ASSOCIATIONS BETWEEN CLIMATE CHANGE AND NATURAL SYSTEMS IN AUSTRALIA

BY LYNDA E. CHAMBERS

Favoring a national approach to a pressing worldwide scientific issue, Australian scientists have commenced a project to learn more about the effects of climate change on their continent's species and natural systems.

Global surface air temperatures have risen approximately 0.6°C since the mid-nineteenth century, and the magnitude of this warming is the largest recorded in any century over the last 1000 years (Houghton et al. 2001). Consistent with global trends, Australia's average temperature increased 0.7°C from 1910 to 1999, with the largest increases occurring since about 1950 (Collins et al. 2000; Nicholls 2003).

Recently there has been a resurgence of interest in the use of natural systems as indicators of climate change, with evidence mounting that the anomalously high temperatures seen in the twentieth century have already been associated with changes in many physical and biological systems around the globe, including accelerated glacial retreat, tree line movements, the lengthening of growing seasons, and alterations in the phenology (timing) of breeding, migration, and flowering of many species (Hughes 2000; Sparks et al. 2002; Sparks and Smithers 2002; Walther et al. 2002; Parmesan and Yohe 2003; Root et al. 2003).

This renewed interest has occurred for a number of reasons. First, many natural systems have been shown to be very sensitive to changes in climate (Menzel 2002; Sparks and Smithers 2002). Many plant and animal species respond to changes in temperature, rainfall, humidity, sunshine, and other climate variables. This makes them valuable indicators of combined changes in the climate system, through their integration of the various climate elements (Menzel 2002).

Second, changes in natural systems, such as alterations in the timing of bird migration or in the flowering of plant species, are often easier for the general public to relate to than, say, a 0.6°C rise in global temperature (Menzel 2002; Sparks and Menzel 2002). In addition, such changes are often seen in "their backyard," making the climate-change issues more relevant and pressing, with the added benefit

AFFILIATIONS: CHAMBERS—Bureau of Meteorology Research Centre, Melbourne, Victoria, Australia
CORRESPONDING AUTHOR: Lynda E. Chambers, Bureau of Meteorology Research Centre, GPO Box 1289, Melbourne, Victoria 3001, Australia
E-mail: L.Chambers@bom.gov.au

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of increasing motivation and the likelihood of involvement in climate-change indicator monitoring programs (Sparks and Smithers 2002).

Third, from an environmental management perspective, it is important to determine the impact of climate change on the environment, with the information obtained supporting policy development and further monitoring used to assess policy effectiveness.

STATUS OF KNOWLEDGE IN AUSTRALIA.

In the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC; McCarthy et al. 2001), figures and tables illustrated global locations where studies of natural process or species had been associated with regional temperature change. Despite many studies being listed for the Northern Hemisphere, there were very few studies listed for the

Table 1. Observed changes in Australia's natural systems associated with changes in the climate. There are no glaciers on mainland Australia.

Region	Natural system change	Reference
Glaciers, snow cover/melt		
Snowy Mountains, southeastern Australia	30% reduction in snow cover over the last 45 years.	Green (2003)
	Earlier ice breakup at Blue Lake; two-month difference in date in past 30 years.	Green (2003)
Heard Island, Australian sub-Antarctic	Glacial retreat; approx 35 km^2 of new terrain exposed between 1947 and 2000.	Bergstrom (2003)
Vegetation		
Australia	Increase in woody biomass, partial link to increased atmospheric CO_2.	Bowman et al. (2001)
Subalpine eastern Australia	Encroachment by snow gum *Eucalyptus pauciflora* into subalpine grasslands at higher elevations.	Reviewed in Hughes (2003)
Northern Australia	Increased forest coverage and expansion of rain forest, at expense of eucalypt forest and grasslands, linked to rainfall changes.	Reviewed in Hughes (2003)
Coastal Australia	Landward transgression of mangroves, possibly related to sea level rise and altered rainfall patterns.	Reviewed in Hughes (2003)
Southeastern Australia	Shifts in flowering dates in four perennial species, ranging from 0 to 46 days later over a 20-year period.	Keatley et al. (2006, manuscript submitted to *Global Change Biol.*)
	Changes in flowering dates of 56 species of Australian plants, over 22 years; 24 species had mean advancement of 13.6 days; remaining species had mean flowering of 20.8 days later.	Keatley and Hudson (2005)
Heard Island, Australian sub-Antarctic	Changes in plant communities, e.g., native creeping herb outcompeting and overgrowing the dominant plant species, a cushion plant.	Bergstrom (2003)
Invertebrates		
Southeastern Australia	Change in genetic constitution of *Drosophila*, equivalent to a 4°-lat shift.	Umina et al. (2005)
Amphibians and reptiles		
South Australia	Changes in mating behavior of sleepy lizards *Tiliqua rugosa*. Warmer, drier winters leading to earlier pairings.	Bull and Burzacott (2003)

Southern Hemisphere, and none for the Australian region, other than a glacier in New Zealand.

