronicity of migration and prey flushes, as they have been elsewhere in the world.

Some species that might otherwise have been able to adapt to climate change will be in trouble because the natural environment is now fragmented. Current protected areas may no longer support the species and communities they were intended to conserve. Ensuring that the landscape mosaic between areas of natural habitat remains hospitable will influence whether such species will persist into the future. Hence, the most important action to enable birds and other biota to adapt is to restore connectivity so that species can shift across the landscape, including (for international migrants) between continents. The two major articles in Section III address the connectivity issue. The first argues the need for meaningful monitoring and management that promotes connectivity. The second describes the important links between carbon, productivity and connectivity.

Other ways to facilitate adaptation include:

- reducing existing threats (clearing of native vegetation, excessive livestock grazing practices, inadequate water for the environment, invasive pests and pasture grasses, etc.);
- incorporation of climate change information into management tools and management planning;
- increased research into and long-term monitoring of the impacts of climate change, potential climate change amelioration actions, and adaptation options for species and ecosystems; and
- as a last resort, ex situ conservation or translocation of species that are unable to self-adapt (but these are expensive, difficult and potentially hazardous activities).

To achieve relief from climate change, the response will need to be at the level of policy and legislation required to reduce greenhouse gas emissions, together with the harnessing of global market forces. The Council of Australian Governments and the Natural Resource Management Ministerial Council (NRMMC) have both identified biodiversity as a priority for climate change adaptation. In 2004, the NRMMC released the National Biodiversity and Climate Change Action Plan, which sets out a series of adaptation strategies and actions to minimise the impacts of climate change on biodiversity by maximising the capacity of species and ecosystems to adapt to future climates. The National Strategy for Conservation of Australia's Biodiversity and National Greenhouse Response Strategy provide policy frameworks, albeit outdated, but there is as yet no national legislation to implement the UN Framework Convention on Climate Change.

All Australians can help by embracing greater energy (and water) efficiency in vehicles, buildings, power plants and elsewhere (provided the monetary savings are not spent on other carbon-releasing consumables and activities). We should be wary of the boom in carbon offsetting, because the same volume of greenhouse gases are emitted in the same way as before, but are compensated for, such as by planting a pine plantation. It is a painless way of contracting out the problem and the environmental and biodiversity benefits are often negligible or may even be negative. Systematic monitoring of birds can help to assess the legitimacy of claims of contribution to biodiversity conservation.

Nonetheless, carbon trading potentially gives biodiversity a value and the incorporation of biodiversity into carbon sequestration schemes could have massive benefits for biodiversity conservation, as is argued powerfully in Section IV. The opportunity to put biodiversity on the carbon market should not be missed.

Carbon sequestration

The capture and long-term storage of carbon in woody vegetation, soils and oceans to slow the build up of carbon dioxide in the atmosphere.

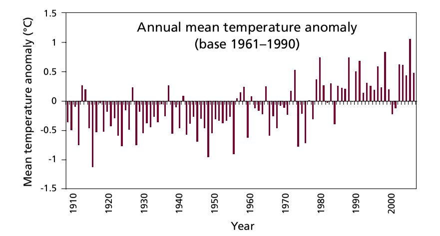

Figure 1. Annual temperature anomalies (i.e., departure from long-term mean 1961–1990) for Australia. Source: **Bureau of Meteorology**

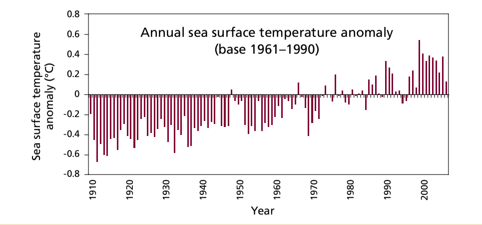

Figure 2. Annual sea surface temperature anomalies (i.e., departure from long-term mean 1961–1990) for the Australian region. Source: **Bureau of Meteorology**

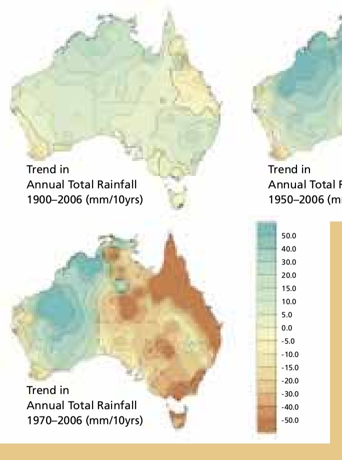

Figure 3a,b,c. Changes (in mm) in total annual rainfall between 1910 and 2006, 1950 and 2006 and 1970 and 2006, showing the drying trend in the east and south-west. Source: **Bureau of Meteorology**

Table 1. Signals of global warming already observed in Australia's weather

Average surface temperature	Increased by 0.9 °C since 1910[1]; warming faster in past 50 years (0.1 °C per decade).
Difference between night and day temperatures over land	Decreased because night temperatures are warming faster than day temperatures.
Frequency of hot days	Increased.
Frequency of cold/frosty days	Decreased during the 20th century.
Frequency and severity of drought	More frequent, persistent and intense during the past 20–30 years.
Rainfall	Declines over southern Australia, particularly in winter rainfall; increases northwest over past 50 years[1]. In the south-west a decrease of up to 20% since the mid 1970s.
Heavy rainfall events	Increased, particularly since the 1960s.
Rise in sea levels	Increase of 20 mm per decade over the past 50 years.
Storms	Possible increase in frequency of intense cyclones and development of severe east coast lows in past 20 years.

Based on *Climate Change: Solutions for Australia* (The Australian Climate Group, 2004); [1]latest estimate from the *Annual Australian Climate Statement 2006* (Bureau of Meteorology, 2007).

Table 2. Some observed and potential impacts of climate change of relevance to Australian birds

Direct effects	Secondary and indirect effects
Increases in temperature	
• Southwards range shifts or expansions in warmer climate species • Southwards and upwards altitudinal range contractions in colder climate species • Changes in phenology (timing of life-cycle events—flowering, egg-laying, migration) • Changes in abundance of species • Species loss • Changes in ranges of weeds and other invasive species, pests and diseases; new species may become pests • Increased frequency and intensity of wildfires • Changes in metabolism (photosynthesis, respiration, growth and tissue composition) • Phenotypic (e.g. body size) and genotypic changes in species adapting to new climatic conditions	• Mismatching of life-cycle and distributional interactions between species (predator-prey; plant-herbivore; pathogen-host; pollinators-flowering plants etc.) leading to species declines and extinctions • Changes in competition among species, and the structure and composition of communities and ecosystems • Increased occurrence of eutrophication of streams, lakes, wetlands and estuaries • Reduced capacity for recovery of natural areas following wildfire and other disturbances
Sea level rise	
• Increased inundation of coastal wetlands and lowlands • Loss of estuarine and coastal species and communities (e.g. shore-nesting birds) • Increased intrusion of salt water vegetation into freshwater ecosystems in coastal areas • Changes in structure of coral reefs and shallow water marine communities	
Increases in sea surface temperature	
• Pole-ward species shifts • Changes in species abundance, distribution and ecosystem composition • Increased coral bleaching	• Increase in plankton and associated species
Altered rainfall and runoff patterns (local increases/decreases)	
• Loss of wetlands and associated biodiversity • Loss of migratory birds dependent on wetlands and streams • Altered river flow and changes to sediment and nutrient dynamics • Altered lowland flood risk • Disruption to stream, estuarine and wetland food webs due to reduced supply of nutrients • Drying of ecosystems leading to loss of species and changes in community composition • Invasion of woody shrubs into drying landscapes	• Increased incidence of eutrophication of streams, lakes and estuaries • Changes in species distribution and ecosystem composition
Altered frequency of extreme weather events (drought, flood, storm)	
• Mass mortality and breeding failure during extreme events • Increased destruction of coral reefs, other coastal ecosystems and terrestrial ecosystems	• Changes in species competitive interactions and species and community composition • Changes in the range of invasive species • Changed cycles of creation of habitat features such as tree holes • Possible increase in fire frequency from lightning strikes
Elevated CO_2 in the atmosphere and ocean	
• Increased disruption to food chains (e.g. Southern Ocean) • Increased ocean acidification • Increased erosion of coral reefs due to ocean acidification and decreased rates of calcification • Increased invasion of woody shrubs into arid and semi-arid rangelands • Changes in photosynthesis, respiration, growth and tissue composition in plants • Decreased nitrogen content in vegetation	• Changes to plant-insect prey relations due to decreased nitrogen content in vegetation • Changes in species distribution and ecosystem composition, e.g., changes in the ratio of C_3 to C_4 plants

Based on: http://www.greenhouse.gov.au/impacts/biodiversity.html

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Increasing numbers of Asian species, such as this Grey Wagtail, are being recorded in Australia, which may be a precursor to more substantial population shifts in response to climate change. The Grey Wagtail formerly wintered only as far south as New Guinea. It is now seen in Australia so frequently that it has been removed from the Birds Australia Rarities Committee review list. Photo by **Rohan Clarke**

I. OBSERVED CLIMATE CHANGE IMPACTS ON BIRDS

Is Climate Change Affecting Australia's Birds?

BY LYNDA CHAMBERS

Regional warming has been associated with changes in physical and biological systems in many parts of the globe. This includes accelerated glacial retreat, lengthening of growing seasons, and alterations in the abundance, breeding, migration and geographical range of many species, as well as changes in the timing of flowering in numerous plant species.

Many of these changes have implications for bird populations. For example, temperature can be an important cue for the timing of biological events and increasingly warm spring temperatures have been associated with earlier laying dates in many bird species, such as the Barn Swallow, Chiffchaff and European Starling in the United Kingdom and the American Robin, Eastern Bluebird and Killdeer in North America. Although earlier laying can result in a longer breeding season and the possibility of multiple broods, disadvantages can occur if associated aspects of the ecosystem, such as cycles in food resources, do not shift accordingly.

Other impacts of climate change on bird species include changes in the distribution of species (both latitudinal and altitudinal), movement patterns (particularly for migrants and nomads), abundance of species (including some local extinctions), the timing of events such as migration and breeding, community composition, physiology, morphology and behaviour.

The vast majority of known impacts of climate change on birds come from studies in the Northern Hemisphere and, until recently, our knowledge of how it may be affecting Australian species was poor. Given that many Australian species are endemic and have already adapted to a highly variable climate system, we need to exercise some caution when taking Northern Hemisphere results and projecting them onto our species. What have we learnt about the impacts of climate change on Australian bird species?

Changes in the timing of breeding and migration

The clearest evidence of links between climate change and biological changes has been provided by studies of the timing of breeding and migration, as these measures are generally less influenced by changes in management practices than are measures of abundance or changes in species distribution.

Some of the first Australian studies of this type looked at changes in the timing of breeding and migration in the Snowy Mountains. Many bird species (e.g. Australian Kestrel and Richard's Pipit) are now arriving in the alpine zone several weeks earlier than they did in the 1970s. Some, such as Richard's Pipit, are breeding earlier. These changes are likely to be the result of earlier snowmelt and reduced snow cover in recent years.

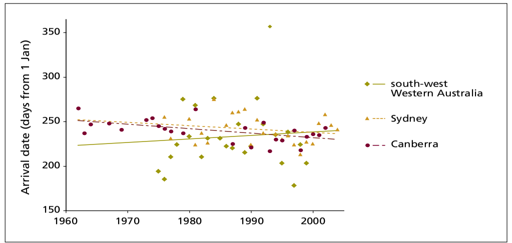
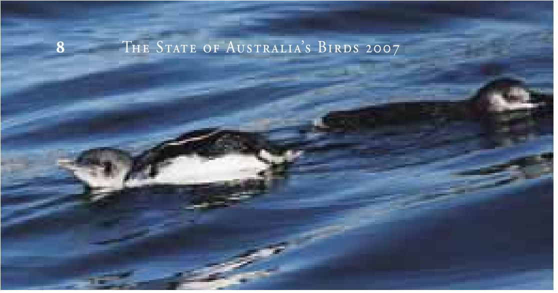


Figure 4. Trends in arrival dates for the Pallid Cuckoo in southern Western Australia (which are not statistically significant) and in south-eastern Australia (Canberra trend significant at 1% level—arrival about 6 days earlier per decade over four decades), illustrating the complexity in a species response to changes in climate.

Changes in the timing of migration have recently been reported for a range of south-eastern Australian birds, several species arriving earlier than in the past (an average of 3.5 days earlier per decade). Similarly, a trend was found toward later departures in many species (an average of 5.1 days per decade). There is also variation in response within species (see Figure 4). Differences have been observed between long and short distance migrants, with short distance migrants generally spending more time in their south-eastern Australian breeding grounds, while the amount of time the long distance migrants were present was slightly reduced.

On the other side of the continent, changes in avian arrival and departure dates have also been observed. Daily bird records from the Eyre Bird Observatory (EBO) have revealed earlier arrival dates for species that have regular absences from the observatory. This was particularly pronounced for the Purple-crowned Lorikeet and Grey Fantail. Many species, such as the Fork-tailed Swift, also departed earlier, while others,



Warmer sea surface temperatures in Bass Strait would enhance Little Penguin breeding success at Phillip Island. Photo by **Madeleine Murray**

such as the Rainbow Bee-eater stayed longer. It appeared that winter (non-breeding) visitors tended to arrive suddenly and depart earlier over time. Summer visitors that breed in the area (e.g. Rainbow Bee-eater) were staying longer and departing later, whereas species that breed elsewhere (e.g. Fork-tailed Swift) were departing earlier over time. Changes in arrival and departure dates have also occurred in the south-west of Western Australia. However, for many of these species changes in rainfall appeared to have a greater influence on the timing of migration than did changes in temperature; this was particularly evident for waterbirds.

A recent study shows that changes in climate also explain changes in the amount and timing of breeding in the Australian Magpie, suggesting that climate change impacts on this species may be both substantial and immediate.

Changes in distribution and abundance

Several Australian bird species are showing shifts in their distributional range consistent with those expected under climate change, such as movement towards higher elevations and southward range shifts in warmer country birds. However, other factors, such as changes in land-cover and land-use, can also play a role (both of which can be affected by changes in climate and vice versa), making it difficult to identify the primary cause of change.

Some of the species in which such range shifts have been observed include northern species such as the Figbird, Common Koel, Noisy Pitta, Pacific Baza and Beach Stone-curlew and some Western Australian seabirds, such the Red-tailed Tropicbird, Bridled Tern and Roseate Tern. Species that breed at higher altitudes, such as the Gang-gang Cockatoo, Flame Robin and Red-browed Treecreeper, may be declining, consistent with shrinkage in the area suitable for breeding as temperatures rise.

Bioclimatic modelling suggests that species losses will occur even under relatively moderate climate change scenarios, with the magnitude of the loss increasing as the expected temperature changes increase.

Changes in movement patterns

In south-eastern Queensland, the White-throated Nightjar and Little Bronze-Cuckoo are now present over winter (previously being strictly summer visitors) and the Forest Kingfisher and Noisy Pitta are now found in the mountain forests all year, when they previously tended to move to lower altitudes in the colder months. These changes are consistent with those expected under a warmer regional climate.

Other potential impacts

Climate change is also expected to affect birds indirectly through its effects on other species, including man. For example, changes in land-use, resulting from climate-related changes in agriculture and coastal infrastructure, are likely to have flow-on effects for bird species. Predicted rises in ocean levels will flood some islands and shorelines where birds currently roost, forage and breed. Increases in some weedy and animal pest species are expected to continue and be exacerbated by climate change. Warming temperatures and increased levels of carbon dioxide in the atmosphere have already been linked to changes in woody biomass in Australia, and to changes in flowering dates, plant communities and distributions. In addition, fire frequency and intensity are expected to increase, potentially vastly modifying many natural ecosystems. All these changes have implications for bird species.

