Wildlife and climate change: are robust strategies for Australian fauna possible?

Daniel Lunney[1] and Pat Hutchings[2]

[1]Office of Environment and Heritage, NSW, PO Box 1967, Hurstville NSW 2220, Australia

[2]Australian Museum, 6 College St, Sydney NSW 2220, Australia

ABSTRACT

The link between climate change and wildlife is far from clear in the public mind. This paper tackles that issue through an overview of this book and a review of writings by scientists and others since 1970, including discussing strategies for conserving biodiversity in a changing Australian climate. The beginning of the modern era of climate change thinking in Australian is vivid in the book *Greenhouse: planning for climate change* (Pearman 1988). Clive Hamilton (2001), in *Running from the storm*, stated that climate change is perhaps the most serious environmental threat facing humanity in the 21st century. In *Science as a contact sport*, Stephen Schneider (2009) recounted the buffeting that he took on both the political front and from the media. Schneider started his academic life as a physicist, but by the time he wrote his book he had understood the fundamental debate about the environment. Schneider says that when he was asked what is the difference between the early, carefully hedged warnings of 30 years ago and now, he replied that it is not that the basic science has changed but that nature is cooperating with the theory. In the second edition of *Climate change*, Pittock (2009) said that developments since 2005 in the science, the observations and the politics of climate change are substantial and the urgency of the climate change challenge is now far more apparent than in 2005. Will Steffen (2009), with seven other Australian ecologists, in *Australia's biodiversity and climate change*, stated that the additional effects of climate change will exacerbate current threats and cause unprecedented additional stresses on Australia's biodiversity in their own right. We asked at the outset: are robust strategies for Australian fauna possible? Our answer is that they are possible. Many ecologists, Jamieson (2008) noted in *Ethics and the environment*, consider that species extinction and biodiversity losses are the early stage of an environmental catastrophe but, he added, not everyone thinks that these things matter. We do, and that was the driving force behind writing this paper and editing this book following on from the Royal Zoological Society of NSW forum on wildlife and climate change.

Key words: adaptation; assisted migration; climate policy; drought; environmental ethics; extinction; extreme weather; Great Barrier Reef; greenhouse gases; human population increase; IPCC; mitigation; sea-level rise; threatened species; weather.

Introduction

The title of the 2010 forum of the Royal Zoological Society of NSW and the title of this book remain the same, namely *Wildlife and climate change: towards robust conservation strategies for Australian fauna*. We participated in the forum and listened to the papers, which are now presented in this book, along with the plenary debates. We are also alert to the broader debate in the community about climate change, particularly how it is represented in the media (Lunney 2012). It is an exasperating spectacle for a supposedly technologically advanced nation, so we are concerned that while a confusing debate ensues publicly, propelled by what Oreskes and Conway (2010) have dubbed "the merchants of doubt" and some mendacious journalism, the fauna will fade away, out of the spotlight. We would like to be taking firm steps towards robust conservation strategies for the Australian fauna, but we are concerned by the social and political milieu which does not appear to share the sense of urgency or focus that we see emerging from the collective concern of our fellow scientists. Consequently, this closing paper is in the form of a question as to whether it is possible to arrive at robust strategies for conserving Australian fauna. It is not that we are pessimistic – we have been in the game of endeavouring to understand and conserve Australia's fauna for too many decades now just to throw in the towel as yet another key threatening process looms over us – but we are extremely concerned. One of the issues of concern for conservation biologists is that the subject of climate change and wildlife is far from clear in the public mind, and therefore in the minds of those with the responsibility for legislating, planning and implementing long-term conservation strategies that not only encompass climate change, but also the suite of other threats which beset Australian ecosystems either on their own or in a synergistic fashion.

This paper adds one more voice to the many urging action on climate change, but our focus is narrower than the broader public debate. We are interested in conserving the fauna, which is more about adaptation of the fauna and our management strategies to climate change than it is about mitigating the causes. Mitigation has apparently proved to be so difficult and so time- and energy-consuming that adaptive management strategies for fauna tend to languish. Whereas mitigation will have to be a world effort, particularly controlling CO_2

Pp 180 - 201 in *Wildlife and Climate Change: towards robust conservation strategies for Australian fauna*, edited by Daniel Lunney and Pat Hutchings, 2012. Royal Zoological Society of NSW, Mosman, NSW, Australia.

levels, adaptation strategies will have to be Australian efforts based upon our knowledge of Australian fauna and Australian ecosystems. Consequently, we consider that much can be done locally to conserve Australia's fauna in the face of climate change. That is the climate change response called adaptation. Consequently, we have framed this book, and this closing paper, to review the broader context of society's reaction to climate change as well as keeping our eye focussed on Australia and its animals. Our first step is to give a compressed version of the papers in this forum, to see the diversity of issues as well as the common themes. By picking up on just one straightforward point from each of the papers, we are glossing over the richness of the investigations by our zoological colleagues, and we urge readers to look at the depth of what they are saying, not try to rely on our one-liners for your view of their research. Our second step is to examine the trend over the last four decades of how the world of ecologists, fellow scientists and science writers has seen the problem and written about it in a way that encourages others to take action. We close with a comment on the trend in action by scientists, and those involved in the policy world, of response to climate change and how we might move forward to make the best use of the science and the resources we have available. First, we see if we can put this book in a nutshell.