Australia contains a high proportion of endemic species, which have already adapted to a highly variable climate system (McCarthy et al. 2001). We therefore need to exercise some care when using Northern Hemisphere climate impact results and projecting them onto Australian species. The movement and breeding in waterbirds is one example. In the temperate regions of Europe and North America, migration of waterbirds is generally predictable and large scale, and increasing daylight and temperature during spring is a major factor in initiating breeding (Frith 1982; Kingsford and Norman 2002). In Australia, massive waterbird movements are often erratic in timing and direction, and the timing of breeding seasons, for many species, is variable (Frith 1982; Briggs 1992; Kingsford and Norman 2002).

Limited progress has been made since the 2001 IPCC report. Although not exhaustive, Table 1 illustrates recent knowledge gains associated with

Table 1. Continued.

Region	Natural system change	Reference
Birds		
Snowy Mountains, southeastern Australia	Earlier arrival of migratory birds; seven species arriving at least one month earlier in 1980s–90s than in the 1970s.	Reviewed in Chambers et al. (2005); Green (2003)
	Arrival and timing of breeding in Richard's pipit *Anthus novaeseelandiae* related to snow cover; earlier arrivals corresponding to years of earlier snowmelt.	Norment and Green (2004)
Australia	Range shifts. Arid and semiarid species moving toward more temperate regions; poleward shifts; southern range expansions.	Reviewed in Chambers et al. (2005)
Western Australia	Reduced productivity in blue-breasted fairy wren *Malurus pulcherrimus*, related to reduced rainfall in southwestern Australia.	Reviewed in Chambers et al. (2005)
	Tropical seabirds extending ranges southward. Southern, high-latitude, cool-water seabirds extending breeding seasons.	Reviewed in Chambers et al. (2005)
	Changes in arrival and departure dates of birds in semiarid regions; overall trend toward earlier arrivals and departures.	Chambers (2005)
Great Barrier Reef	Reduced reproductive success in wedge-tailed shearwaters *Puffinus pacificus* associated with high sea-surface temperatures.	Reviewed in Chambers et al. (2005)
Heard Island, Australian sub-Antarctic	Population increases in black-browed albatross *Diomedea melanophris* and king penguin *Aptenodytes patagonicus*.	Reviewed in Chambers et al. (2005)
Mammals		
Eastern Australia	Poleward range shifts in grey-headed and black flying foxes.	Tidemann (1999)
Snowy Mountains, southeastern Australia	Increased penetration of feral mammals into alpine and subalpine areas. Prolonged winter presence of browsing macropods; both attributed to reduced snow cover.	Green and Pickering (2002)
Heard Island, Australian sub-Antarctic	Population increase in fur seals *Arctocephalous gazella*.	Budd (2000)
Macquarie Island, Australian sub-Antarctic	Rats moving into upland herb fields and breeding more often.	Bergstrom (2003)

climate change impacts on Australia's natural systems. Many of these studies give a consistent picture of climate-related changes to natural systems, for example, reduced snow and ice cover, southward expansion of avian ranges, and earlier arrival of bird species to alpine areas. However, for many of the categories, particularly for invertebrates, amphibians, and reptiles, it is clear that we have very little idea of how changes in climate are affecting these species and systems on local, regional, or national scales. There have also been very few studies, of any type, in western and central Australia or in the northern tropical rainforests.

NEED FOR A NATIONAL APPROACH. The lack of a national coordinated approach to the analysis and cataloging of climate change effects has seriously hampered current efforts to detect and attribute climate change signals in Australia's natural systems. For without this national approach, it is difficult to determine regional and national climate change effects on natural systems and their climate tolerances. This in turn influences the accuracy of climate change scenario models of future species abundance and distribution (Chilcott et al. 2002; Hughes 2003). If we do not know exactly how species and systems are currently restricted by climate, as opposed to restrictions due to additional pressures, such as land-use practices, it will not be possible to provide soundly based predictions of how future climate will affect them.

By using a national approach it is possible to observe how many natural systems currently respond to a wide range of climate types, giving insights into their potential to tolerate, and adapt to, projected climate changes. Continental and national analyses of butterflies in North America and Europe and birds in the United States, United Kingdom, and the Arctic provide evidence of changing distributions in response to a warming climate (Root 1994; Parmesan 1996; Thomas and Lennon 1999; Parmesan and Yohe 2003).