Some Australian birds are already showing adjustments consistent with climate change, as in the Northern Hemisphere. Yet our understanding of climate change and its current and potential impacts is still in its infancy. Hopefully, this will change as more studies are undertaken into how species are likely to respond.

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Further reading

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As temperatures rise, species such as the Tooth-billed Bowerbird, restricted to high altitudes, have nowhere to go. Photo by **Rohan Clarke**

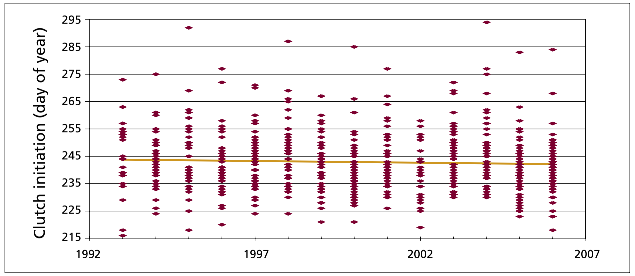

Figure 5. Since 1993 Peregrine Falcons have been monitored at nest sites in Victoria. The date of clutch initiation was estimated by back-calculating from the age of the eldest nestling, estimated using winglength. There was a tendency towards a slight advance in laying date of 2 days over the 15 years, but this was not significant ($y = -0.13x + 497$; $P = 0.23$; $n = 679$). Such consistently collected data potentially give a more robust picture of any trend towards change than opportunistically collected nest data. Data source: **Victor Hurley**

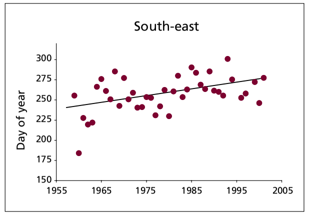

Figure 6. The trend towards laying progressively later over the past 40 years in Masked Lapwings in south-east Australia.

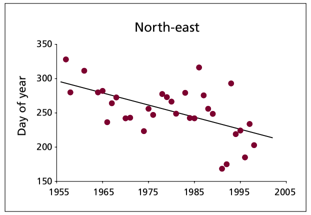

Figure 7. The trend towards laying progressively earlier over the past 40 years in Masked Lapwings in north-east Australia.

Timing of breeding in Australian birds: no climate change fingerprint detected in several common species

Trends in the timing of breeding were investigated for a suite of Australia's more widespread and abundant birds: Welcome Swallow, Yellow-rumped Thornbill, Willie Wagtail, Magpie-lark, Noisy Miner, Common Blackbird and Common Starling.

Hatching dates for these species were estimated using more than 4,800 nest records in Birds Australia's Nest Record Scheme, from two temperate climatic zones—south-eastern and south-western Australia. Trends in hatching dates were investigated in relation to mean annual temperature and rainfall over a 25–30 year period from the early-mid 1960s to the early 1990s (the actual period varied according to the availability of data for different species).

Few clear relationships were detected between average annual temperature or rainfall and the timing of breeding, nor were there any clear long-term trends over time. Nonetheless, the data were not completely random. The Willie Wagtail, for example, bred earlier in south-east climatic region in years with higher average temperatures ($r^2 = 0.202$, $p = 0.013$) (see Figure 8).

High levels of variation were apparent in all of the analyses conducted, which potentially weaken the analyses, and may be explained by three main factors. Firstly, the protracted breeding seasons of many Australian birds result in significant inherent variation in timing; secondly, the data were collected opportunistically; and thirdly, Australia's highly spatially variable climate means that data need to be partitioned prior to analysis, and this limits the amount available within individual climate zones.

Changes in the timing of bird breeding may yet provide us with useful links to changes in Australia's climate, as they have in the Northern Hemisphere, but more robust data will be needed to confidently establish their presence or absence.

By Glenn Ehmke, Birds Australia Nest Record Scheme, and Heather Gibbs, Deakin University, Victoria

The Nest Record Scheme is supported by the Vera Moore Foundation, the Friends of Birds Australia and the volunteer contributors of data.

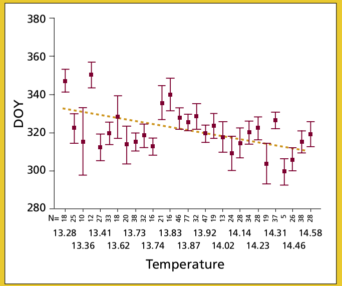

Figure 8. Estimated hatching date (mean ± 1SE) in relation to mean temperate for the south-east climate region for the Willie Wagtail, 1964–1992. DOY refers to the day of the year eggs hatched.

Right: Masked Lapwing. Photo by **Graeme Chapman**

Trends in reproductive timing and success: Masked Lapwings

There have been few studies of the impact of climate change on bird breeding in Australia, but we have recently examined spatial and temporal variation in the timing of breeding of Masked Lapwings using data from the Birds Australia Nest Record Scheme (1957–2002) and Atlas of Australian Birds (1998–2006), and climate data from the Bureau of Meteorology (1952–2006). Masked Lapwings seemed an ideal study subject, because they are widespread, readily observed when breeding, and a reasonable number of breeding records were available over a considerable time span.

The regions of Australia for which we had data on Masked Lapwing experienced significant warming trends in air temperatures over the study period; the north-west also experienced a significant increase in annual rainfall, and the eastern regions experienced significant decreases in annual rainfall. Thus, we examined data within regions to control for regional variation in climate.

Were there any climate change signals among breeding Masked Lapwings? In the north-east of Australia breeding became earlier over time (at a rate of about 2 days per year) while in the south-east breeding became progressively later (c. 1 day per year); in other regions temporal trends were not evident (Figures 6 & 7).

At this stage it is difficult to explain these temporal trends—earlier breeding has most commonly been reported in relation to climate change, but the delay in breeding in the south-east was unexpected. It may relate to decreased rainfall rather than warming.

Only in Tasmania did lapwings show a significant change in breeding success over time, with a decrease of around 1.5 % per year. There was little to no relationship between the amount or success of breeding, clutch size and the climate variables considered (with the possible exception of Tasmania), suggesting either that data limitations precluded us from detecting subtle effects, or that Masked Lapwings have been little influenced or are resilient to the changes in climate experienced to date over most of their range.

The one limitation we faced is common to all those who wish to examine birds and climate change in Australia—there is almost never enough data over long-enough time periods to permit powerful, robust analyses of change in relation to a changing climate. The available data is fragmentary, and so too are our insights. Australia would do well to improve long-term monitoring of its natural assets including birds. This should be designed and targeted to produce data that can be used to answer key questions on the ongoing effects of climate change.

By Lynda E. Chambers, *Bureau of Meteorology*, Heather Gibbs, *Deakin University*, Michael A. Weston, *Birds Australia and Deakin University*, and Glenn C. Ehmke, *Birds Australia, Victoria*

The authors acknowledge the support of the Vera Moore Foundation, which sponsors the Nest Record Scheme, the Bureau of Meteorology and the School of Life and Environmental Sciences, Deakin University.

Volunteers monitoring change: The Atlas of Australian Birds

BY ANDREW SILCOCKS AND CHRIS SANDERSON

While the response of birds to climate change may be harder to detect in Australia than in countries with more defined seasons and predictable bird movement patterns, long-term monitoring is already revealing trends (see Figures 9–12) and will continue to help us track climate change and guide environmental management in adapting to change.

Long-term monitoring is currently being scoped by Birds Australia in a number of projects, the largest of which is the Bird Atlassing in Regions project. This is a pilot study in ten Natural Resource Management (NRM) regions around Australia to set up long-term bird monitoring projects using the Atlas of Australian Birds to manage the data. Other Birds Australia schemes employing long-term monitoring include the Important Bird Areas project, which requires ongoing monitoring to ensure values are being maintained, and the new Shorebirds 2020 project that will monitor Australia's migratory shorebirds over time. These targeted projects also feed into the Atlas of Australian Birds database, informing a national perspective as well as providing local information.

Monitoring changes and trends over large distances and timescales is difficult, but with the assistance of volunteers, and collaborations with groups like the NRM bodies, the task becomes far more manageable. The skilled volunteers who collect data for the various Birds Australia projects are dedicated birdwatchers—their efforts make long-term monitoring programs possible.

The best way an interested birdwatcher can contribute to monitoring is to choose one or more sites and visit at least once a season, or even once a month. The sites don't have to be remote national parks—they can be a backyard, local park, or favourite birding spot. The key is to complete several evenly spaced 20-minute 2-ha surveys through the year, noting every species seen.

For further information on the Atlas, and how bird distribution changes by month or season, please visit: http://www.birdata.com.au.

ANDREW SILCOCKS AND CHRIS SANDERSON, *Birds Australia, Victoria*

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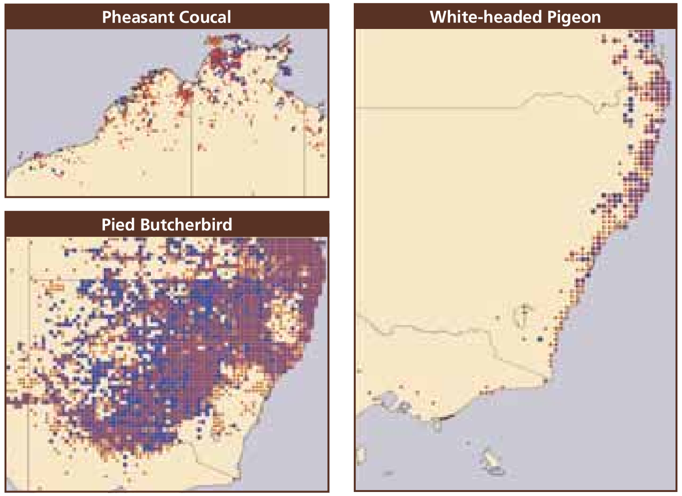
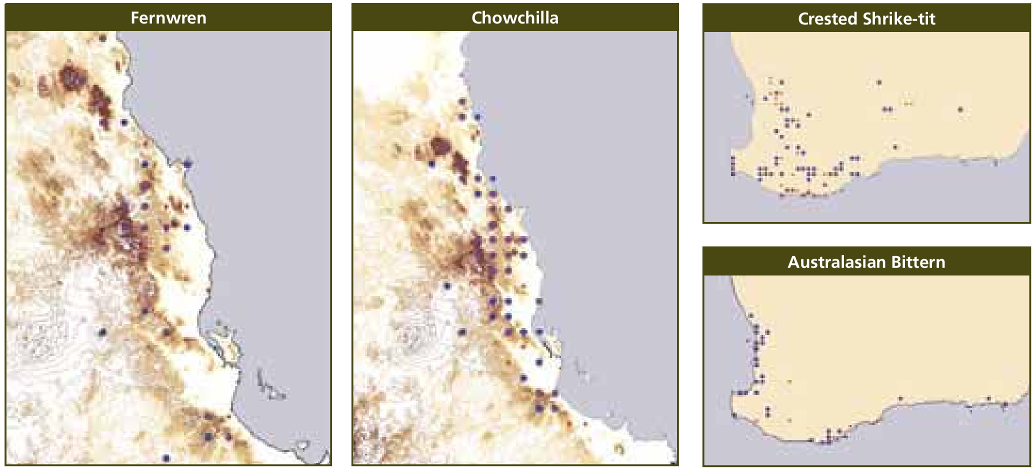


Left: Figure 9. Examples of northern species which extended their ranges southwards between two Atlas periods-records for 10-minute grid cells 1977-1981 (blue dots) and 1998-2007 (red dots): Pheasant Coucal, White-headed Pigeon and Pied Butcherbird. All have expanded southwards up to 2-3 degrees of latitude or 200-300 km; a rate of roughly 100-150 km per decade. Although other interpretations are possible, these extensions are consistent with those expected under climate change.

Below: Figure 10. Examples of temperate and high altitude species that have contracted in range between the two Atlas periods (see caption Figure 9). In north-east Queensland, the Fernwren, a highland bird which occurs above about 600 m, seems to have contracted upland (darker brown areas); the Chowchilla shows a similar pattern, especially in the more southern parts of its range where the mountains tend to be lower. In south-west Western Australia, the Crested Shrike-tit appears to have retreated somewhat from the more easterly part of its range, east of Esperance, and the range of the Australasian Bittern has retracted coastwards. [Note that the method of plotting by grids might falsely suggest some occurrence off the mainland, which is not the case.]



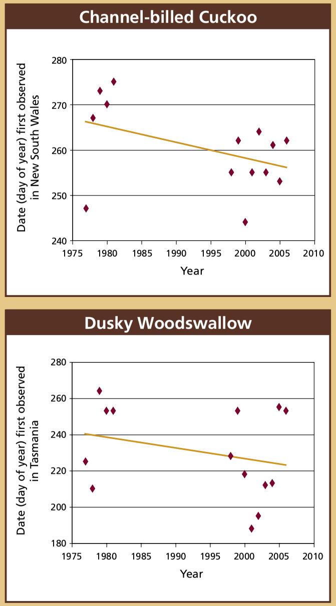


Figure 12. The migratory Channel-billed Cuckoo and Dusky Woodswallow are among the birds that are showing a tendency towards earlier spring arrival back in their breeding range.

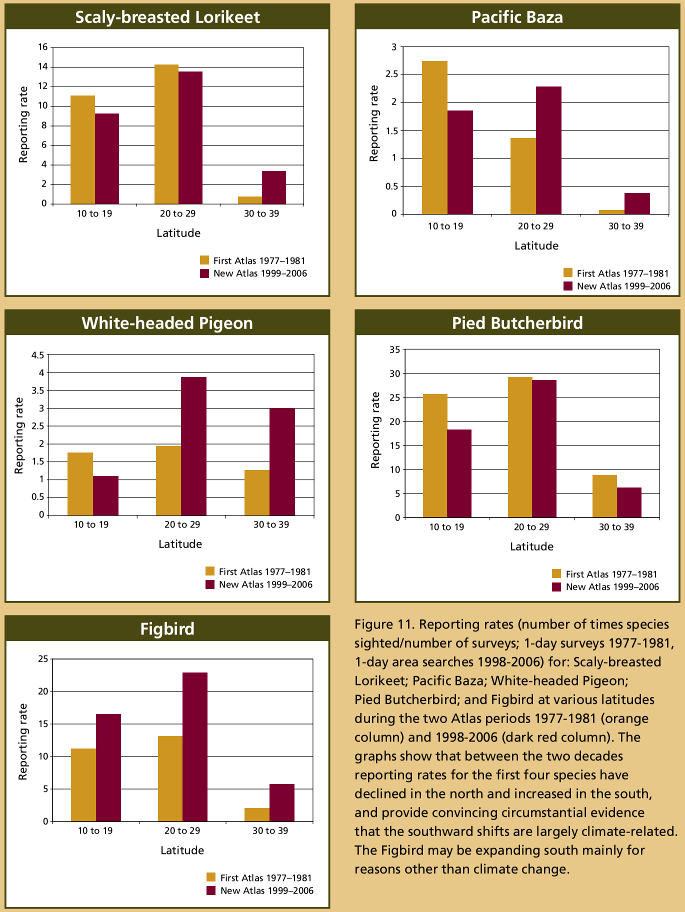


Figure 11. Reporting rates (number of times species sighted/number of surveys; 1-day surveys 1977-1981, 1-day area searches 1998-2006) for: Scaly-breasted Lorikeet; Pacific Baza; White-headed Pigeon; Pied Butcherbird; and Figbird at various latitudes during the two Atlas periods 1977-1981 (orange column) and 1998-2006 (dark red column). The graphs show that between the two decades reporting rates for the first four species have declined in the north and increased in the south, and provide convincing circumstantial evidence that the southward shifts are largely climate-related. The Figbird may be expanding south mainly for reasons other than climate change.