The book in nutshell

Matthew England set the scene in his foreword to this book, and showed that climate change has arrived and we must deal with it. His presentation on the day was breathtaking and no one could listen to what was said, nor read what he has now written, and be left in any doubt about the magnitude of the problem and the pressing timetable confronting zoologists and conservation biologists. With that established, the focus then narrowed onto the biological world. Here the issues were diverse and complex, and required a profound understanding of the animals themselves and the ecosystems in which they live. The contributors to this book were all keen to explain their science, their animals and their concerns in ways that are comprehensible to a much wider audience than their immediate colleagues who are equally immersed in their specialities.

Lesley Hughes noted the compounding impacts of climate change with invasive species and loss of habitat, such as for urbanisation. She identified three mechanisms by which species will adapt: 1) shifting location of populations. There is some support for this occurring, but it is not feasible for all species. Habitat fragmentation will probably prevent this happening for most species. 2) Phenotypic plasticity. There is some support that this will occur, but for marine species it depends whether food (such as phytoplankton) will be available for pelagic larvae if breeding occurs earlier. 3) Genetic adaptation sounds good, but there is limited support for this being a solution. From that overview, the focus shifts to one of the world's icon locations, the Great Barrier Reef.

Morgan Pratchett and colleagues identified the loss of fish associated with bleaching of corals. The fish that are most susceptible are those that depend on live coral for food or shelter, and a change in the climate affecting corals will lead to local extinctions. Pat Hutchings examined the loss of suites of invertebrates with bleaching of corals, which often leads to coral death. The bleaching is especially critical for those invertebrates which inhabit only live coral. Climate change that adversely affects the corals will lead to local extinctions of a large suite of invertebrates. Alex Campbell and co-workers have been studying the increase in diseases which impact on native fauna and flora in marine environments, with particular interest in micro-organisms and the bleaching of seaweeds. Increasing temperature leads to changes in secondary metabolites, which are known to inhibit bacteria. This impact could cascade through the food chain – also leading to the corals' loss of zooxanthellae, commonly known as coral bleaching. Pauline Ross and co-workers studied the impacts of ocean acidification on larvae, which are very susceptible to such changes with devastating consequences.

Moving inland, but still linked to water, Fiona Loudon and Ricky Spencer examined how climate change will affect Murray River turtles along with feral animals. The turtles have a slow rate of reproduction, late onset of maturity, and temperature affects sex ratios in the nest. With rainfall changes, changes to water levels, and predation from introduced species, the turtles face an increasingly difficult future. Frank Lemckert and Trent Penman have a close interest in the biology of amphibians, and their need for moisture, and the increased impact of diseases. The frog species of most concern are those with narrow ranges from the fossil record to the modern day. Among the Australian frogs, there are some predictable extinctions – smaller populations with less genetic diversity may be less capable of adapting to climate change. Some species are more susceptible to changes in rainfall pattern, and rainfall patterns are critical for reproduction. The frogs may lose winter breeding cues. However, many Australian frogs already have to put up with varying water regimes, and this may have pre-adapted them to climate change. The most threatened species are those without a water stage and restricted geographical ranges. The arid and semi-arid lands of Australia are also susceptible to climate change. Tony Popic and Glenda Wardle give an example of the need to consider communities, not individual species, and biologists must include both plants and animals. They illustrate this with a wonderfully complex web of interactions in the arid zone.

Similarly, Australia's high country is exposed to a changing climate in an almost classic formulation. Alison Matthews and co-workers, from a detailed study of Common Wombats *Vombatus ursinus* in the high country of Kosciuszko National Park, noted the likely changes in wombat distribution in the alpine areas. The changes in climate may lead them to increase their area of occupancy at a higher altitude where hitherto they had not been present. Linda Broome and colleagues are studying the Mountain Pygmy Possum *Burramys parvus*, which is confined to the alpine region and therefore has nowhere

to go as the climate warms. They advocate a breeding program, but ask where do we put the bred animals? They have some novel solutions including lowland rainforest, which is where the palaeontological record shows that they first appeared in the fossil record. Consistent with that theme, Rebecca Spindler and co-workers clarified the role of zoos in spreading information on climate change, and how targetted species can be maintained in zoos to provide an insurance policy.

That the changes are underway is now becoming well established. Lynda Chambers took a national perspective on biodiversity from within the bureau of meteorology and identified changes, such as the ranges of some bird populations, and breeding times, and noted that some species, such as the Little Penguin *Eudyptula minor*, are linked to sea surface temperatures, with cooler oceans leading to later egg-laying in Victoria and warmer oceans leading to earlier laying in Western Australia. The fossil record is another of the specialist ways that a zoologist can see how climate affects fauna. Sue Hand has followed the fossil record of bat extinctions and noted that, in the past, this has varied among the groups and is a normal function of evolution, but that the current climate change threatens this natural pattern and increases the speed of these changes.