An example of the benefits obtained from a national approach comes from the Woodland Trust in the United Kingdom (www.phenology.org.uk). A small number of people in the United Kingdom had been keeping personal records of the first flowering of daffodils in their backyards, but it was not until the records were combined, through each person contacting a central depository (the Woodland Trust), that clear, spatially coherent climate-impact signals were discerned—even though the records came from very different locations in the country (www.phenology.org.uk/garden). Trends observed in the individual records, such as those for the daffodil, cannot be regarded as representative of a general trend and concerns could be raised as to how much of the trend results from the influence of climate and how much comes from other sources, such as local garden management techniques (e.g., frequency of watering). By combining the records, and identifying large-scale patterns, we can be more confident that coherent trends reflect a more wide-scale phenomenon, such as changes in the climate.

Most importantly, the extent of historical natural systems data that have already been collected within Australia is largely unknown. Chambers et al. (2005) give examples of the many avian datasets that are currently known, many of which are yet to be analyzed for climate change signals. Many more datasets are expected to be held by smaller naturalist organizations and by individuals, but these are yet to be documented in a systematic way. Less is known about the availability of nonavian data, such as historical flowering information and the breeding and migration of mammals, reptiles, invertebrates, and amphibians. A coordinated effort is long overdue to document historical information and to analyze this data both for climate change signals and for relationships between natural systems parameters and climate. We need to better coordinate our efforts to make better use of the resources available, and ensure that both natural resource managers and climate scientists are aware of each other's efforts. Otherwise, valuable research and information may not reach the appropriate people, and policies and reports, such as future IPCC assessments, run the risk of being based on incomplete information or continuing to have huge knowledge gaps. One way of achieving this is to have a central depository of information on natural systems datasets.

WAYS FORWARD. A relatively fast and cost-effective method of gaining knowledge of how climate changes affect Australia's natural systems involves analyzing historical phenological and other records.

Australia does not currently have a historical register of datasets of potential use to climate change, such as the U.K. Phenology Network (www.phenology.org.uk) or the European Phenology Network (EPN) (www.dow.wau.nl/msa/epn), and much could be gained by implementing such a scheme. Researchers at the Australian Bureau of Meteorology, Macquarie University, and the University of Melbourne are planning to do just that.

Over the next two years, and using the EPN and U.K. Phenology Network Web sites as guides, a Web-based database of natural systems metadata will be developed covering the Australian region, including Australia's sub-Antarctic territories.

By documenting existing datasets the project aims to improve our knowledge of the impacts of climate change on biodiversity; provide baseline data for future monitoring programs; provide a central location, making it easier to locate and access relevant data; encourage sharing of knowledge between regions and institutions; and improve the capacity of natural resource managers to adapt to climate change through improved understanding of climate–species relationships.

Information stored in the database will include the type of data, such as plant, bird, insect, aquatic, mammal, pollen, etc., as well as information on the spatial and temporal extent of monitoring (including the years covered and periods of interruptions to monitoring) and details of the individuals/organizations responsible for the data collection and storage. Access to the metadatabase will be freely available through the Bureau of Meteorology's Web pages, and this organization will be responsible for data archives and project coordination.

Raising awareness of the usefulness of natural systems data for climate change studies to government and universities, as well as to the general public, will be a priority, for without their involvement and support, many potentially useful datasets may go unrecorded. To encourage their involvement and to ensure project success, organizations and individuals will be contacted either by phone, face-to-face meetings, or, in the case of ecological or field naturalist societies, by short articles in group newsletters and/or seminars. The database will also be highly promoted at conferences, such as those held by the Ecological Society of Australia and the Australian Ornithological Congress.

An advantage of having a central location for storing information about natural system datasets is that it becomes easier to systematically analyze the data and to ensure that any results obtained are fed back into national and international programs and assessments, such as IPCC.

The greatest asset of this project is its ability to greatly enhance our knowledge base with regard to climate change impacts on Australian biodiversity. Results from the analysis of data contained within the database will assist natural resource managers in improving their management practices, by becoming better informed, resulting in improved environmental outcomes. Knowing how species have responded to changes in climate, and how they are likely to respond in the future, can influence decisions on preferred areas for natural resource management (NRM) interventions within a region and has the potential to improve efficiency and effectiveness of NRM interventions. The information contained in the database will also assist the Australian government in making informed decisions on climate change, climate variability, and NRM policy development and policy delivery and could be used to assess responses to past policy changes. The information may also be used by natural resource managers to develop action plans for responding to climate change. A lack of knowledge as to how natural systems in Australia respond to climate change and variability currently restricts the capacity of government and natural resource managers to make decisions and to implement change.

Should you be interested in learning more about this project or would like to know how you might assist in the analysis of the data, please contact the author.

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