The range of carnivorous Pied Butcherbird appears to be shifting southwards. Photo by **Graeme Chapman**

Changes in Ranges: An Historical Perspective

by Ian McAllan, Dick Cooper and Brian Curtis

As a co-operative activity, atlassing by birdwatchers is becoming more important as time goes on. Atlassing formally became Australia-wide in 1977. During this first RAOU (aka Birds Australia) Atlas, historical data was recognised to be of some importance—the more we can find out about past distributions the more we are able to tell whether current distributions differ.

In New South Wales, the collection of both current field data and historical records at the scale of the 10-minute grid (10-minute blocks of latitude and longitude) has been continued through to the present by the New South Wales Bird Atlassers. Collection of historical data has involved countless visits to libraries, museums and the homes of individual birdwatchers, as well as trawling through old notebooks, diaries, literature, specimens and banding records. From this we have gleaned some idea of the changes in bird species distribution since European settlement. The challenge is to determine if any of these are due to climate.

A major problem in assessing these changes is the confounding influence of humans. It is often assumed that before 1788 there was some form of balance between the activities of the Aborigines and the environment. Although such assumptions cannot be proved or disproved, there is no doubt that the situation dramatically altered with the arrival of the First Fleet. Clearing for broad-scale agriculture, overgrazing of grassland, more efficient hunting, introduction of exotic plants and animals and draining of wetlands has led to changes that have benefited some species and been detrimental for others.

When the first Europeans came to eastern Australia the world was experiencing much cooler conditions than today. This period, usually referred to as the Little Ice Age, lasted from the 16th to mid-19th centuries and was associated with increased snowfalls and frosts. There is only minor evidence in the New South Wales records that there may have been changes to bird distribution as this period closed. The first Europeans in the Sydney area collected specimens of birds for their novelty value. In this context the first Grey Currawongs and Crescent Honeyeaters were collected somewhere close to Port Jackson, though neither has been recorded nearby since. Although the end of the colder conditions may have reduced the habitat for these species which are now considered to be high altitude birds at this latitude, it is more likely that clearing of suitable habitat was more significant. Another possibility is that the records were of vagrant individuals, though the Grey Currawong is rarely a vagrant in New South Wales.

From the mid 19th to the early 20th centuries a series of severe droughts in south-east Australia coincided with the rapid expansion of pastoralism into western New South Wales and the introduction and spread of the rabbit. At the same time several species of birds began to spread eastwards. The Crested Pigeon and Galah moved to the coast from the Riverina and Central West, and the Little Corella population expanded from the ranges of the far west. In each case movements eastward have been anecdotally linked to drought years at various localities, though there is no evidence that the birds retracted west again in wetter years. This indicates that the spread of these species was more affected by clearing and the provisioning of regular water holes than by any other factors. Around 1915, the Double-barred Finch began to move east towards the coast and south in the inland towards the Victorian border. Similarly, the Red-rumped Parrot began to move into the Hunter River Valley and Sydney area. Again both changes are probably due to the clearing of forest and woodland. The Apostlebird also began to move west of the Darling River at this time. Increased watering points through building of farm dams and tanks have been suggested as a cause, although Apostlebirds were already found along the central Darling River, so the reasons for this expansion in range are unclear.

In recent times Wompoo Fruit-Doves and White-headed Pigeons have moved south along the coast where there has been an increase in food available through the planting of fig trees and an increase in the exotic fruiting Camphor Laurel and other weed species, and a cessation in the hunting of these birds for food. Such human-caused factors continue to influence the distributions of birds and many other examples could be cited.

But what of potentially climate-related changes? The distribution of the Figbird began to shift at around 1945 from its original range north of the Bellinger River (there are only two 19th century records of vagrants from the Hunter River and Sydney). It was at Port Macquarie by 1929 and reached Harrington on the Manning River in 1941. The same year it was found at the Hunter River and three years later was in Sydney. It arrived in the Illawarra in 1955 and continues to move south, recently being recorded at Eden near the Victorian border. The Bar-shouldered Dove has also made a southerly coastal expansion since 1940. It was originally found south to the Clarence River but by 1950 was breeding at Port Macquarie and by 1966 had reached its current southern limit at the Shoalhaven River. As its range has not changed appreciably in the last 40 years, there is evidently some factor limiting its further spread southward—perhaps lack of suitable food plants.

Various bird species associated with mangroves also had a southward range expansion along the New South Wales coast during the last century. The Mangrove Gerygone has changed its distribution significantly. It was first found on the east coast at Brisbane in 1908. The first New South Wales record was at Brunswick Heads in 1936, though it may have already been present there. It has continued to expand in range: Harrington 1956; Newcastle 1967; Botany Bay 1982; and Port Hacking 2001. The Mangrove Honeyeater has also moved south: Tweed Heads 1907; Yamba 1947; and Stuarts Point in 1958, though it has stalled in these latitudes with only the odd vagrant venturing further south. The most recent mangrove-associated bird species to enter New South Wales is the Dusky Honeyeater. This was first recorded in 1997 at the Tweed River and the number of records there is increasing rapidly. Two other species, the Collared Kingfisher and Shining Flycatcher, are only found in the far northern rivers and are unchanged in distribution since their local discovery in New South Wales.

Why have some mangrove birds changed their distribution and others not? The area dominated by mangrove plants has increased in area in south-east Australia over the 20th century, though the species composition at any latitude has not changed. The reason for the vegetation changes is believed to be an increase in sediment deposited in the estuaries, caused by erosion from clearing. However, more recently mangroves have moved inland, invading saltmarsh areas as a result of minor rises in sea level—itself caused by global warming. Thus, the mangrove response is at least in part an outcome of climate change. The consequent response from birds has differed, depending on whether their preferred diet is restricted by the distribution of particular mangrove plant and invertebrate species, or whether they are responding to the mangrove forest habitat as a structural entity.

Temperature increases have probably begun to influence bird distributions. Up until 1912 the Pacific Baza was restricted to north of the Bellinger River, with only vagrants occurring to the south (see Figure 13a). By the 1960s there were summer vagrants near Sydney, but the number of records increased through the 1970s and 1980s and species is now found year-round in Sydney and south to Narooma. The Baza has also become more common on the North West Slopes and foothills of the Northern Tablelands. Unlike many other species this increase in range and numbers has occurred without any obvious change in their preferred habitat, eucalypt forest (which has actually reduced in area), or food—large winged insects of the canopy. A likely reason could be warmer conditions, particularly overnight, allowing the Baza to survive in what would previously have been hostile areas. Two other species have moved onto the North West Slopes: the Chestnut-breasted Mannikin and the Figbird (see Figure 13). In both cases this seems to be despite a marked reduction of suitable habitat locally: natural grassland that previously supported a diverse range of finch species; and vine thicket, now reduced to a fraction of its original area. Again it could be that climate change is primarily responsible.

Recent published reports have suggested that in Australian ocean waters the greatest changes will be on the coasts of New South Wales and south-east Queensland where there will be a strengthening of the East Australian Current. Atlassing might be expected to show changes, but this has not been the case. Unfortunately, the methodology has changed. Up until the mid-1970s most seabird records were of birds seen from shore or in the hand, usually beach washed, and there were intensive searches on all beaches in the early 1970s. However, in the late 1970s many local councils began to rake the beaches to remove rubbish, thus disrupting the beach surveyors' activities. In the same period, pelagic trips specifically looking for seabirds started and have since become regular—now one is conducted on almost every weekend somewhere on the New South Wales coast. From Atlasser results it might appear that some cold-water petrels are more common and that other pelagic birds more easily observed from the shore, such as frigatebirds, have not changed much at all. In neither case is this necessarily true because the methods of record collection are not comparable.

Climate change will continue for some decades, even if ameliorative action is taken now. As a consequence some birds are likely to be adversely affected, in particular those limited to mountain tops or habitats that are likely to undergo water stress, such as Mallee woodland. In this context, atlassing and other co-operative surveys will come into their own, determining those areas of greatest value or where remediation can create corridors. However, if long-term changes are to be assessed through bird monitoring projects, the survey methodology itself must change as little as possible.

Ian McAllan, Dick Cooper and
Brian Curtis, *New South Wales
Bird Atlassers Inc.*

Right: Pacific Bazas are on the move, in the last few decades their population has shifted southwards presumably in response to warming.
Photo by **Ian Montgomery**

Above: A female Figbird about to swallow a Carpentarian Palm berry. Figbirds are one of several species possibly expanding southward.
Photo by **Raoul Slater**

Opposite page: A Dusky Honeyeater sups from a grevillea; first recorded in New South Wales in the late 1990s, it is one of several northern mangrove-associated species shifting southwards.
Photo by **Ian Montgomery**

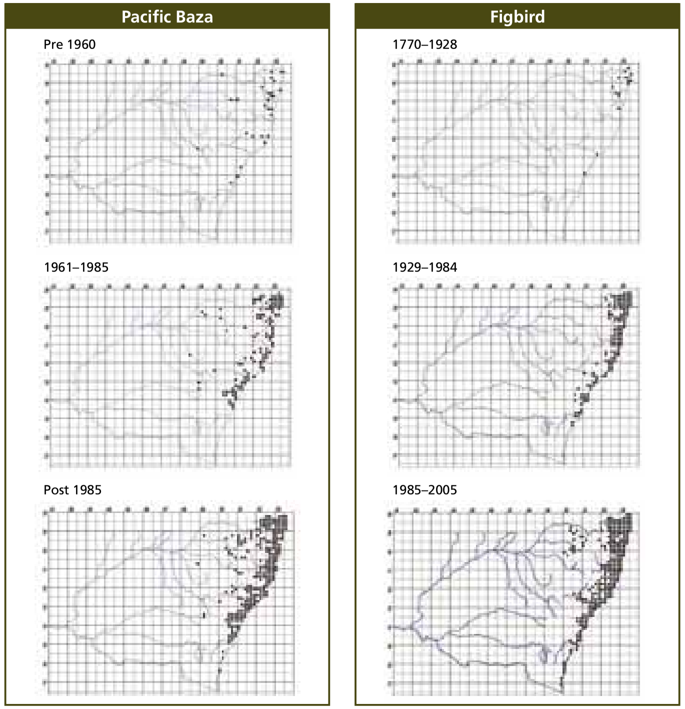


Figure 13. Incremental changes in the ranges of the Pacific Baza (left) and Figbird (right) in New South Wales from records in the New South Wales Birds Atlassers database.

Far left: Decreases in the numbers of birds at breeding colonies have been observed for many species that breed at low to mid-latitude (tropical and subtropical) colonies. For example, over the past two decades breeding populations of Frigatebirds in the Coral Sea have markedly declined. Photo by **Carol (Erwin) Devney**

Left: On Michaelmas Cay a Sooty Tern feeds its chick; the population there seems to respond to changes a year in advance of an El Niño, perhaps because their prey (tuna and mackerel) begin to move to greater depth and are less available to them as the El Niño builds. Photo by **Carol (Erwin) Devney**

Demographic and Reproductive Impacts on Seabirds?

by Carol (Erwin) Devney and Brad Congdon

Ominous predictions of the impacts of global warming on marine ecosystems, from highly productive polar oceans to tropical coral reefs, have put seabirds in the limelight as indicators of broader marine impacts of climate fluctuations.

For 20 to 30 years seabird monitoring in Australia has focussed on colonies of the Great Barrier Reef (GBR) and adjacent Coral Sea Islands, in south-western Australia, and in Bass Strait. These programs have shown that seasonal, or longer-term, changes to seabird reproduction patterns are linked to large-scale oceanographic processes, such as the *El Niño* Southern Oscillation (ENSO) and increased average sea surface temperatures (SSTs). Key demographic and reproductive parameters have been impacted, including population size, timing of breeding, year-to-year recruitment and breeding participation, as well as hatching and fledging success.

Substantial population declines have been observed for many species that breed at low to mid-latitude (tropical and subtropical) colonies (see map). The most dramatic include reductions in breeding populations of over 85% for Brown Boobies in the Swains reefs, southern GBR, and between 35 and 25% for two pelagic foraging tern species at Michaelmas Cay, northern GBR. In the Swains these declines have been attributed to one or two significant *El Niño* events in the 1980s from which the populations are yet to recover, while at Michaelmas Cay they have been directly correlated with ENSO intensity over the past 20 years. Over the same period, breeding populations of the majority of taxa breeding at Raine Island, far northern GBR, and of Frigatebirds in the Coral Sea, have also significantly decreased.

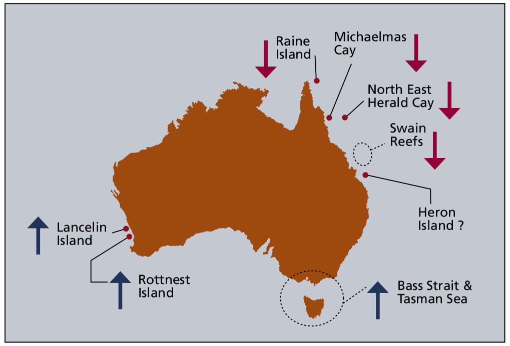


Figure 14. Long-term monitoring datasets from around Australia indicate a pattern of potential climate variation-driven population declines at tropical and sub-tropical seabird colonies (red arrows) and suggest at least some population increases have resulted at temperate colonies (blue arrows).

Interestingly, the Sooty Tern and Common Noddy populations of Michaelmas Cay are sensitive to ENSO precursors up to a year in advance of ENSO indices formally registering an event. This suggests that participation in breeding at the cay can 'predict' future *El Niño* intensity. This unusual relationship has been documented twice previously outside Australian waters, but potential explanations for it remain untested. Our understanding from Michaelmas Cay is that it is a result of depth changes in the 20 °C Pacific Ocean thermocline that also occur up to a year in advance of a registered *El Niño* event. Thermocline depth probably influences the distribution/abundance of seabird prey species directly, or affects its availability via the distribution of underwater predators such as tuna and mackerel, which force prey to the surface.

Prey reductions during *El Niño* events have also driven mass breeding failures in Australian waters. For example, throughout the 2002 *El Niño* coral bleaching event in the southern GBR, food availability to shearwaters dropped to one-third of normal levels. Adults were required to forage three to four times longer for equivalent meal sizes. A sustained lack of food resulted in the complete reproductive failure of the Heron Island colony, with almost 100% mortality of chicks and the loss of at least 2,000 adults. It is likely that similar reproductive failures occurred throughout the Capricorn-Bunker island group at this time. Reproductive failures were observed for Black Noddies of the southern GBR during both 1998 and 2002, Sooty Tern populations on Lord Howe Island in 2002, and seabird populations of the Northwest Shelf and Houtman-Abrolhos Islands off the west coast of Australia in those same years (see box p. 16).

As well as these long-term and seasonal scale events, short-term within-season increases in SST have recently been shown to negatively impact on feeding frequency, meal size and chick growth in many pelagic foraging species across the GBR. These data indicate that even in a good, non-*El Niño*, breeding season a 2–4 °C increase in SST can result in provisioning rates becoming so poor that chicks of both terns and shearwaters begin to lose weight (see Figure 15). If maintained for periods of two weeks or longer these temperature increases can cause colony-wide reproductive failure among even the most robust pelagic foraging species, such as the Wedge-tailed Shearwater.

Such findings demonstrate that predicted increases in both SST and the intensity or frequency of *El Niño* events will have serious detrimental impacts on seabird populations of northern Australia. Current evidence also suggests that at least some species, and possibly the majority of species, at all significant breeding colonies in north-eastern Australia are already in decline due to climate change related phenomena and/or show no recovery from recent ENSO impacts.

In contrast, seabird populations in temperate Australia have undergone a number of opposite trends with recent climate fluctuations (see Figure 14). Over 22 years there has been a three-fold increase in the Australasian Gannet population of Bass Strait that is thought to be related to ENSO-associated increases in SST and higher pilchard abundance. Similarly, warmer SSTs in the same region would enhance Little Penguin breeding success at Phillip Island, by allowing earlier laying, increased chick numbers and increased chick fledging mass. Founder populations of traditionally tropical-breeding tern and shearwater species at newly established more southern colonies off the West Australia coast have also been expanding rapidly in size (see box p. 16).