A decline in the nutrient content of leaves on which Koalas *Phascolarctos cinereus* feed as carbon dioxide levels rise, and the sharp increases in mortality from an increase in heatwaves, was the focus of a study by Dan Lunney and colleagues. Collectively, these changes will have major impacts on Koala populations, particularly during droughts. Clive McAlpine and colleagues pointed to the loss of Koalas through increased droughts, and conflict between conservation and agricultural needs. With the fragmentation of conservation areas, the losses will only become greater and they predict a bleak future. They also see the stress placed on the importance of politics, and noted that the science is largely ignored. One aim of this book is to help ensure that the science is not ignored, its complexity not swept aside. Zoologists and fellow scientists have much to contribute to adapting Australia to the world phenomenon of a changing climate that is hotter and drier in the south-eastern part of the continent, and more likely to experience extreme weather events.

We are not alone in Australia in trying to deal with this matter. Susan Rhind is an Australian zoologist who spent a year in Vietnam studying climate change. For an Australian audience, she pointed to the issues that are surprisingly common. She noted that sea level rises will inundate coastal national parks in areas of high biodiversity and thus it is necessary to review the long term comprehensiveness of protected areas. She also noted that climate change will compound other anthropogenic impacts from the human population, including illegal hunting, wildlife trade and logging.

Paul Adam sees the need to reduce human populations, identified the problems from increased affluence, plus other impacts such as pollution and land clearing. He noted that reduction of greenhouse gases will require fundamental changes to economic and social systems. Besides the issues of food security and renewable energy, there are the problems of loss of coastal wetlands following sea level rises. He raises the problem of threatened species and the need to protect the rest of biodiversity, and the continuing issues of finding and managing corridors of habitat and fragmentation of what remains.

The authors in this book who have been looking at particular species, and the ecosystems of which they are a part, have arrived at a diversity of solutions, or are working towards them more precisely. The responses are simultaneously growing both more detailed and more comprehensive as the issue becomes more universal and more pervasive. We need the detail, we need the overviews, and we need the specialists and the synthesisers to work in tandem. It can be more tempting for a manager or politician to support the synthesisers, but unless we know about the detail of ocean acidification at the same time as the potentially disrupted plant and animal communities of the arid zone, we shall continue to generalise about the impact of climate change.

Shelley Burgin and Pauline Ross commented on how student projects might assess impacts of climate change on species. They doubted that short term projects are of much value because of the problems of disentangling climate change from other impacts like urbanisation, and clearing of vegetation. Lukas Clews examined the whole matter from an administrative perspective. He identified the need to change current environmental legislation for conserving biodiversity. The changes need to include responses to climate change. Environmental impact statements need to consider climate change. He noted that there are some changes in NSW and other states, and at the Federal level, but he commented on the lack of any legislative clout that would modify the actions of developers.

Gary Luck noted that a range of actions is available to conservation managers wishing to improve fauna conservation as the climate changes. Preferred actions must be directly related to measurable and tangible objectives (expressed at the local or regional level at least, but preferably relevant to broader national and global objectives), and embedded in a systematic conservation planning framework that considers, among other things, the broader consequences of actions (e.g. stakeholder impacts), cost-benefit tradeoffs, and options for monitoring. This is particularly important for controversial actions such as assisted colonisation. Gary Luck's cautionary note should prevent the hasty adopting of solutions that do not meet the standard criteria of good management of an issue. We might add that, with such a short timetable, we have little room for error. Not only do we need to draw on the best zoological information available, but we also need to see the broader context for good governance, and most importantly, how others see this issue. Gary Luck's paper grew from a discussion that he had with Harry Recher on the way home from the forum. Harry suggested that he send it to us, and we were delighted to receive it. It is our guess that some of the things that Harry Recher

said during the last plenary set Gary Luck thinking about how to tackle this matter, with a semblance of discipline, particularly for such novel, indeed controversial, topics as assisted migration, that is, transporting animals to new locations if they are likely to become extinct in their current range due to climate change. The plenary sessions were engaging, and drew out interesting ideas as to how to cope with the rising menace of a changing climate. What follows is a condensed version of part of the last plenary to show the vitality of the thinking that the topic brings forth. The example shows the range of zoological thinking on the ideas that are thrown up by assisted migration and the consequences of animals shifting their range, whether by people, by their own capacity to move, or a combination of both.

Harry Recher: "Mike Soule from the United States was visiting me last week, and he brought me up to speed on some of the current novel ecological conservation thinking going on in North America, and it is called rewilding. Instead of just thinking about returning the North American fauna to what it was before Europeans colonised the North American continent, they are actually thinking about restoring the North American fauna to what it was like before *Homo sapiens* colonised the North American continent, and bringing back to North America things like camels, elephants, allowing horses to run wild instead of treating them as feral animals. It is not much further from what Linda Broome and colleagues were talking about – taking Mountain Pygmy Possums from the snow country of Kosciuszko National Park and putting them into lowland rainforest in Victoria. That's rewilding, and those of you that are really opposed to exotic organisms and moving exotic organisms around the continent, and around the planet, really might want to think about that as being a very radical and unacceptable idea. I think it's great. Why not play with the planet? We've mucked it up completely, so why not really try planetary engineering, biological planetary engineering? It might win in the end."

Duncan Bourne: "I wondered if anyone could give an update on another introduced species, the Dingo, what has happened with the progress on it becoming more widely spread?"

Mike Archer: "The Dingo is a very interesting question. If you'd raised a question like that 4,000 years ago, I think every one of us would have said, 'Give us a gun,' and we'd all be out there trying to blow away every last Dingo. But the reality is the Dingo probably – and I hate saying this, being a lover of the pouch – outcompeted our Thylacine on the mainland, which leaves the Dingo as the premier mammalian carnivore on the Australian mainland. To remove it would invite the same kind of disasters that have occurred by removing wolves from Yellowstone, USA."