Whether individual species and/or colonies can adapt to changing climate regimes is currently uncertain. This capacity rests largely on foraging adults or growing chicks to respond to SST-associated changes in food availability. Our recent, early-stage studies into Wedge-tailed Shearwater and Black Noddy resilience on the southern GBR suggest that the ability of two these species to adapt in the short term is limited.

Potential negative impacts of climate variation have been documented in all ocean basins of the world, at many sites and across a range of taxonomic and functional groups. However, responses vary according to the species concerned and its location, and make generalising about adaptive capacity difficult. Thus, we'll need to manage for forthcoming climate change impacts on seabirds on a colony by colony or regional basis.

Carol (Erwin) Devney and Brad Congdon,
James Cook University, Cairns, Queensland

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Wedge-tailed Shearwater and chick. Photo by **Carol (Erwin) Devney**

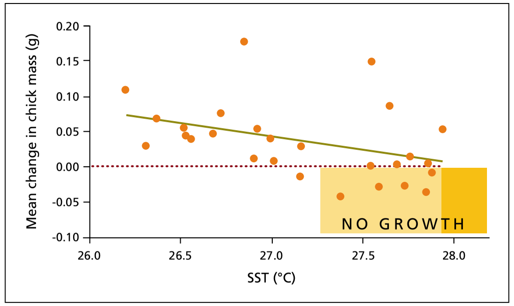


Figure 15. The relationship between day-to-day variation in sea suface temperatures and chick growth rates for Wedge-tailed Sheerwaters breeding on Heron Island during 2003.

Below left: High levels of reproductive failure were observed at Black Noddy colonies in 1998 and 2002 associated with food shortages during *El Niño* events. With an increase in the frequency of *El Niños* predicted, mass seabird breeding failures may also become more common. Photo by **Carol (Erwin) Devney**

Below: Predictions of increased sea-surface temperatures and changes to major weather patterns in regions such as the Great Barrier Reef suggest that species such as the Sooty Tern may suffer from more frequent catastrophic breeding failures due to chronic starvation of chicks. Photo by **Carol (Erwin) Devney**

Climate change signals in the population dynamics and range expansions of seabirds breeding off South-Western Australia

The oceanography off mid-western and south-western Australia between North West Cape and Cape Leeuwin is unique as it is the only eastern boundary of an ocean basin dominated by a southerly, warm, low salinity current. The Leeuwin Current originates, in part, from a through-flow of tropical water from the Indo-Pacific region and meanders along the edge of the continental shelf, blanketing up-wellings from the cold Westralia Current. Offshore waters in the region are tropical and oligotrophic conditions (low in plant nutrients and high in dissolved oxygen) prevail throughout. The distributions of tropical marine organisms extend well to the south of their normal latitudinal limits, some as established populations and others maintained or re-stocked by the Current from sources further north. For example, hard corals are reef-building at the Abrolhos Islands to 28°S, but are not self-regenerating at Rottnest Island at 32°S.

The Pacific through-flow is affected by the *El Niño* Southern Oscillation (ENSO) such that the Current and its eddy structure is weakened during *El Niño* periods and strengthened during *La Niñas*. However this impact appears to be modulated by a poorly understood oscillation in the Indian Ocean, the Indian Ocean Dipole. This oscillation can partly mask or alternatively enhance the impact of ENSO on Leeuwin Current behaviour.

The frequency of *El Niño* conditions has increased since the early 1900s to become the dominant climatic pattern by the 1980s. At the same time, there has also been a background rise in sea temperature off mid-western Australia approaching 1 °C, somewhat higher than that observed elsewhere.

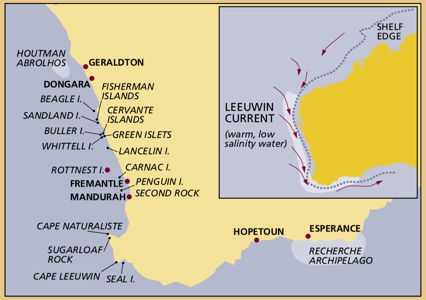
The historical record indicates that tropical seabirds such as the Roseate Tern, Sooty Tern, Bridled Tern, Common Noddy, Lesser Noddy and Red-tailed Tropicbird occurred as far south as the Abrolhos Islands in around 1900. Since then 'irruptions' of these species have been observed further south, new colonies have established and colonies of established tropical seabirds have expanded. Such trends have been observed in Crested Tern (autumn-breeding sub-populations), Roseate Tern (both autumn and spring breeding sub-populations), Bridled Tern, Common Noddy, Sooty Tern, Red-tailed Tropicbird and Wedge-tailed Shearwater. Whilst the Abrolhos is a strategically important reference location it cannot be inferred that it is the source of all the 'frontier' colonies and in some cases, such as the Red-tailed Tropicbird, is almost certainly not. No equivalent changes have been observed in populations of species of cool water bio-geographical origin that breed in the same region.

Monitoring and ecological studies by Chris Surman on the North West Shelf and at the Abrolhos have shown that colonies of tropical species (e.g. Wedge-tailed Shearwater, Common Noddy, Lesser Noddy, Roseate Tern and Sooty Tern) have low breeding performance during *El Niño* conditions and complete, or almost complete, failure during strong events such as those in 1997/1998 and 2002. The first appearance of 'prospectors' south of existing colonies seems to coincide with the El Niños although the appearance of new seabird colonies may lag for some years. The new colonies tend to out perform the long-established ones during the *El Niño* years although these may still show symptoms of food stress.

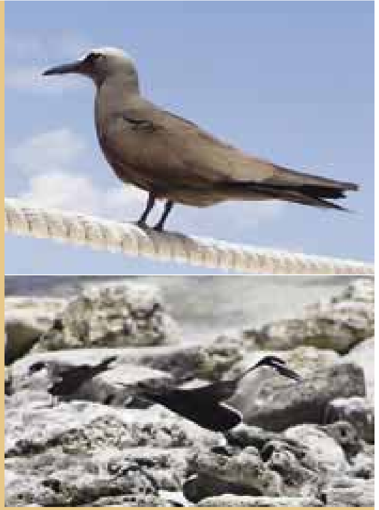
These observations suggest that the demographic changes observed in seabirds in this region are driven at least in part by the increasing *El Niño* frequency and the associated reduced forcing of the Leeuwin Current. Rising sea temperatures may also be a factor in allowing tropical prey species to persist further south.

Our present understanding is that the *El Niños* cause food failure in established parts of the breeding distribution such that birds disperse in an effort to locate prey resources further south. In species with strong site-fidelity, the dispersers are individuals from the pre-breeding pool, but in species with low site attachment (e.g. Roseate Terns) adults might also be involved. These prospecting flocks may be attracted to new islands within foraging range of newly found prey resources, possibly by following commuters of similar species. Nonetheless, there is a significant 'information barrier' to be overcome with the acceptance or recognition of new breeding sites, which may prevent immediate colonisation.

The opportunity to do a banding study of a new Common Noddy colony at Lancelin Island, from its five founding pairs, has provided a demographic model that might have currency with the other documented 'frontier' colonies. This colony underwent a demographic transition through an initial colonisation phase to a very rapid immigration phase, followed by a phase characterised by slowing immigration with early natal recruitment. It finally stabilised at around 1100 pairs maintained mainly by natal recruitment. It is anticipated that this latter phase will continue unless breeding habitat becomes limiting, at which point the colony may begin to produce emigrants. The process took a decade for the Common Noddy, but is evidently taking much longer for the Rottnest Island Wedge-tailed Shearwater colony, which is still expanding exponentially nearly a century after colonisation (i.e., still in its rapid immigration phase).



The area of influence of the Leeuwin Current off south-west Western Australia.



Historically, on the west coast the Common Noddy *(top)* and Bridled Tern *(above)* occurred only as far south as the Abrolhos Island; both have now established colonies further south. Photos by **Carol (Erwin) Devney**

Not all frontier colonies would appear to be taking hold. For example, the Red-tailed Tropicbird colony at Sugarloaf Rock, the extreme southern limit of its current range, has clearly not produced sufficient natal recruits to maintain its size and lingers on the strength of its immigration phase in the 1960s.

The invasion of islands by new breeding species will produce competition with established species for nest sites and affect breeding habitats through alterations in the guano balance. However, if the inevitable consequence of changes in ocean climate is for eventual redistribution of tropical seabirds southwards, then we must ensure that secure, managed breeding sites are available on the frontier to accommodate them. For threatened species, we may also choose to breach the information barrier and encourage the establishment of breeding colonies by using artificial decoys to attract founding pairs, or by translocating youngsters.

BY J.N. (NIC) DUNLOP,
Conservation Council of Western Australia

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II. PREDICTED CLIMATE CHANGE IMPACTS

The Possible Effects of Projected Sea-level Rise

BY SIMON BENNETT, SHARON KAZEMI, SUSAN KELLY, PETER MARSACK, NAOMI NELSON AND JANE HOSKING

One expected effect of enhanced greenhouse climate change is an increase in global mean sea level. The extent of this increase is uncertain, but the Intergovernmental Panel on Climate Change has recently projected that the increase will be 18–59 cm by 2095, and CSIRO predictions point to the potential for a rise of 10–20 cm above that level. This sea-level rise, and storm surges, will lead to increased risks to coastal systems and adjacent low-lying areas of:

- direct inundation, increased flooding, or intrusion of saltwater into low-lying areas; and
- increased coastal erosion, the extent of which will depend on the local geomorphology. Low-lying sand and mud substrates would be most affected, with an expected 50–100 m of horizontal erosion for every 1 m of sea-level rise. Conversely, shorelines of massive, stable rocks would be subject to little erosion in the near-term.

Bird habitats likely to be most at risk to sea-level rise impacts are coastal wetlands, salt marshes, mangroves, inter-tidal zones and low-lying islands and near-coastal low-lying dunes and plains, especially on unconsolidated sediments. These habitats will be most vulnerable where they are constrained on their landward side—for example, by high value land uses such as urban areas, protective barriers, and stable cliffs or uplands—or starved of sediment.

The Department of the Environment and Water Resources (DEW) is undertaking a range of activities relating to biodiversity and climate change, including an assessment of the vulnerability of Australia's biodiversity to climate change. This assessment, due for completion in 2008, aims to build knowledge and future capacity to help identify priorities for adaptation action and planning in the management of biodiversity. Aimed at governments and decision-makers, the assessment will profile the vulnerability of Australia's biodiversity to climate change and highlight key national research and management priorities. It will also assess the effectiveness of current approaches to managing biodiversity and climate change and provide a basis for identifying further priorities for national collaboration.

One particular study is an analysis of terrain and geomorphology of the Australian coast to highlight areas with high, medium or low exposure risk to the impacts of sea level rise, storm surge and flooding. This initial assessment will be followed by a more comprehensive coastal vulnerability assessment, involving the generation of more detailed terrain data in coastal areas of high priority.

As an interim measure, the DEW has undertaken a preliminary analysis of sea-level rise on nationally threatened birds. This involved overlaying distribution maps of threatened birds with those of coastal areas of less than 10 m elevation. Low-lying areas of Australia and coastal islands were mapped using a 3-second digital elevation model (employing a grid of approximately 100 m and with a vertical accuracy of ±5 m with 90% confidence) developed by Geoscience Australia in 2007. These maps were overlain with the species distribution maps used to support the *Environment Protection and Biodiversity Conservation Act*. Species with a high proportion of their breeding range (>40%) occurring in low-lying coastal areas were identified. In addition, an assessment was made of threatened birds occurring in low-lying areas of external Territories (but not including Sub-Antarctic islands and Antarctica).

A number of other threatened birds breed on higher rocky islands, for example, Gould's Petrel and Cape Barren Goose (south-western subspecies). High rocky islands can be considered to be at lower risk from sea-level rise than low-lying less stable islands.

Many bird species not presently considered threatened are dependent on coastal habitats at risk from sea-level rise. These include many species of migratory shorebirds using estuarine habitats in Australia, or in other parts of their annual migratory pathways, and birds that breed on low-lying sand cays or beaches, for example, the Little Tern. Many of these species are listed under the migratory and marine provisions of the EPBC Act, and some specific habitat sites are listed as Wetlands of International Significance and also protected under the Act. As new information on coastal geomorphology becomes available, a full risk assessment of these coastal habitats could be undertaken to better understand the impacts of projected sea-level rise.

Nationally threatened birds that occur or breed largely in low-lying coastal areas or on islands at risk from inundation by climate change induced sea-level rise.

Species	EPBC Act Status	Distribution and comments
Herald Petrel	Critically Endangered	Breeds on low-lying Raine Island, Qld, also elsewhere in the Pacific Ocean.
Round Island Petrel	Critically Endangered	May breed on low-lying North Keeling Island, also three other islands in Indian and Atlantic Oceans. Recent reports suggest that the North Keeling birds may be Herald Petrels (see above).
Lesser Noddy (Australian subspecies)	Vulnerable	Breeds only on three low-lying islands within Houtman Abrolhos, WA, and probably Ashmore Reef, WA.
Buff-banded Rail (Cocos (Keeling) Islands subspecies)	Endangered	Occurs only on low-lying North Keeling Island.
Painted Button-quail (Houtman Abrolhos subpecies)	Vulnerable	Occurs only on six low-lying islands within Houtman Abrolhos, WA.
Orange-bellied Parrot	Critically Endangered	Occurs in saltmarsh and low-lying areas of coastal south-eastern Australia.
Yellow Chat (Capricorn subspecies)	Critically Endangered	Occurs only in near-coastal low-lying plains near Rockhampton, Qld.
Yellow Chat (Alligator Rivers subspecies)	Endangered	Occurs only on near-coastal low-lying plains in the Top End of NT.
Crimson Finch (white-bellied subspecies)	Endangered	Occurs mainly on near-coastal low-lying plains of western Cape York Peninsula, Qld. Also in southern New Guinea.

The critically endangered Capricorn Yellow Chat occurs only in near-coastal low-lying plains near Rockhampton, Queensland, that are likely to inundate with sea-level rise. Photo by **Graeme Chapman**

SIMON BENNETT, SHARON KAZEMI, SUSAN KELLY, PETER MARSACK, NAOMI NELSON AND JANE HOSKING, *Australian Government Department of the Environment and Water Resources*

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The range of Scaly-breasted Lorikeets is shifting southwards, a sign of a warming climate. Here a feeding group is disturbed by a bossy Noisy Miner, an adaptable species that is already overabundant where woodland has been degraded, and likely to become even more common with climate change. Photo by **Raoul Slater**

Warming, Invasive Pests and Birds

BY TIM LOW

Invasive species will be big winners from climate change, and that bodes ill for many birds. Invasive pests do best today in places degraded by grazing, logging, pollution, frequent fires and other disturbances. Climate change will become a major form of disturbance, one that benefits opportunistic invasive species by subjecting native plants and animals to stress. A rise in the number or severity of cyclones, storms, fires, floods and droughts will greatly worsen the problem.

Weeds will prosper. Athel Pine is a telling example of a weed that exploits severe weather, to the detriment of birds. During the extreme wet year of 1974 when floods in central Australia destroyed many River Red Gums, thousands of Athel Pines germinated in their place. Unlike River Red Gums, these trees produce no hollows that birds can nest in, no nectar for birds to feed on, and foliage with few insects for birds to feed on. Now rated one of Australia's 20 worst weeds, Athel Pine is expected to thrive after future floods by displacing more eucalypts.

Australia has many habitat-transforming weeds that spread during floods and storms and reduce habitat for birds. Olive Hymenachne, an aquatic pasture grass, smothers tropical lagoons. Other flood-promoted transformer weeds include Mimosa, Prickly Acacia and Alligator Weed. The spread of Lippia—emerging as the major weed on the Murray Darling system—is facilitated by frequent short floods.

As temperatures rise, fires will burn more often and more fiercely, and fire-adapted weeds will accelerate this trend. The one to watch is Gamba Grass, an enormous pasture grass from Africa that fuels extremely dangerous fires. Eucalypt woodlands subjected to several Gamba Grass fires soon die, and this has led the Queensland Government to conclude that vast tracts of northern woodlands could end up as treeless plains. Gamba Grass promotes fire and is promoted by fire via a well-studied grass-fire cycle of invasion that will worsen climatic trends by increasing carbon emissions. In a report to the Federal Government I nominated this grass as the invasive species posing the greatest threat to Australian biodiversity under climate change; modelling shows it could establish across much of northern Australia and in parts of New South Wales. Gouldian Finches and Partridge Pigeons are identified as facing a high risk from the spread of Gamba Grass.

Fires, by removing protecting vegetation, also assist foxes and feral cats to prey on ground-feeding birds. In another kind of interactive impact, rising sea levels and Water Buffalo will both exacerbate wetland loss in the Top End, which supports Australia's highest waterbird densities. A 1–2 m sea level rise could see the Alligator River's freshwater swamps converted to saline systems. Buffalo have already eliminated many freshwater lagoons by forcing swim channels that let in seawater through shallow marshes. Their numbers are rising fast since control efforts ceased in the mid 1990s. The habitats of Magpie Geese and Brolgas are at risk.

On Macquarie Island, proliferating rabbits, benefiting both from climate change, removal of feral cats, and reduced impact of myxoma virus, pose a severe threat to seabirds. The survival rate of rabbit kittens is rising because temperatures are higher and there is less snow to melt and flood burrows. The rabbits are causing massive erosion and vegetation loss. The Federal and Tasmanian governments are committed to eradicating them soon.

Climate change may see some birds contributing to problems. In the Australian Alps, Laughing Kookaburras now hunt at higher altitudes than before, preying on alpine skinks that fail to recognise them as predators. These skinks are very vulnerable because gravid females spend long periods basking. In eastern Australian eucalypt forests and woodlands, tree deaths from climate change should benefit Noisy Miners, aggressive birds that colonise damaged forests then exclude smaller birds. Birds will also contribute to the spread of weeds into eucalypt forests. Native plants may need to migrate southwards to track climate change, but woody weeds such as Camphor Laurels, cotoneasters and privets, whose seeds are dispersed by birds, will spread much faster than eucalypts, she-oaks and native peas, whose seeds travel very slowly.

To help birds and other species adapt to climate change, the recommendation is often made to 'reduce other environmental stresses'. Invasive species are an obvious stress to focus on, since they so often exacerbate climate change impacts. More funding should go into eradication of weeds in the early stages of spread, and the right of graziers to plant fire-promoting grasses should be challenged.

BY TIM LOW, *Chapel Hill, Queensland*

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Fewer insects for birds?

Of the many problems facing our birds, one that is attracting little attention is the role of carbon dioxide in reducing leaf quality for the insects birds eat.

Studies all over the world have found that plants given more carbon dioxide produce less-nutritious leaves. Carbon dioxide is fertiliser for most plants, greatly increasing their photosynthetic efficiency (until nitrogen and phosphorus reserves are depleted). It allows them to invest less in Rubisco, the enzyme that promotes photosynthesis, and which provides much of the nitrogen content in leaves. Nitrogen is a key nutrient for leaf-eating insects, and a major determinant of insect abundance on foliage. Leaves grown at elevated carbon dioxide concentrations not only carry less nitrogen, they are also tougher and often higher in tannins and other unpalatable carbon-based compounds.

Less leaf nitrogen has been recorded in seedlings of Forest Red Gums, Sugar Gums and two Queensland rainforest trees grown under elevated carbon dioxide in the laboratory (and subject to high and low nutrient levels). These findings have prompted dire predictions for Koalas, possums, Greater Gliders and tree kangaroos, with the CSIRO's Stephen Cork warning that leaves in many forests where Koalas and possums now feed could 'become virtually inedible'.

The implications for birds could be serious as well because the insects they eat may fare worse than these mammals. Marsupials may be able to compensate for a poorer diet by eating more leaves, but this option may not hold for newborn insect larvae faced with tougher and sometimes thicker and waxier leaves. The extinction of some insect species has been predicted. Some insects are likely to become rarer, grow more slowly and thus succumb more easily to parasites and dire weather.

Experiments on insect performance on leaves grown under high carbon dioxide have often, but not always, shown reduced survival or growth rates. Those studies conducted in greenhouses using plants in pots can be criticised as very contrived, and experiments where carbon dioxide is pumped into patches of habitat are likely to yield more trustworthy outcomes. The best studies to date are probably those conducted on a stand of fire-stunted oaks in Florida, where a team led by Peter Stiling of the University of South Florida found fewer leaf miners (the insects he investigated) on all five of the plant species studied.

But this experiment, like many others, may be misleading because temperatures were not increased. In only a few experiments has heat as well as carbon dioxide been added. In a review of the six projects that altered both variables, insect survival was mostly unimpaired, despite plants producing foliage that was tougher and contained less nitrogen. Perhaps we should not worry, but the sample of studies was very small, with only eight insect species investigated, one of which fared poorly. Possibly, temperature need not always be considered given predictions that many plant populations will migrate southwards to climatic zones matching those occupied before. In a more recent review of 75 carbon dioxide-enrichment studies in which temperatures were not raised, insect abundance fell by an average of 21.6%.

The prospect of less nutritious leaves is especially serious for Australia because our forest soils are so infertile, farmers having cleared the best lands. Leaf-eating possums and gliders are often absent from forests on the poorer soils, a situation that probably holds true for many insects as well. The nitrogen content of eucalypt foliage is often marginal for herbivores, leading zoologist Ivan Lawler and colleagues to predict that if rising carbon dioxide reduces foliage nutrient levels significantly, 'the consequences for insect herbivores may be great'. Australian birds will suffer especially if psyllid bugs, the insects responsible for lerp, become rarer, given the major role that lerp plays in the diet of honeyeaters, pardalotes and many other birds.

One change should benefit insects—improved water thrift in plants. Because plants will absorb carbon dioxide more efficiently in future they will transpire less and thus lose less water to transpiration. The water content of leaves should remain higher during dry times, increasing insect survival and improving digestion of scarce nitrogen. However, if droughts are worse in future, as predicted, they will cancel out some of this benefit.

Other changes are expected. Trees and shrubs fed more carbon dioxide produce thicker canopies. How this will affect the ability of birds to find prey remains to be seen. Experiments suggest there will also be more flowers (with less nutritious nectar?), more seeds, and bigger seeds, but containing less nitrogen (which animals need to build protein).

The uncertainties won't be resolved anytime soon because the kind of experiments we need—pumping carbon dioxide and heat into forests for years on end—are too expensive to mount and need to be run for many years.

BY TIM LOW, *Chapel Hill, Queensland*

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Climate change is expected to reduce leaf quality, which will in turn impact on leaf and sap-eating insects and the birds, such as this Chestnut-rumped Thornbill, that depend on them. Photo by **Raoul Slater**

Compounding threats: threatened birds and climate change in the tropics

Some 387 species of birds live in the savannas and rainforests of tropical Australia. The populations of about 42 (12%) have declined in the past, or are currently of concern for reasons such as altered fire regime, cattle grazing or invasive species. A recent modelling analysis shows that many of these species share characteristics such as small ranges and a limited capacity to disperse. This allowed creation of a threat index; unsurprisingly, many of the threatened birds had a high threat index. The analysis also identified some species, such as the Black Grasswren, that are not currently considered to be threatened, but perhaps should be.

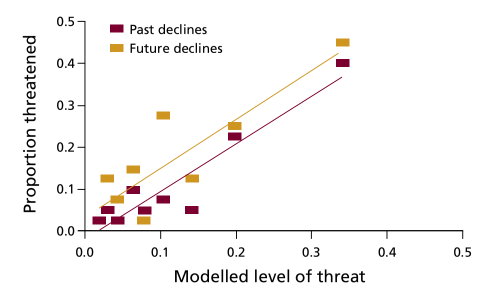
Of greater interest in terms of climate change were prospects for the future. The model predicts that, in 30 years time, 66 species (17%) will be threatened, an increase of about 50%. Fire, weeds and feral animals will continue to be problems, but by far the greatest predicted threat is from changes in climate, with 55% of species anticipated to suffer substantial population declines.

Two main groups will be affected. In Queensland's wet tropics a range of endemic rainforest species will gradually lose their climatic envelope (the climate range that defines where a species normally lives) as temperature rises. So too will a suite of species that persist at high altitudes in the tropics—isolated populations of species that are more common in the forests of south-east Australia.

The second group of species that will lose habitat and decline in abundance are the birds of the freshwater wetlands around northern Australia. The vast swamps of Kakadu, the Gulf plains and many other coastal regions are only just above the current sea level. At present, they provide some of the greatest bird spectacles in the country. Each year the severe dry season kills the vegetation of the previous wet, releasing nutrients for plants and animals when the rains return. However, a slight rise in sea level will turn the productive areas to barren saltpan and surviving flocks are likely to be much smaller.

The changing climate will also exacerbate some existing threats. Increased levels of carbon dioxide will favour trees over grasses, which in turn will affect fire regimes. Some grassland birds that are already suffering as trees invade their habitat, such as Golden-shouldered Parrots, will come under even more pressure.

Then there is the possibility of more and stronger cyclones. Birds like Chestnut Rail and Southern Cassowary appear to suffer short-term losses when cyclones come ashore. It remains to be seen whether areas affected can be recolonised before such events recur.



Based on past threats there is a close correspondence between a modelled level of threat to the 387 tropical Australian birds analysed and the proportion of threatened species in each group of 20 species ranked by threat. In the future (orange line), the proportion of species threatened at any particular level of threat is predicted to increase, indicating that species with a low level of threat today are as likely as rare species to decline in the future-due largely to climate change. In other words, climate change is predicted to worsen the impact of other threats.

When the predicted effects of climate change were fed into the model it became apparent that not only would sedentary species with small ranges come under greater threat, but so too would species with far wider distributions, particularly the birds of tropical freshwater wetlands. Thus human-driven climate change is something new, on top of and different to existing threats. This makes it difficult to predict which species need extra monitoring as the climate changes and where emergency conservation measures are most likely to be required.

BY STEPHEN GARNETT, *Charles Darwin University, Northern Territory*

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Modelling has indicated that the Black Grasswren, with a very small geographic range but currently not considered to be threatened, may be at risk of extinction even in the absence of climate change. Photo by **Don Hadden**

A dust storm near Wilcannia: with increasing temperatures and decreasing rainfall more of southern Australia can expect such events. Photo by **Graeme Chapman**

III. BUFFERING AGAINST CLIMATE CHANGE

Research and Management Needs

BY BOB SUTHERST, JUDIT SZABO AND EVAN CLELAND

The implications of anthropogenic (human-caused) climate change and enhanced concentrations of CO_2 differ from those of previous, prehistoric climate changes in that humans have recently fragmented the landscape, degraded natural ecosystems and reduced numbers of most species of plants and animals. These changes will make natural adaptation by flora and fauna more difficult.

Temperature and soil moisture currently vary in both north-south and east-west directions in Australia (Figure 17). Climate change will manifest itself through regional changes in these temperatures and an increase in the intensity of hydrological cycles, producing greater extremes of climate. A general drying is expected.

Climate change will have consequences for birds. Their seasonal and regional movements will be affected by changes in the ambient climate and consequent changes in the timing and nutritional quality of food resources. Birds will be under pressure to adapt behaviourally and/or genetically. The challenge for researchers, managers and policy makers is to find ways to facilitate the natural, adaptive responses of birds to climate change across Australia.

In the face of much uncertainty, there is little merit in designing adaptive strategies to track specific climate-change scenarios. Instead we need to manage for increased variability and uncertainty of the climate. Adapting to climate change will involve combined monitoring, interpretive studies and adaptive management.

Long-term monitoring of processes and patterns to identify changes in bird populations and their causes, and to measure the effectiveness of adaptation measures.

How can we best monitor birds in Australia to track natural adaptation to climate change and to measure the success of management? Changes in the suitability and connectivity of habitats need to be the focus of research.

Large and relatively undisturbed natural ecosystems need to be monitored to track changes in the population dynamics and geographical distribution of birds. These programs should ideally consist of regular surveys of species and individuals over a sufficient number of replicate areas to generate decades-long series of counts. The data must be amenable to statistical analysis of trends over time and space. Innovative approaches to data collection, such as systematic acoustic monitoring, will be needed.

- Monitoring sites need to be located to reveal geographical and seasonal changes in species occurrence and behaviour. This means placing transects across climatic gradients with emphasis on covering the present and future edges rather than just the centres of the geographical distributions of species of concern. As a 1 °C increase in temperature translates into about 170 m of altitude or 100–130 km of latitude (in the temperate zone), transects will need to cover substantial distances.
- Survey sites need to be chosen to isolate the effects of climate change from other anthropogenic changes in land use and land cover. It is also vital to measure concurrently as many habitat and larger-scale environmental variables as possible to track changes in habitats.
- This approach can draw on the skills developed for the Atlas of Australian Birds but will require modifications to the way sites are chosen for atlassing. Current records are suitable for local management but new problems call for additional, fresh approaches. We now need greater emphasis on long-term series collected at the same regularly monitored sites. Birds Australia now has eight years of such data at 2-ha survey sites and plans to build on them. The data requirements for climate change will depend more on team-based and perhaps technology-based surveys.

In addition, the occurrence and dispersal abilities of less mobile species of flora and fauna in fragmented, narrow and isolated habitats need to be defined in order to determine the minimum amount of connectivity that different bird species need to track climate change.

Life history and modelling studies to develop and test our understanding of species population dynamics and geographical distributions.

Most issues related to natural adaptation of flora and fauna are generic in nature and few relate specifically to birds. Nevertheless, there are many gaps in our understanding of the factors that determine the population dynamics and geographical distributions of birds. We need to understand these processes if we are to underpin policy with sound science.

Current efforts to predict species' ranges and to map biodiversity are plagued by too much statistical modelling of patterns of occurrence and not enough biology to support mechanistic models. The biological information necessary for predicting future trends can be gleaned by:

- Addressing bird issues on a species-by-species basis rather than at the community level because each species will respond differently to climate change.
- Conducting life history studies, including more targeted ecophysiological studies of species likely to be most sensitive to climate change.
- Studying the ecological relationship between birds and climate (e.g., see box p. 24), food, shelter, and competitors, predators and pathogens.
- Using explanatory models (e.g., Figure 18), otherwise referred to as 'mechanistic' or 'process-based' models, rather than descriptive, statistical models. Models must have proven predictive capability based on testing against independent data. Also, analyses should include estimates of uncertainty before they are used to guide management.
- Capturing the potential synergy from collaboration between climate change, biodiversity and invasive species researchers.

Adaptive management of habitats to protect them from human-induced disturbances and to restore the quality and connectivity of vegetation and its associated birds.

Adaptation to climate change must be proactive because a reactive approach means that we will never catch up. Indeed, we are already behind and this is the point that climate change sceptics fail to understand. Environmental managers need to include climate change risks into their day-to-day decision-making, in the same way that they include other non-climatic threats. Climate research bodies must serve a collaborative, capacity-building role rather than a driving role in climate change adaptation.

Birds are best viewed as indicators of ecosystem quality rather than as the focus of specific, taxon-based land-use management. We cannot address the interests of birds without targeting their habitats and the other organisms they interact with. In particular, rare and less mobile species of birds, and those with specialised shelter, feeding and breeding requirements, will be particularly vulnerable to environmental change and warrant special attention to their habitat needs. That requires holistic approaches to the setting of priorities for conservation of habitats based on the three criteria of threats, costs and biodiversity values.