Chris Dickman: "Over the last five years or so there has been accumulating evidence that in areas where there is a lot of Dingo activity you get very strongly suppressed fox activity, and in areas, perhaps where there are few or no trees, suppressed cat activity as well. If you look at the biodiversity benefits in terms of threatened species of vertebrates that would otherwise fall prey to foxes and cats, then by allowing Dingoes liberation across the continent, you can expect biodiversity benefits to accrue to around 2.4 million square kilometres of direct biodiversity benefit from having Dingoes in the system."

Hal Cogger: "I think this is a really interesting discussion, but it takes me back to a rather proactive discussion with Tim Flannery, who wanted desperately to introduce Komodo Dragons to northern Australia on the basis that any country that didn't have a large carnivore in the middle of the desert ought to be corrected. So I think the point I'm making is that we think as mammalogists in terms of mammals, we think as serpentologists in terms of reptile fauna, and we need to think of the totality of the system rather than just the impact of one species or two species into a system if you introduce it."

Sue Hand: "The interesting twist on that is that the Komodo Dragon has actually been found in fossil deposits now in Australia. In the Mount Etna deposits, there is clear evidence that the Komodo Dragon probably evolved here, and what is in the Komodo islands is actually an offspring of Komodos that were here, and these are actually Komodos, not just large varanids, so there's a twist there. So maybe they could come back."

Harry Recher: "That's a logical extension of what people have been talking about, and parallels the North American philosophy. But I'll come back to something I think I said earlier on. We're still avoiding the real issue, and the real issue is ourselves. We need to do something about our society. That's the dangerous idea, and I think the scientific community really needs to be much more vocal and active in promoting sustainable use of the planet and sharing the planet with other species. We want everything for ourselves, and until we change that philosophy, we can fiddle all we want, and in the end we're going to lose everything."

The range and diversity of topics tackled, and the depth of scholarship in these papers, and the plenary debates, demonstrate that Australian zoologists have a grasp of what is at issue, and how to tackle the issues with the animals and the ecosystems in which they live. What also emerges is that Australian scientists can articulate the problems and potential solutions and make their study area and their animals fascinating on the way. The individual papers would not capture the public attention, or expect to be highlighted in the media. Collectively, however, their effort raises the issue to a higher level and demonstrates that support for each of the individual efforts will fill in parts of the jigsaw that give others a chance to see the overall pattern. It also provides material for the media, university lectures, high school courses and the next round of research programs. Catering to such a wide range of interests is no easy task, yet the attractiveness of the animals, in the places where they live, is so engaging that people will listen more than they might have done if they were subjected to an apocalyptic threat. We turn now to how the subject is currently portrayed in some of the more general learned works, and the popular press.

Climate change emerges as an issue, but first we check the weather

There is a way of looking at the Australian environment that many Australian ecologists share, and that is a legacy of the teaching of Andrewartha and Birch and their landmark 1954 book, *The Distribution and Abundance of Animals*. Andrewartha taught at Adelaide University and Birch taught at the University of Sydney. The long association with one of us (DL) was with Charles Birch. He was convinced of the importance of weather as being the driving force for change in the distribution and abundance of animal populations. He was an entomologist, and abundance referred to the hordes of insects that afflicted crops in his early years as a researcher in Adelaide. Yet the phrase "distribution and abundance" has become part of the lexicon for Australian ecologists, and others, such as ecologist and international author Charles Krebs (2009), who added "experimental" to the concept, and kept the word "abundance". However, the term abundance is an odd word to use when we are dealing with small, declining or extinct populations. To talk about the abundance of a critically endangered species is a misuse of the language. It really should be the distribution and numbers of animals. Notwithstanding that bit of insect pest jargon hijacking the ecological lexicon, there remains the critical thesis of the weather.

Whether or not one considers that the weather is the primary underpinning of the changes in numbers and distribution of animals, or whether there are other key influences, the thesis pushed by Birch for decades has stuck. It follows that if the weather patterns change, that is, the climate changes, with climate being the average of the weather, then the ecological impact will be immense. Birch had prepared his students with devotion to this central concept. One example will suffice. In the 1970s, DL was one of a group of ecology post-grads at the University of Sydney that had morning tea regularly with Birch. He delighted in asking seemingly obscure questions, such as: What is the most important Cold Spring Harbour Symposium? By good luck, I had the right answer, 1957. That was the year that Birch had presented his paper on the weather. (In 2011, when DL recounted this story to Roger Kitching, co-author with Steffen *et al*. 2009 on climate change, he laughed, because it was the only Cold Spring Harbour Symposium that covered ecology.) DL never did speak to Charles Birch in the years just before he died in 2009, but the question to him would have been, "Do you think that your views were prescient of the current furore over climate change?" It was mentioned in his book about the environment, *Confronting the future*, in 1975, but he did not foreshadow its current prime position in the environmental debate. The point would be, though, that he had grasped the ecological importance of climate, and its pervasive influence on the distribution and numbers of animals.