Climate change will cause disturbances and each bird species will have to adapt uniquely. As a result, current ecosystems are unlikely to be sustainable in their present states. The best chances of retaining bird species under climate change are to:

- Increase the area of each habitat type under protection in order to provide buffers for climate refugia.
- Protect wetland habitats, which are particularly vulnerable to development on our coasts and rivers.
- Enhance the quality and extent of connectivity between such sites, both within Australia and on international migration routes (particularly wetlands).
- Reduce the fragmentation of natural vegetation caused by insensitive land clearing and grazing.
- Redress the disturbances caused by invasive species of plants and animals, for example, by enhancing the understorey to lessen exclusion of small birds by the Noisy Miner in areas where it has become overabundant.

The bones already exist on which to build biodiversity corridors in the form of riparian systems, road and rail reserves and the stock routes in the eastern States (see box p. 23), and protected areas such as the proposed Alps-to-Atherton forests, and 'Biolinks' in Victoria.

The quality and linkages of natural vegetation on private property, which constitutes the vast majority of land in rural Australia, are key areas for attention. A lot of funded and unfunded effort is already being put into this initiative in areas like the New England Tablelands and north-eastern Victoria, but it will need to have national coverage and continue in perpetuity.

In summary, we need to provide sufficient habitat with adequate structural complexity and connectivity to enable our bird fauna to adapt naturally to climate change. There will be winners and losers and, depending on the degree of climate change, some extinctions, but we have the ability to protect the majority of species. Do we have the political will?

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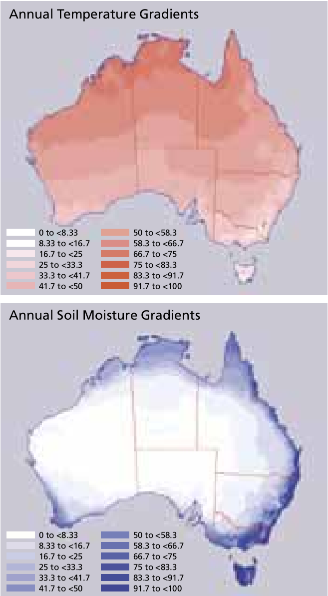
Scarlet Robin. Photo by **Ian Montgomery**



Left:
Figure 17. The current gradients of (a) annual temperature and (b) soil moisture across Australia. Unlike the general situation in the Northern Hemisphere, the gradients are not overwhelmingly north-south—they also have a strong east-west element.

Above:
Figure 18. Bioclimatic modelling is used to infer the *potential* range of species in relation to climate. Such models can be used to estimate changes in a species range with climate change provided the species is able to disperse to track the climate. The likely change in the range of the Scarlet Robin with a 2 °C rise in temperature is shown using the CLIMEX model. The observed range (a), which is larger than the breeding range, is used as the basis for the modelled range (b) and projected future range (c). The model does not include rainfall changes and assumes that other components of the robin's habitats do not change materially in response to the increased temperatures. The analysis shows that the robin's range will be somewhat reduced in the south-east and more so to the west where the projected decrease in rainfall may exacerbate the effects of warming.

The Stock Routes and road network—strengthening the biodiversity links

In some landscapes road reserves and travelling stock routes hold the only remnants of the former vegetation. They take on even greater importance in the face of climate change because they allow movement of birds across the landscapes. Photo by **Graeme Chapman**

Many of us are aware of the connectedness of Australian riparian systems and their importance for the movement of wildlife. Yet, few recognise the potential of road and rail reserves and stock routes—known as Travelling Stock Routes (TSRs) in New South Wales and the Stock Route Network (SRN) in Queensland—as wildlife corridors, let alone the extent of their coverage. In New South Wales, TSRs and road reserves cover about 5% of the State, nearly as much as the 7% dedicated to National Parks. In Queensland stock routes cover 71,650 km or 2,601,510 ha, plus 762 stock reserves of 395,879 ha and 742 water facilities. Road and rail reserves, and the road system itself, add greatly to this resource. These ribbons of public land form part of the so-called 'Unseen Conservation Estate'. Whereas reserves are discontinuous and tend to be targeted to a specific landform or vegetation, stock routes and roads are continuous and incorporate a variety of local landform and vegetation types, and watering points. They also often contain fertile soils, remnant vegetation and much greater biodiversity than adjoining private, grazed land.

In the context of climate change, road and rail reserves and stock routes form an extraordinarily fortuitous, extensive network of corridors (see Figure 19), which, with a contribution from the road network itself, could facilitate the movement of species in response to shifting climatic zones. This network is in public hands and its potential in protecting biodiversity under climate change makes it imperative that its managers, Local, State and Federal governments, as appropriate, recognize and manage it for its biodiversity values.

In New South Wales stock routes are under separate tenure/title to roads and managed as such. However, moves by the State to divest itself of some stock routes and leasehold lands are a real and urgent threat to the potential of their value as refugia and corridors in the face of climate change (http://www.npansw.org.au/web/conservation/crown_land_selloff.htm).

Queensland stock routes are considered part of the road system, with limited management for their biodiversity values. Many are leased for static grazing which may threaten their value to wildlife. A Stock Route Network Management Bill is proposed to bring a degree of regulation—but no additional funding has been provided by the State or national government to enable local governments to implement the policies.

Current funding models do not recognise the national environmental and social benefits that transport routes provide for Australia. Neither Queensland nor NSW included climate change in their last reviews of stock route policy. With the advent of climate change, it is time to strengthen the protection of biodiversity offered by this network. The opportunity to adopt new biodiversity and public use policies and legislation, with State and national funding, to protect endemic species and rehabilitate degraded sections of these routes, should not be lost. There is also scope for widening biodiversity corridors opportunistically by enhancing the native vegetation on adjoining properties and strategically purchasing adjoining land when it becomes available.

These iconic stock routes and road networks are an important part of the unseen conservation estate and connect the seen conservation estate. Their protection and enhancement could give the term 'the long paddock' a whole new meaning under climate change. Do we have the vision to capture the moment before it passes?

By Bob Sutherst, Judit Szabo and Evan Cleland

Figure 19. Declared Stock Routes of Queensland, showing their extent as potential corridors for species movements with climate change. Stock routes are pathways for travelling stock on hoof along roads, reserves, unallocated state land and pastoral leases. Most are public roads, which may also carry traffic and public utilities. Along the coast, road reserves provide vast additional corridors with dense coverage. The total road network forms an even denser web.

What do we know about the effects of climatic variation on Australian birds?

Climate affects all birds but we only understand some of the details for some of the species. This brief analysis compares the breeding responses of 16 common species to three climate proxies—altitude, latitude and the Southern Oscillation Index (SOI) (see Table).

Altitude is regarded as a proxy for temperature change—it gets about 0.7 °C colder for each 100 m of elevation. Birds often breed later at high altitudes because the increase in resources for breeding, such as flowering or insect activity, occurs later. In ten of the 16 species, breeding was indeed clearly later at high altitudes (above 600 m). Another three species tended not to breed at high altitudes, and hence provided insufficient data for comparison. The three remaining species showed no clear altitudinal pattern, perhaps because they breed opportunistically or year round (e.g. Crested Pigeon), making it difficult to compare breeding seasons. Where an effect of altitude was detected, the breeding season was 2–6 days later per 100 m of elevation above 300 m; below 300 m no consistent effect of altitude was detected. The species that bred preferentially at high altitude tended to be migrants, as might be expected if they take advantage of seasonally favourable montane conditions.

Latitude is also generally regarded as a proxy for temperature, although in Australia even the coldest latitudes are not particularly cold. Latitude also influences seasonality through changes in day length (daylight hours being relatively constant in the tropics, but varying greatly between summer and winter in temperate regions). As expected, breeding seasons were later and shorter further south (especially in Tasmania), whereas the few data available for the far north suggest breeding seasons are less distinct there.

Lastly, lower breeding effort across a wide range of species (12 of the 16 species had consistently strong positive correlations with SOI; none had a negative correlation) tended to be associated with warmer, drier years in eastern Australia.

These relationships between various aspects of bird breeding and climate have potential to translate into profound changes in bird populations and communities in species under global warming. Whether this eventuates will in part depend on the adaptability of individual species. A poorer breeding effort, for example, will only have adverse impacts on the population if compensation cannot be achieved by increases in survival and recruitment. Some species will be able to adapt by shifting their range southwards and/or upwards to track changing climatic conditions, although they may have to shift vast distances across fragmented landscapes to find similar climates and plant communities, which may not make this transition easy. Other species will have nowhere to go.

BY HEATHER GIBBS, ***Deakin University, Victoria***

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Grey Fantails are one of several species that breed later at more southerly latitudes and at higher altitudes. Depending on its impact on the fantail's prey, climate change is expected to advance egg-laying dates, so fledglings like this will be singing for their supper earlier in the year. Photo by **David Stowe**

Noisy Friarbirds are blossom nomads and insect eating migrants that need a diversity of habitats to forage over in both their winter and summer ranges. To allow such species to adjust to climate change a whole-of-landscape scale of management is needed. Photo by **Graeme Chapman**

Common name	Migration?[1]	Breed more commonly at high altitude?[2]	Days later per 100 m increase in altitude above 300 m[3]	Later breeding in south than north[4]	More breeding in south than north[5]	More breeding records when SOI positive than when negative[6]
Welcome Swallow	Yes	No	3.4	Yes	YES	YES
Grey Fantail	Yes	Yes	4.3	YES	Yes	Yes
Noisy Friarbird	Yes	YES	5.0	Yes	YES	Yes
Red Wattlebird	Local/Altitudinal	Yes	5.1	-	Yes	-
Pied Currawong	Nomadic/ Altitudinal	YES	3.6	-	YES	-
Willie Wagtail	Local	No	3.5	YES	Yes	Yes
Yellow-rumped Thornbill	Local	Equal	2.8	Yes	-	-
Magpie-lark	Maybe	No	4.5	YES	Yes	YES
Superb Fairy-wren	No or local	YES	-	-	Yes	YES
Galah	No?	Equal	6.3	Yes	No	Yes
Crested Pigeon	No	No	-	YES	Yes	Yes
Noisy Miner	No	No		-	YES	-
Australian Magpie	No	No	2.3	Yes	Yes	Yes
Common Blackbird	No	No		-	-	Yes
House Sparrow	No	No		Yes	Yes	Yes
Common Starling	No	No	-	-	-	Yes

The responses of 16 common species and to climate proxies

Capitalisation indicates the strength of the response, blank cells indicate insufficient data and a dash indicates a non-significant result.

[1] The species are listed in order, from most migratory to least migratory

[2] Migration pattern is taken from the *Handbook of Australian, New Zealand and Antarctic Birds*, Volumes 1–7, (Oxford University Press, Melbourne.)

[3] As judged by comparing the ratio of breeding records at high (above 600 m) and low (below 300 m) altitudes to the corresponding ratio of number of surveys.

[4] Based on linear regression of breeding dates for altitudes above 300 m (using Birds Australia's New Atlas and Nest Record Scheme data).

[5] South is south of the median latitude of the species' range, based on New Atlas data.

[6] SOI values (from http://www.bom.gov.au/climate/current/soihtm1.shtml) were averaged over June, July and August and regressed against Atlas data.

The strengths of the responses indicated in the last three columns were determined using t-tests.

Habitat Productivity, Connectivity and Bird Conservation

BY SANDRA BERRY AND BRENDAN MACKEY

Over the last two centuries the habitat of many of Australia's plants and animals has been lost, fragmented or altered by land clearing and land use change. The extent of the change in land cover is shown in Figure 20. Most of the temperate and subtropical woodlands have been cleared for agriculture, half of the forest cover has been replaced, and the vegetation condition of much of the rangelands has been degraded from its pre-European settlement state as a result of pastoralism and introduced herbivores. In addition, the natural vegetation cover has been degraded by the introduction of exotic plant species, many of which are invasive and have altered fire regimes. Introduced predators, especially the cat and fox, also have an impact. On top of these threatening processes, we now face the prospect of rapid climate change.

The accumulated human impacts on plant and animal habitats are such that we are now in the midst—globally and nationally—of a mass extinction crisis, only the sixth in Earth's history. There is an urgent need to put in place a long-term conservation plan for Australia. However, the success of such a plan is dependent on our understanding, at the continental scale, of the natural adaptation processes that have enabled species to persist through past periods of major, natural disturbance and rapid climate change. An understanding of natural adaptation processes will give conservation planners the know-how to protect and, where necessary, restore habitats, ensuring the future long-term survival of Australia's biodiversity. Through research we are improving the understanding of the ways in which birds have adapted to natural climate variability and human impacts on their habitat.

Plant productivity and patterns of bird movement

Birds, like all animals, are sustained by the productivity of plants. Many birds eat plant produce, for example seeds, foliage and flowers, nectar and sap, and some eat other animals that have fed on plant produce. The biomass produced by plants also provides sites for nesting (and material to build the nest with) and shelter. Plant productivity is dependent on the availability of resources required for photosynthesis and to build plant tissues. These resources include sunlight, water, carbon dioxide and mineral nutrients. Climate affects both the supply of these resources (e.g. rainfall, evaporation and sunlight) and their availability (e.g. through the soil temperature and moisture).

We know that many Australian bird species move from one place to another annually, within the course of a year, or only during some years. Sandy Gilmore and colleagues found that half of our bird species showed either a regular or irregular movement pattern. They proposed that the productivity of the vegetation was the primary driver of the four basic patterns in Australia: no movement (i.e. resident or sedentary); one-way movement (from A to B, for example when birds are dispersing from a source population, or are relocating following destruction of their habitat); regular, predictable migratory movement (from A, their non-breeding site to B, their breeding site); and irregular or nomadic movements between a number of sites. Some species exhibit a range of patterns. For example, there may be partial migration within a population (only some of the population moves), or a normally resident population may make a long-distance movement during drought.

We can test the propositions that birds track the productivity of the vegetation by using observations of birds recorded by the 2 ha 20-minute surveys in Birds Australia's Atlas of Australian Birds, along with estimates of the Gross Primary Productivity (GPP) of the vegetation. GPP is a currency for the total amount of energy from sunlight absorbed by green plants through photosynthesis (the process whereby plants transform solar energy into the energy of the chemical bonds in biomass). This chemical energy fuels the metabolic needs of all the biota, including the plants themselves, humans and birds. We can calculate GPP from satellite-gathered greenness data and estimates of solar irradiance.

The main factor that influences GPP at the continental scale is rainfall, followed by the amount of solar energy received. Thus, although both the Wet Tropics and south-west Tasmania receive abundant precipitation, GPP is greater in the Wet Tropics because it is closer to the equator and receives more solar radiation (Figure 21). The distribution of GPP of the evergreen vegetation (mostly trees and shrubs) is determined by the need of evergreen plants to access water throughout the year. These grow where there is regular reliable rainfall within and between years, or where they can access water that is stored underground. The seasonally green (herbaceous) vegetation makes use of the water that is available for short periods in the upper soil layers. These plants grow quickly, flower, produce seeds prolifically and die.