In the foreword to Birch's (1975) book *Confronting the future*, the Australian Club of Rome Council wrote, "Charles Birch has written this book to explain in simple, non-technical language the consequences of man's blind, unplanned progress in an age of explosive growth and technological development." Under the heading "The atmosphere", Birch wrote that politicians are primarily concerned about the acute local effects of air pollution on human health, but says Birch, there are global effects to be concerned about as well, and these may be greater threats in the long run. Birch then became cautious, and stated that although there are reasons for supposing that human activity may contribute to changes in the climate of the Earth, it is not possible yet to attribute changing climate directly to human activity. He nonetheless added that, in the meantime, it is imprudent to proceed as if we can continue with impunity to add enormous quantities of gases, particulate matter and heat to the atmosphere. Birch finished his book with a story – he had many stories and was a wonderful presenter in public lectures. His story was that when John F. Kennedy spoke to the US National Academy of Sciences in 1963, he urged scientists to carry out their experiments immediately, even though some may not bear fruit right away. He then reminded his audience of what the great French Marshall Lyautey once said to his gardener, "Plant a tree tomorrow". The gardener said, "It won't bear fruit for 100 years." "In that case," said Lyautey, "plant it today".

By 1993, in the second edition of *Confronting the future,* the issue was much clearer in Birch's mind. Birch (1993) noted that the increase in carbon dioxide that was then occurring was expected to have dramatic consequences to life on Earth as a result of the so-called greenhouse effect, which will make the earth hotter. Such changes, says Birch, would have profound effects on the climate of the Earth, and we must also anticipate that biodiversity may be further decreased as species are unable to adapt rapidly to changing environments. What is important to note here is that Birch, a zoologist, was anticipating a decrease in biodiversity, without being explicit as to where and what changes to expect. That was not the context of his book, which was to a much more general audience. He would have expected that any one of his zoology/ecology students would to be able to elaborate on the point at some length. In one sense, that task has fallen to us, and this book is part of the next generation of thinking on this matter.

A 1970s generation of thinking on the subject of climate change

Paul and Anne Ehrlich (1970), in their ground-breaking book *Population resources environment*, understood the potential of the issue. They posed the question as to how human activities can affect the climate of the Earth and promptly answered it by saying one obvious way is by influencing the overall balance, for instance when fossil fuels are burned, carbon dioxide is added to the atmosphere and carbon dioxide contributes to the greenhouse effect. They say that it is worthwhile to consider some of the climatic changes that *might* occur. The 'might' in italics is in their text (p. 147). They note that all the speculated climatic changes might be viewed merely as a continuum of age-old processes of change, and therefore be held to involve risks that have always been present in one form or another. But, unhappily they say, there is a difference. At just the time that humans have populated the planet

to the point of stretching food resources to the maximum, humanity is almost certainly accelerating climatic changes. They concluded by saying that, should rapidly accelerating air pollution, a new volcanic incident, or melting of the north polar ice pack, destroy the northern hemisphere's granaries in the next decade or so, even worse famines than those that they predict would be inevitable. Ehrlich and Ehrlich had foreshadowed climate change, the role of rising CO_2 levels from human activity, and the dire consequences, although they used the word *might* in italics. That was the state of play in 1970 by two of the most perceptive and articulate environment writers of the age.

In *Climate, man and history*, science journalist Robert Claiborne (1970) produced an entertaining book where he opens with an observation about science. It makes the important point that science, despite its often recondite subject matter and forbidding terminology, is frequently not as far beyond the layman's comprehension as some scientists would like to think. He repeats an old maxim: one need not be able to lay an egg in order to tell a good one from a bad one. In writing his book, he aimed to distinguish good scientific eggs from dubious ones and to encourage fellow citizens to look critically, and with an awareness that scientists, like any other experts, do not invariably know what they are talking about. We agree, and add that action to conserve our native fauna, and the ecosystems on which they depend, will require more than scientific input. There was very little in his book about fauna. In the section under the heading "Climate present and future", he recounted that sometime after 1850 the chill began to slacken with the ice drawing back on both land and sea. He illustrated the consequences by commenting that seal and walrus populations of southern Greenland declined, as animals drew back towards their preferred colder waters, to the dismay of the indigenous people who depended on them for food. In compensation, great schools of cod now made their appearance in the same waters. Birds began migrating and breeding further north, and in Iceland alone seven new southerly species were reported, while some Arctic species dropped in numbers. This was not a zoology text, but it gives a hint that zoologists can monitor change, and if one were to extrapolate, they would need to adjust conservation programs to match the changes. Claiborne was unambiguous in that he stated that 20th century climate may be abnormal in the sense that it may be the result of human activities, specifically the consequence of various substances that humans have been tossing into the atmosphere by the billions of tonnes. The first of these he said was carbon dioxide, an atmospheric gas responsible for the greenhouse effect. He said that should the warming trend continue for a few centuries, as a carbon dioxide theory indicated it must, temperatures will become distinctly sticky. By sticky, Claiborne said that an estimate had been made that, by the time all known fossil fuel deposits are exhausted, the Earth will be more than 20°C warmer than at present, which would make New York tropical and London, Paris and Berlin at least subtropical. He added, assuming that there is still a New York and a London, because a rise of this magnitude might well be enough to melt the Greenland and Antarctic ice caps thereby adding enough water to the sea to raise its level by at least 150 feet (46 m). That, he said, would put his own 5th floor New York apartment under some 16 fathoms of water. This was prescient writing, but it did not capture the mainstream imagination, or contemporary ecological thinking.

In 1971, a group of international ecologists met to discuss global ecological problems. Their report was published in a book entitled *Man in the living environment*, and surprisingly the book is undated, but it is clear that it is from 1971. The date is important because it discusses the collective analysis of important problems of environmental quality and management by a group of ecologists. The aim of the group was to transmit the ecologists' view of such problems to the 1972 United Nations Conference on the Human Environment. They opened with a few points that remain germane today. They comment that ecology has become a catchword of the 1970s representing a movement to clean up our environment. In the process, they say, the meaning of the word ecology has become broadened and confused to a point where the study of ecology is often considered synonymous with environmental science. They point out there is a distinction, in that ecology is concerned not only with the environment but also with the organisms in an environment and their relationship to each other and their surroundings. They make the point that humans are one such organism and many of the techniques which ecologists have developed for the study of plant and animal populations are applicable to human population as well. They note that humans have to live with other organisms in this environment, or perish. Their book was planned as an analysis of that relationship. Their opening section is on population resources and they state that it is clear that we are in a period of population crisis and that the gains in personal well-being, which technology has brought to most of the world population in some degree, are in the process of being nullified by population growth. In short, they said the human population is on a collision course with nature. With that problem firmly identified, the workshop covered many features which remain familiar today: pollution, land management issues, pest management, the challenge to produce more food, and the use of resources, and they covered these in some detail. For example, in their discussion of the national forests in the western United States they said that recreational use of these forests has increased 50-fold in the last half-century, and in this period greater values had been placed on wildlife production, scenic beauty, watershed stability and water quality and quantity. When these values are coupled with demands for timber products, the result is a critical conflict of interests. However, the concept of climate change or greenhouse gases was not canvassed. One might reasonably conclude that this was not an issue for a group of the world's leading ecologists in 1971.

A book entitled *Inadvertent climate modification*, without a stated editor but copyright to the Massachusetts Institute of Technology (1971), reflects the thoughts of 30 scientists (principally climatologists) from 14 countries. They considered that their study provided an authoritative assessment of the present state of understanding of the possible impacts of human activities on the regional and global climates. Early in the introduction they stated that it

was clear that without additional research and monitoring programs, the scientific community would not be able to provide the firm answers which society may need if large-scale, and possibly irreversible, inadvertent modification of the climate is to be avoided. The group concluded *inter alia* that since accurate thermometers became available we have been able to make more precise records of the climate and we know that the mean temperature of the northern hemisphere increased by 0.6°C from 1880 to 1940, and since 1940 has decreased by more than 0.3°C. They comment that while it is conceivable that humans may have had a small part in these most recent climate changes, it is clear that natural causes must be sought. As a disclaimer, they state that is hard to identify any human effect because we do not know how to relate cause and effect in such a complex system, and that human effects will be obscured by the natural changes that we know must be occurring. Notwithstanding their high level of caution about rushing to any conclusions, they did state that they had a conviction that humanity can influence our climate, especially at the present accelerating pace of human development. They expressed the hope that the rate of progress in our understanding can match the growing problems and enable us to take action before some devastating forces are set in motion. They note optimistically that it is fortunate that the atmosphere and ocean seemed to possess enough inertia that will probably provide enough time to obtain a much better understanding before serious changes occur. They then wryly add that unfortunately the machinery through which effective international action could be taken is ponderous, and that we shall have to invent such machinery.

In the section on predicting the future, the meeting discussed inadvertent climate modification in some detail. The group stated that there is little doubt that humans have reshaped the environment and changed the climate of large regions of the earth. They tentatively added that human activity has probably had some influence on the global climate as well. They state unequivocally that there is no doubt that whenever people change the landscape, it modifies the microclimate. They note that the term "climatological sheath" has been used to describe the space around a single building. They point out that when structures merge into towns and cities, the term "climatological dome" is used. The group covered many other features, but one of the striking conclusions was that the Arctic sea ice and terrestrial ice caps are very sensitive to climatic changes. It makes them, they stated, vulnerable to the effects arising from human activities. They added that there is a serious possibility the global rise of a degree or so, such as from injections of CO_2 from human activity and heat into the atmosphere within the coming century, will lead to the melting of the Arctic ice. They added that the implications for regional and global climates and for low-lying coastal areas could be profound.

Now, 40 years later, we can see that the group was looking in the right direction, had a sense of what could happen, and their call for more research was well justified. We agree with Carroll L. Wilson and William H. Matthews, in their preface to the book, that since the objective was to raise the level of informed public and scientific discussion and action on global and regional problems, this report was published as quickly as possible. They list the number of places where they specifically sent draft manuscripts, including the secretariat of the 1972 UN Congress on the Human Environment. It is thus clear that the subject of inadvertent climate modification was on the public and scientific agenda by 1972. It was, however, replete with caveats and cautions about lack of data, but the apocalyptic scenarios it portrayed should have been more chilling for those who understand risk analysis. Even if the risk is low, but the outcome horrific, action is required to deal with the matter. That had to wait. We also note that there was no discussion of fauna. That was left to the imagination.