At this stage we do not have enough bird data to directly investigate the relationship between the temporal movements of birds over the continent and the time-series of GPP. However, the Atlas data does allow for the investigation of the GPP domain of bird species. In our preliminary investigations we have focused on the finches, and here we present our findings for the two most commonly reported finches in the Atlas, the Zebra Finch (5,136 observations) and the Red-browed Finch (4,392 observations). Both species are reported to be predominantly sedentary, but capable of making occasional long-distance movements. To determine the GPP domains of

Range restricted species in semi-arid environments, such as the Mallee Emu-wren, are particularly susceptible to extended drought periods. Such events are predicted to increase in frequency with climate change. Increasing aridity in semi-arid regions is also likely to increase the incidence of other landscape scale disturbances such as too frequent wildfires that destroy wildlife habitat and contribute to greenhouse gases. Photo by **Rohan Clarke**

Red-browed Finch *(right)* and Zebra Finch *(far right)* are both common, widespread species but even they are suffering from human over-use of Australia's limited plant productivity. Photos by **Ian Montgomery**

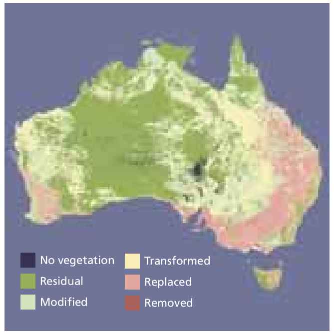

Figure 20. The relative condition of Australia's natural vegetation cover (from Thackway & Lesslie 2006). The category 'no vegetation' indicates naturally bare ground. 'Residual' vegetation has not been significantly affected by post-European settlement land use change; in contrast, 'modified' cover comprises native vegetation that has been altered by some land use change such as for pasture or forestry. In those areas categorised as 'transformed', vegetation cover has been more strongly impacted by land use. 'Replaced' or 'removed' indicate where there has been clearing of the vegetation for agricultural cropping and other land uses.

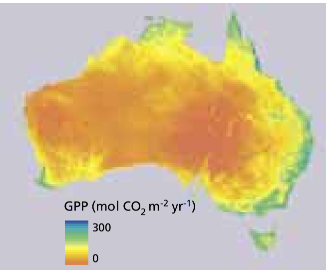

Figure 21. The average Gross Primary Productivity (GPP) over Australia between July 2000 and June 2005, derived from the MODIS MOD13Q1 250 m resolution dataset described by Barrett et al. (2005). The GPP is the amount of carbon dioxide taken up through photosynthesis of the vegetation over a year. It is the ultimate source of all food for animals.

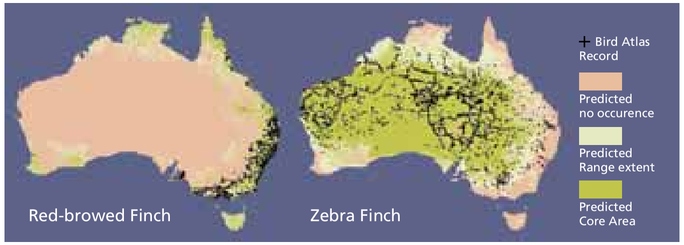

Figure 25. The mapped GPP domains of (a) Red-browed Finch and (b) Zebra Finch. The Predicted Range extent shows all parts of Australia having herbaceous and woody GPP within the boundaries for 99% of sites where the finches were observed. The Predicted Core Area shows the GPP domain for the core 90% of sites. Base records are from The Atlas of Australian Birds.

these species we extracted the mean GPP of: (a) the evergreen (trees and shrubs; see Figure 22); and (b) the seasonal (herbs and grasses; see Figure 23) vegetation. We then made histograms of the GPP (Figure 24) and determined the GPP boundaries that included: (a) 99% of the data points—to estimate the extent of the predicted GPP domain range; and (b) 90% of the data points—to estimate the extent of the predicted GPP domain core (see Figure 25).

The results show that the Red-browed Finch prefers vegetation that is evergreen but also has a substantial seasonal component (Figure 25a). In contrast, the Zebra Finch distribution is characterised by habitat with low evergreen and seasonally green GPP (Figure 25b). Most observations of these species are within or very close to vegetation that remains in 'residual' or 'modified' condition as categorised in Figure 20. Thus, although these finches are widespread their habitat has and is being diminished. These ongoing habitat impacts may impede the natural adaptation processes that have allowed species to survive previous year-to-year climatic variability and long-term climate change.

Natural adaptation processes

Climate change, including rapid climate change, impacts on birds in two ways. First, climate regulates the broad geographic limits of a species distribution by setting the boundaries of an organism's physiological niche—the set of basic environmental conditions within which a species can function and complete its life cycle. Second, climate provides the energy and water inputs to ecosystems that determine (along with the supply of carbon dioxide and mineral nutrients) the rates of photosynthesis, growth and decomposition of the vegetation and thus the main habitat resources of birds. Climate is also a major determinant of the fire regimes operating in a region.

Earth's climate is never stable for long periods, and the extant bird species are here because their predecessors survived past climatic fluctuations. Analyses of gases and the oxygen isotope composition of water trapped within cores of ice taken from glaciers in the Antarctic by Petit and colleagues have revealed evidence of several large oscillations in the climate, and in the concentration of CO_2 in the atmosphere, over the past 400,000 years. Each time, over approximately 100,000-year intervals, Earth's climate made a slow and bumpy descent into full glaciation, followed by a rapid and steep climb into interglacial conditions. These upheavals undoubtedly caused the local extirpation of some species, and some extinctions. However, the rich bird species diversity in Australia today, and its ancient lineage as revealed by analysis of molecular data, attest to the capacity of bird species to survive these changes.

We can infer that in response to previous climate change, and resultant changes in optimum niche conditions and the distribution of habitat resources, bird species avoided extinction through one or more of four possible responses:

1. Species could have dispersed to somewhere that still had the necessary habitat resources. This is obviously a useful life history strategy in the face of environmental variability at any time scale;
2. Species could have evolved new traits (behavioural, physiological, and morphological) which enabled them to persist in the same location by exploiting different habitat resources in response to shifting ecosystem dynamics;
3. Within each species' genome is some degree of phenotypic plasticity, and some species have, for example, a broad physiological niche or the capacity to shift to new food resources as they come on-line; and
4. Some species could have taken refuge in locations that retained a micro-climate similar to that previously dominant in the surrounding region. Refugia are known to be important for animals in tall wet forests (fire refugia) and arid Australia.

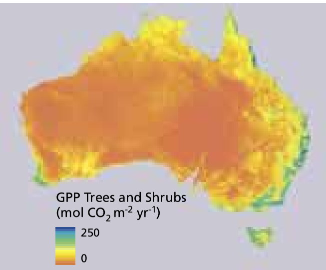

Figure 22. The amount of the GPP (shown in Figure 21) that was obtained by the evergreen vegetation (mostly trees and shrubs). The highest evergreen GPP (dark blue) is in those regions where the vegetation cover is tropical or sub-tropical rainforest. From the bird perspective, this is a map of the relative abundance of food (nectar, pollen, sap eating insects, bark invertebrates, flowers, fruits, etc.) and nesting resources (branches, tree hollows, etc.) of woody vegetation.

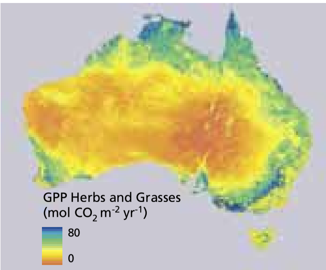

Figure 23. The amount of the GPP (shown in Figure 21) that was obtained by the seasonally green vegetation (comprised mostly of herbaceous plants). The highest seasonal GPP (dark blue) occurs in those regions where the vegetation cover is agricultural crop (southern Australia), or tropical woodland (northern Australia). From the bird perspective, this is a map of the relative abundance of food (grain, foliage, root feeding insects, leaf-eating insects) and nesting resources (grass tussocks, etc.) of grassy vegetation.

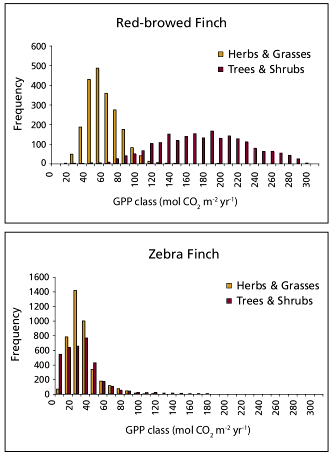

Figure 24. The GPP domain of (a) Red-browed Finch and (b) Zebra Finch. These histograms are graphic expressions of the preferred herbaceous and woody GPP domains of the two finch species. To determine the domain of the finches, the GPP of (i) the herbs and grasses (see Figure 23), and (ii) the trees and shrubs (see Figure 22) was extracted for all intensive survey sites in the Atlas where these species were reported. Then GPP values were assigned to classes and the frequency of observations within each GPP class was counted.

These four adaptive responses are still available to extant bird species in the face of human-forced global warming. However, their capacity to respond is being interrupted by the ecological footprint of humans on Australia's environment, including appropriation of the most productive lands for human land use (as illustrated by Figures 20 and 21). During previous periods of rapid climate change, natural vegetation cover could exist wherever sufficient resources for plant growth were available, and the structure and composition would have been in tune with the environmental conditions of the time. However, bird species today face a very different situation.

The appropriation and degradation of bird habitat in Australia

The Australian continent no longer presents a continuous natural land-cover for birds to utilise. As noted above, extensive areas have been largely cleared of their native vegetation cover, with the temperate and sub-tropical woodlands being the worst affected (Figure 20). The most productive terrestrial ecosystems, the forests of the alluvial plains, have been largely cleared for settlement and farming. The most productive of the remaining temperate forests are being subjected to industrial logging. Across eastern and southern Australia, water is being diverted from natural flood plains and wetlands are being drained. While these impacts are now well documented, the implications for nature in Australia have not been fully grasped. Consider again the Zebra Finch and Red-browed Finch. Given the prospects for further broad scale clearing and intensification of pastoralism in the remaining, most productive intact landscapes, especially in northern Australia, the habitat of even these two commonly reported species cannot be guaranteed.

To assess the magnitude of our human ecological footprint we calculated how much of the GPP (Figures 21–23) occurs on land used to meet the consumer needs of humans and how much has been allocated to nature conservation (Figure 26). Only 10% of GPP is protected within the formal protected area reserve system (IUCN categories I–IV), whilst almost 70% is on freehold and leasehold lands where, as noted above, a significant portion of the GPP is appropriated for human use.

By area, protected areas currently comprise little more than 8% of Australia (see Figure 27). Much of what is protected represents extreme environments including the alpine regions, the rainforests and the most arid parts of the country, and the rocky, highly dissected sandstone plateau. However, the habitat of many birds lies largely outside these protected areas. Many of the protected areas are tiny fragments within an expanse of other land tenures. Such small fragments are very vulnerable to impacts from wildfire, disease, and edge effects, as well as impacts of climate variability and climate change. Because of this, we cannot be certain they are adequate to protect in the long term even those species that are mostly sedentary.

The imperative to protect, restore and reconnect bird habitat

The challenge suggested by the maps is three-fold in that we must concurrently endeavour to:

(1) protect what is left of intact bird habitat;
(2) restore and rehabilitate cleared, fragmented and degraded habitat; and
(3) re-connect the ecological processes that maintain the health and productivity of landscapes.

For many species, especially birds, ecological connectivity means much more than corridors of native vegetation linking habitat patches. Rather, ecological connectivity can refer to maintenance of a regionally scaled network of habitat patches used variably over space and time, such as those required by frugivorous birds and water birds.

It is becoming clear that promoting the long-term conservation of biodiversity requires planning and action at a range of scales, from local to continental. Bird species vary

The impressive Channel-billed Cuckoo is shifting south and breeding somewhat earlier, presumably in response to global warming. A frugivore, the cuckoo needs to be able to forage over a broad landscape to find fruit year round; it has long been viewed as a harbinger of Spring. Photo by **Ian Montgomery**

in the scale and pattern of their movements, but even resident species are ultimately dependent on healthy vegetation ecosystems that provide their necessary food and other habitat resources. Birds and the ecological processes that sustain their habitat do not stop and start at protected area boundaries. Given the rate of human-driven environmental change, a minimalist approach to conservation may well fail to achieve even the modest conservation goal of halting global extinctions of vertebrate animals. Rather, a whole-of-landscape approach to conservation is needed that includes all land tenures and land managers. The term connectivity conservation has been coined to capture this 'big picture' approach to conservation. Examples of connectivity conservation in Australia include the community-based Gondwanalink project in south-west Western Australia (see *Wingspan*, December 2007) and the Alps-to-Atherton initiative of the New South Wales government.

A call for connectivity conservation

Our examples of the Zebra Finch and the Red-browed Finch illustrate how the human ecological footprint is impacting on habitat resources for even widespread and commonly reported species. The conservation of Australia's biodiversity requires more than the piecemeal addition of fragments to the reserve system. Human appropriation of GPP—or, more accurately, the biomass produced by plant GPP—increasingly diverts food and other vegetation-related habitat resources away from wildlife. Ultimately, the long-term future of Australia's bird fauna will depend on our collective generosity and willingness to make room for nature in an increasingly crowded world. Continental scaled connectivity conservation projects, such as Gondwanalink and Alps-to-Atherton, will help give bird species resilience in the face of climate change by maximising their ability to utilise the natural adaptation responses that have served them so well in the past.

Sandra Berry and Brendan Mackey,
The Australian National University, Australian Capital Territory

This research is supported by ARC Linkage grant and a grant from The Wilderness Society Australia courtesy of a generous donation from the Dara Foundation.

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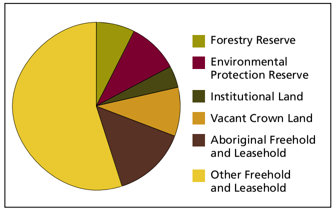
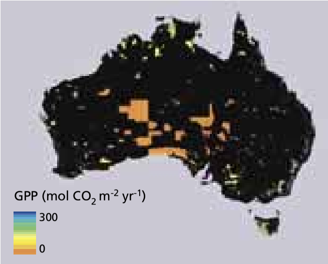


Figure 26. Who owns the GPP? This pie chart shows how the continental GPP is partitioned between various land tenures. Only 10% is dedicated to nature. We humans have appropriated about 75% for our needs.

Figure 27. The extent of areas currently unprotected in Australia, overlain on the GPP map (Figure 21). Many reserves are small islands within a sea of other land tenures (black).



IV. Putting Biodiversity Conservation on the Carbon Account

Protecting Biodiversity and Climate: Making the Most of Biodiverse Carbon

by Margaret Blakers

The conjunction of biodiversity loss and climate change is an awesome threat to the planet, but could also be a new opportunity for biodiversity conservation. While climate change threatens to wreak havoc on the world's natural environments, protecting natural vegetation is increasingly recognised as a vital element in slowing greenhouse gas emissions and improving resilience against its impacts. In effect, biodiversity has found a 'use' which the world might be willing to pay for.

The Stern Review estimated that emissions from deforestation account for over 18% of global greenhouse gas emissions and stated that 'action to preserve the remaining areas of natural forest is urgent'. Stern's main focus was the vast tropical forests in developing countries that have especially high carbon stocks and are being logged and cleared for agriculture at an alarming rate. The United Nations Framework Convention on Climate Change (UNFCCC) is convening an active discussion about reducing emissions in developing countries from deforestation and forest degradation (logging, disturbance and other activities that reduce carbon storage). But this is only part of the wider discussion needed about the relationship between carbon sequestration and biodiversity protection.

The amounts of money in the emerging carbon markets are huge. The World Bank estimated the total value of transactions in 2006 at $US30 billion, but only 1% related to the Land Use, Land-use Change and Forestry (LULUCF) sector which incorporates the natural environment. According to the World Bank, demand in this sector is limited by regulatory complexity and restricted access to the carbon markets created so far. Consequently, while there is great potential for channelling investment to biodiversity protection as a contribution to reducing greenhouse gas emissions, if it is to be realised these limitations will have to be addressed.

There will need to be reliable and coherent systems of measurement for both carbon and biodiversity, a sound institutional and policy framework to underpin the system, and appropriately designed market and other funding mechanisms.

Carbon accounting

Carbon accounting is overseen by an international body, the Intergovernmental Panel on Climate Change (IPCC), under the jurisdiction of the UNFCCC. Australia prepares two sets of greenhouse accounts in accordance with the IPCC methodology: a comprehensive account which attempts to measure and report on all sources of emissions and all forms of carbon uptake (the UNFCCC account); and the Kyoto account which reports only the categories recognised under the Kyoto Protocol. The Kyoto account is the relevant one for gauging whether Australia is meeting its international emission targets.