Linacre and Hobbs (1977) produced a timely textbook entitled, *The Australian climatic environment*. In the enlightening foreword to that book, F. Kenneth Hare wrote that this book is being published at the height of a new public awareness of climate as a factor in the world economy. In 1971, he recounted, we have witnessed dramatic anomalies of weather that have starved people and animals in Africa, upset prices of cereals on the world market, and reduced such well-watered countries as the United Kingdom to considering freshwater imports from overseas. It is not, in fact, obvious, said Hare, that these strange events have been in any way unique, or that this signals a lasting, hostile change in the Earth's climate. Hare noted that what they have done is to sharpen public interest and, said Hare, they have led to the inevitable question: will they continue? The next sentence may come as a surprise. Hare then says that at present such questions have to be ducked by the meteorologist, because they cannot predict variation of climate or adequately explain the past. Hare adds that it is easier to dismiss this failure as being due to poor thinking and inadequate research, but scientists who work on easier problems (then Hare adds parenthetically, "and most problems are easier"), are especially apt to take this line. He pointed out that the atmosphere is an extremely complex system that interacts with oceans, living organisms and the continental surfaces, that it is notoriously difficult to study such interactive systems, and climate is no exception. This is as much as a world expert could confidently say to students of climatology at the time. He gives a hint of climate change, but a far more definitive statement on the complexity of the matter, and a reason for a working scientist in this area to duck the question.

Linacre and Hobbs (1977) wrote that the difficulty of forecasting arises from the short-term instability of the atmosphere, but in the long term any one place has a relatively constant characteristic pattern of weather, which is its climate. They add that climate is an abstraction based on the frequency, mean and extreme values of all the meteorological elements, such as radiation intensity, wind, fog, and storms. They add that particular attention is paid in practice to temperature and rainfall, which affect soil moisture, supply of drinking water and many other aspects of life. Average values, they point out, are derived preferably from a record of at least 30 years of measurements to reduce the effects of extraordinary years.

Linacre and Hobbs (1977) stated that Australian climates are notable for extremes of high temperature and drought. They also commented that it is a common view that climates are not what they used to be, with minimum temperatures rising in Australian capital cities, and a slight general increase since the 1940s. They point out that there is still no consensus on the causes of the various changes of climate, partly because the evidence is still so sketchy. They point to four factors causing changes: the random element inherent in atmosphere; the regular rhythms due to the Earth's spin on its orbit around the sun; there may be threshold states due to positive feedback of energy within loops of interactions, and they refer the reader to a diagram of the complexity of the linkages between features of the atmosphere taken from Kellogg and Schneider (1974); and human activity from pollution of the atmosphere, creation of heat islands and the alteration of the surface albedo (reflection) by deforestation and agriculture. Which processes are dominant, the authors point out, is the subject of vigorous debate and a paucity of firm evidence. They do state that a more important influence on future climates is activity of human societies. A concern that was socially dominant in the 1970s emerges here. They fear that nuclear warfare would entail not only its own horrors, but also do great damage to the atmospheric ozone layer. They then added that the current trends of population growth, industrialisation, and agriculture will increase atmospheric pollution by chemicals, dust and heat. They then elaborate that carbon in carbon dioxide emitted by human society is now 400,000,000[1] tons annually and will increase the air's carbon dioxide composition by a third over the next 50 years. They postulate that, if the resulting greenhouse effect was sufficient to melt the polar ice, the sea level would rise and drown 17% of the Earth's land surface, and force the relocation of 19% of the world's population. This writing is as apocalyptic as any of the current writings, but it was well buried in a chapter called "The future". In a later chapter, entitled "Climate and life", they noted a few examples of the link between climate and fauna: the relationship to bushfires, evolutionary adaptation, rainfall-limited distribution of fauna, extreme temperatures and swarms of plague locusts. There was nothing alarming in that list, except to note that such factors are among the ones that are altering the distribution and numbers of animals in Australia. They close their account of the Australian climate by stating that many interesting and important problems remain to be solved. We can all now agree on that. A student of climatology in the 1970s would have been well placed to understand the debate, including the uncertainty, that has ensued on this topic. That student, however, would not really have been impelled to join the public debate on climate change, or even the focus on that as a likely subject for special attention.

In his book *The greenhouse effect*, Bernard (1980) was forceful in his introduction by saying that before the end of the next four decades, the climate of the Earth may be warmer than at any time in the past thousand years. He added that this ominous prophecy is a preliminary view of recognised scientists who have studied the effects of the world's continued reliance on fossil fuels (coal or oil and natural gas) as its primary energy source. He summarised the problem by saying that the carbon dioxide released from the burning of fossil fuels may accumulate in the atmosphere to the point where it begins acting like a greenhouse, allowing the sun's energy in but not allowing the Earth's heat out. He closed the introduction by quoting *Nature* of 3 May 1979 which stated that the release of carbon dioxide by the burning of fossil fuels is conceivably the most important environmental issue in the world today. Bernard's focus was the United States and he finished the book with some comments on options. He pointed out that the United States is tremendously wasteful of energy, with 6% of the population of the world consuming 30% of the world's energy. He made the simple point that energy conservation is the cheapest, cleanest, most readily available way to make the most efficient use of our energy resources.