The two accounts treat the Land Use, Land Use Change and Forestry (the LULUCF category) differently. The Kyoto account is restricted to the impacts on carbon stocks of changes in land use since 1990: that is, carbon uptake resulting from afforestation and reforestation (tree planting); and carbon losses from deforestation (tree clearing). The Kyoto account does not include emissions from logging native forests or logging plantations established prior to 1990; nor does it include carbon uptake from the growth of native forests and pre-1990 plantations. The differences between the two accounts are significant, with total emissions recorded by the Kyoto account of 559 Mt CO$_2$ in 2005, compared with 522 Mt CO$_2$ recorded by the UNFCCC account (see Table 3).

The limitations of the Kyoto account and targets derive from negotiations at the time. They reflect the rudimentary state of carbon accounting in 1997 and concern that the inclusion of green carbon (see small box p. 31) would militate against genuine action to reduce fossil fuel emissions (which, in Australia, indeed it has).

The IPCC accounting methodology was designed to evolve and has improved enormously in the last decade. Correspondingly, NCAS (Australia's National Carbon Accounting System) is being progressively upgraded in its capabilities and comprehensiveness. The next step should be to improve the compatibility of carbon and biodiversity accounting systems such as by using the same vegetation classifications and reporting separately on landscapes with biodiversity value or potential, and those without. This will not necessarily require major adjustment. For example, in the Australian accounts, native forests and plantations are already reported separately.

A recent drought victim, a Red Gum, in an agricultural landscape in Western Victoria. The loss of such significant old remnant trees removes habitat for birds and sources of natural regeneration. The retention and replacement of such trees across the landscape helps to lock up the carbon that is the main contributor to global warming and benefits biodiversity. Recognition of such 'green' carbon could help fund vegetation restoration and stewardship programs. Photo by **Rohan Clarke**

Biodiversity accounting

Birds Australia is well versed in the difficulties of measuring biodiversity through its two Atlas projects and other monitoring schemes. The Millennium Ecosystem Assessment discusses this complexity and observes that:

> *Despite the difficulties, it is worth gathering better evidence about benefits created by natural systems. One goal of such research could be to establish a system of biodiversity accounts to track changes in the status of biodiversity, in much the same way that national income accounts are used to track the status of national economies. For example, application of a calculus of biodiversity may provide one pathway for addressing the monitoring requirements of the 2010 biodiversity target.*

It is precisely such a mechanism that is needed as a counterpart to carbon accounting. This need not necessarily be a unitary system (i.e., under one authority), but it must be global because carbon trading and other financial mechanisms will be global. It has to be credible and authoritative if it is to underpin investment decisions by a variety of agents: landholders, governments, companies and individuals.

A useful step would be to undertake something similar to the IPCC process where an agency such as IUCN brings together scientists from around the world to develop and accredit accounting standards for biodiversity.

Institutional frameworks

Neither at the global level, nor in Australia, is there a formal or enforceable institutional framework governing the interaction between climate protection and biodiversity conservation (Table 4). Such links as exist come largely from private initiatives. There is no formal capacity to ensure that climate protection initiatives do not adversely impact on biodiversity, or to look for synergies where biodiversity protection can help the climate.

In the case of climate change, the global instrument is the UNFCCC, given effect through the Kyoto Protocol, which includes enforceable greenhouse gas emission targets for developed (Annex 1) countries. For biodiversity, the equivalent is the Biodiversity Convention (combined with numerous other multilateral environmental agreements such as the

Plantations may offset some greenhouse gas emissions and can also benefit biodiversity, but their carbon sequestration values are generally not captured in markets and their value for biodiversity usually goes untested. Blue Gum plantation in agricultural landscape, Western Victoria. Photo by **Rohan Clarke**

Table 3. Australia's carbon accounts (Mt CO_2[1], 2005)

Net emissions	Kyoto account	UNFCCC account
Total	559	522
Land use, land use change and forestry[2]	38	-3

Source: Australia's National Greenhouse Accounts: www.greenhouse.gov.au/inventory/

[1] Mt = million tonnes; by convention, carbon emissions are represented by positive numbers, carbon uptake (sequestration) by negative numbers.

[2] These are 'Article 3.3' activities under the Kyoto Protocol. Annex 1 countries also have the option of including Article 3.4 activities, enabling them to claim credits for additional carbon sequestered through the management of forests, grasslands and croplands since 1990. Australia has not taken up this option.

Ramsar Convention on wetlands of international importance, and the Bonn Convention on migratory species). But the Biodiversity Convention is not enforceable.

Australia lacks national legislation to implement the UNFCCC and refuses to ratify the Kyoto Protocol. The Biodiversity Convention is implemented through the *Environment Protection and Biodiversity Conservation Act* (EPBC Act), but this hardly mentions climate change and greenhouse gas emissions are not a trigger for environmental impact assessment. At a policy level, the Biodiversity Strategy adopted in 1996 and updated in 2001 is currently being revised and the recently released Australia's *Climate Change Policy* does not refer to biodiversity and barely to land use.

The lack of institutional frameworks to integrate biodiversity and climate protection results in disasters like the widespread destruction of rainforest, especially in south-east Asia, to grow oil palm for biodiesel amongst other uses. Within Australia, while reduced rates of clearing have helped bring the Kyoto target within reach, activities that destroy biodiversity and increase greenhouse gas emissions continue if they are not in a Kyoto Protocol sector. Old growth forests, which have the highest carbon stocks of any terrestrial ecosystem, are being liquidated (see box at far right). On the Tiwi Islands forests are being replaced by acacia plantations, impacting on species like the Red Goshawk, and in Tasmania, old growth forest continues to be logged at the expense of the Tasmanian Wedge-tailed Eagle and breeding habitat for the Swift Parrot.

Financing biodiversity and carbon sequestration

The World Bank divides the carbon market into a 'compliance' sector where emission reductions are required by law, and 'project-based' transactions, such as through the Clean Development Mechanism. Because they are based on the Kyoto Protocol, neither of these dominant markets generally covers avoided clearing or forest degradation. As it stands, emissions from agriculture and land-use (including clearing and logging) will not be part of carbon trading in Australia either, on the recommendation of the government's carbon trading taskforce, largely because of measurement difficulties.

There are nevertheless carbon trades taking place that benefit biodiversity. Australian examples include avoided clearing of woodlands in Queensland and strategic savannah burning in western Arnhem Land in order to reduce greenhouse gas emissions from uncontrolled large-scale burning. Globally, there is a small but growing market for voluntary emission reductions by companies and individuals, including for green carbon. This entire market is at present held back by the lack of standards for carbon accounting (let alone biodiversity accounting), to assure investors that the benefits they are paying for are real, verifiable and lasting.

Even with such standards, the incorporation on a large scale of green or biodiverse carbon into existing markets will be fraught with difficulty. The Stern Review points out the risk that emerging carbon markets could be swamped by the inclusion of green carbon on a large scale.

Getting biodiversity on the carbon account

Economic instruments are not a substitute for policy; they operate within regulatory regimes set by governments and alongside a variety of other economic and practical measures. Critically, the future for green carbon, specifically biodiverse carbon, depends on how it is treated in the globally agreed post-Kyoto framework. There are strong differences within the scientific and environmental communities as to whether green carbon should be included at all and if so on what terms. Even if the accounting issues are resolved, there are formidable political challenges to negotiate the rules for the future, between developed and developing countries, and between different categories of emissions and sinks.

The political process to negotiate the post-Kyoto response to climate change is well underway. Australia, as a developed country with rich biodiversity, could take a lead, if not initially through government, then through non-government and scientific organisations. There is no time to lose if biodiversity conservation is to get a look in.

Margaret Blakers,
Green Institute, Tasmania

This paper summarises ideas from M Blakers and A McGregor (2007). Climatescapes: mechanisms, measurement and money. *(In prep.)*

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Table 4. Selected legal and policy frameworks linking climate change and biodiversity protection at the global and Australian national level

Scale	Climate change	Links	Biodiversity
Global			
Legal	Climate Change Convention		Biodiversity Convention (and numerous other multi-lateral environmental agreements)
Policy framework	Kyoto Protocol—enforceable		2010 biodiversity target; IUCN Red Book
Measurement	IPCC accounting framework	Climate, Community and Biodiversity Alliance standards[1]	Millennium Ecosystem Assessment
Financial	Clean Development Mechanism Carbon trading	Non-government organizations, e.g. Conservation International	Global Environment Fund (GEF)
Implementation	Kyoto targets	Many examples	World Heritage properties; GEF projects
Australia			
Legal			*Environment Protection and Biodiversity Conservation Act*
Policy framework	Greenhouse strategy 1998		Biodiversity Strategy 1996
Measurement	National carbon accounting system		State of the Environment Report
Financial	Possible carbon trading 2010–2012	Private carbon offsets	Natural Heritage Trust
Implementation		Private initiatives, e.g. Carbon Pool, Greening Australia Biodiverse Carbon Program	National reserve system including Indigenous Protected Areas

[1] www.climate-standards.org

Green carbon

In this paper, the term 'green' carbon is used to denote carbon associated with living systems, natural and cultivated. It includes biomass in (both above and below ground vegetation), dead wood, litter and organic matter in the soil. 'Biodiverse' carbon is a subset of green carbon—the carbon in ecosystems which have value for biodiversity conservation.

Getting our green house in order

Global warming is the greatest threat that our natural environment has ever faced. I might be wrong about that, but even in the face of uncertainty the consequences of over-reacting would seem to be far less dire that those of under-reacting. If we assume the threat is real, immediate, severe and avoidable, and that fixing the root cause of the problem is a responsibility we all share, what is Birds Australia doing to contribute to the solution?

Conservation through Knowledge is the motto of our organisation and the generation and sharing of new knowledge about the impact of global warming on habitats and species is likely to be the biggest contribution we can make. However, this must come through active inquiry into potential solutions rather than simply emphasising post hoc analyses of passively accumulated data. We must make climate change an issue that cuts across all of the organisation's activities, so that every opportunity is taken to understand its impacts and the viability of potential solutions.

Another approach we have adopted is to take responsibility for the organisation's carbon emissions by reducing our energy use as far as practicable and offsetting the rest. An important reason for the recent relocation of Melbourne Office to the 60L Green Building in Carlton was to reduce our reliance on non-renewable energy sources and increase awareness and ownership of the issue among staff, volunteers and Members.

In our old premises in Hawthorn East, inefficient air conditioning, heating and lighting wasted energy. Consider the inappropriateness of air-conditioned storage rooms. The suburban location and inadequacy of cross-town public transport forced most staff to drive to work.

In establishing The Green Building (website: www.60Lgreenbuilding.com) the Green Building Partnership aims to provide a highly energy and resource efficient workplace by reducing reliance on artificial light, temperature conditioning and mains-treated water. Tenants are required to abide by a strict Environmental Management System. The building's location on the edge of the CBD means it is readily accessible via public transport from all of Melbourne. All staff now routinely commute by public transport or bicycle.

It is not possible for us to have a net positive impact on the environment simply by occupying an energy efficient building and cycling to work. As a national organisation our work involves considerable interstate travel and appropriate offsets must be made if we are to achieve our goal. We have established a system where a carbon tax is made on all work-related travel and the proceeds paid into an internal carbon fund. The fund will be used for revegetation schemes with the dual aims of providing bird habitat and a carbon sink.

BY GRAEME HAMILTON, *CEO, Birds Australia*

Forests: vital for climate protection

Native forests have a vital role in Australia's greenhouse profile. They are our most biologically productive ecosystems and contain a very large store of CO_2, with great potential for additional sequestration. They are also a significant source of emissions as a result of clearing and logging. Clearing is monitored closely by the government because reduced clearing rates are the main way Australia might be able to claim to have met its Kyoto target (even though it has not ratified the Protocol). In 2005, emissions from clearing were estimated at 58 Mt CO_2, down from 115 Mt CO_2 in 1990 (the baseline year).

Emissions from native forest logging have largely escaped attention because they do not count towards Kyoto targets and because they are not clearly identified in Australia's national greenhouse gas accounts. For example, in 2005 'managed native forests' are reported to be a net sink, with an uptake of -43.5 Mt CO_2 in 2005 (UNFCCC account; see Table 3). This figure is actually a composite, it includes: annual uptake of CO_2 from growth of 'managed' native forests (those available for logging); on-site emissions resulting from post-logging regeneration burns and decay; losses of CO_2 from soil organic matter following logging and disturbance; CO_2 uptake by forests in conservation reserves; and it excludes emissions resulting from the processing and use of logs removed from the site. In other words, the size of this sink would be very much greater if native forests were not logged and conservation forests were included, but the amount of emissions attributable to logging cannot readily be extracted.

A reliable measure of emissions from native forest logging requires area-specific assessments of the CO_2 sequestered in forests of different types and ages. This work is underway. In the meantime, I have used the available information to estimate that native forest logging results in emissions of 38 Mt CO_2 per annum, equivalent to 7% of Australia's total emissions (UNFCCC accounting; see Table 3). This is likely to be low because it does not adequately account for the huge volumes of CO_2 stored by old-growth forests nor for soil organic matter. For comparison, in 2005, Australia's entire estate of Kyoto-compliant plantations (those established since 1990 on previously cleared land) sequestered 19.6 Mt CO_2.

Almost all emissions from native forest logging are released to the atmosphere either immediately or within a few years. On site, branches, leaves and undergrowth are burned or decay (within seven years according to Australia's accounting methodology). Most of the logs are converted into pulp, which is regarded as a 'very short term product' with a maximum estimated life of three years.

Over time, the CO_2 emitted to the atmosphere after logging will be recaptured as forests re-grow. But the recapture time is critical—that is, the time taken to completely remove the CO_2 from the atmosphere again. This will vary, according to the age of the forests, from a few decades to several centuries for old growth forests.

Old growth forests have the highest carbon stocks of any terrestrial ecosystem. Their continued logging in Tasmania releases that carbon to the atmosphere and also destroys breeding and feeding habitat for the endangered, nectar-eating Swift Parrot. Photo by **Graeme Chapman**

Until it is recaptured, the CO_2 remains in the atmosphere and causes global warming just the same as CO_2 from fossil fuels.

Full carbon accounting is likely to be adopted for the global post-Kyoto framework, now being negotiated, if not before. That means emissions from native forest logging will be counted in the future and, with a price on carbon, someone will have to pay. Protecting forests from industrial logging is one of the quickest and easiest ways to reduce Australia's greenhouse gas emissions. It is far more efficient than establishing new plantations which take decades and many times as much land to store the same amount of carbon as a mature forest. Forests have, in addition, inestimable value for conserving birds, biodiversity in general, and water.

BY MARGARET BLAKERS

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Photo by **Graeme Chapman**

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Cover photo:
A Willie Wagtail with a winged offering seems undecided which eager chick to feed. Which birds will adapt to climate change is just as uncertain and there are no black and white answers. Photo by **Raoul Slater**

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Birds Australia welcomes new members and volunteers

The **Atlas of Australian Birds** is a long-term, nationwide, volunteer-based bird-monitoring project that welcomes new participants. Contact Andrew Silcocks (03 9347 0240; a.silcocks@birdsaustralia.com.au; www.birdata.com.au)

The **Threatened Bird Network** links volunteers with recovery efforts for more than 25 threatened species. Contact Dean Ingwerson (03 9347 0247; d.ingwerson@birdsaustralia.com.au)

The **Important Bird Area** project identifies areas critical to the survival of native birds. Contact Guy Dutson (03 9347 0246; g.dutson@birdsaustralia.com.au)

The **Nest Record Scheme** collates information from volunteers on all aspects of nesting biology. Contact Glen Ehmke (03 9347 0244; g.ehmke@birdsaustralia.com.au)

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