Bernard (1980) asked, what can we do? He noted that scientists in the CO_2-climate field stress that their results are still preliminary. He noted that Dr Frank Press, President Carter's science adviser, said that everyone agrees that CO_2 is increasing and will have a warming effect, but how great the effect will be is not certain. Bernard examined some of the public discussion by scientists in authority. He said that some, such as Dr J. Murray Mitchell Jr, US Environmental Data Information Service, National Oceanic and Atmospheric Administration, advocated action, and took the view, in 1977, that this is the generation that may have to act to phase out our accustomed reliance on fossil fuels before we have all the knowledge to be sure that such action is necessary. He added we can scarcely afford to leave the carbon dioxide problem to the next generation. By contrast, Bernard noted, that other researchers, such as Dr Kirby J. Hanson, director of the National Oceanic and Atmospheric Administration's geophysical monitoring for climate change, hesitated to speak out on the matter. Bernard said that Hanson said, in a personal communication to Bernard, that he feels that scientists should only advise policymakers on the probability of certain environmental changes happening and not attempt to state or make policy. Bernard gave an example of what he sees as a limited field of view, given as testimony to a House Science Subcommittee in September 1979 by Ruth Clusen, Energy Department Assistant Secretary. She stated that the interpretation of her staff was that the potential increase in CO_2 from synthetic fuels, by itself, would not be large enough to cause climatic change. Bernard (1980) concluded his book with his own hope, but noting that he has no reason to think it will be fulfilled, that 50 years from now the greenhouse effect will be no more than a subject of an old book with yellowing pages, gathering dust on a shelf. His book has been sitting on the shelf of one of us (DL) for decades and the pages are yellowing, but he was right, his hope has not been fulfilled.

1. The imperial measure of 400,000,000 tons converted to the metric measure gives 406,418,765 tonnes.

The paradigm shift from the end of the 1980s

Planning for climate change

The modern era of climate change thinking in Australian is vivid in the book *Greenhouse: planning for climate change* (Pearman 1988). In his opening paper, Pearman (1988a) stated that not until the middle of the 20th century did scientists start to suggest that CO_2 released into the atmosphere during combustion of fossil fuels might induce global warming. He added that the last decade has seen an enormous growth in knowledge of the trace gas composition of the global atmosphere. He concluded that an effective doubling of the CO_2 levels is expected within the next 50 years, because of the combined effect of all greenhouse gases. This might be expected to bring about a global surface warming of 1.3-4.0°C. What is important about this book for zoologists, and all those who are interested in nature conservation, is that there was a section devoted to the natural environment. The material in it remains relevant to today's concern with climate change. Main (1988) covered such topics as barriers to wildlife movement because of human settlement, the need for large reserves across climatic transitions and the consequences of rainfall patterns affecting wetlands and wetland birds. He considered that the combined effects of climate change are likely to have serious implications for nature conservation management, especially with respect to retaining species in the face of fire hazards, predators, introduced species, competitors and disease. Arnold (1988) focussed on the possible effect of climate change on wildlife in Western Australia. His final thought was that the fate of endangered species is very uncertain, and it is paramount that individual studies be undertaken so that a strategy for their survival can be implemented as climate changes develops. Busby (1988) considered the potential impacts of climate change on Australia's flora and fauna. He drew on BIOCLIM, a bioclimatic analysis and prediction system, to simulate geographic implications of climate change. He found significant distribution changes, with severe reductions in at least some cases, making management of the native flora and fauna using the present conservation reserve system a more difficult task. He then added that the actual impact of climate change will be very difficult to assess, being dependent on the ability of the species and its predators, competitors and prey, to adapt to change. Graetz *et al.* (1988) attempted to forecast the most likely consequences of global climatic change and land use in arid Australia, the innermost 70% of the continent. Their most important conclusion was, in their view, that forecasts of future climatic conditions should include not only the mean values, but also the variance associated with those means. They state that without some forecast of changes to the frequency of extreme events, it will be difficult to appreciate the full spectrum of ecological responses to all hazards that land managers may face. The final paper in the book was by Bee *et al.* (1988) looking at the policy implications for the Commonwealth government. Under the heading "National policy perspective", they stated that speakers at this greenhouse conference pointed out that the predicted climate changes, if they come to pass, are likely to have a considerable impact on a wide variety of sectors and areas. We note the caveat: "if they come to pass". That does seem at odds with the opening part of the book (Pearman 1988a). They also note that not all impacts will be negative and some may be locally beneficial, for example in some agricultural sectors and for certain geographic regions such as the Great Barrier Reef. Such a statement is in sharp contrast to today's views of the matter. They concluded their chapter with a series of dot points, including the sanguine view that, providing policymakers and planners are alert to the potential changes, existing planning mechanisms are likely to be able to cope with the impacts in many areas. They do agree that climate change due to the greenhouse effect is one of the major issues facing policymakers, and that all levels of government will be affected. That comment is relevant to all state agencies which have the responsibility of conserving the State's fauna, and for the local government authorities to recognise that they too have a role in this global matter.

Pearman's (1988) academic text was followed by *The greenhouse effect* by Ann Henderson-Sellers and Russell Blong (1989) who, although scholars themselves, addressed their book primarily to the citizens of Australia. They gave two reasons for this choice: we live here, and that global-scale problems mean little to anyone. They had little to say about fauna, but what they did say was alarming: "For natural systems, changes may well exceed the ability of the ecosystem to adjust without alterations to species composition." (P 37). We note the use of the word "may" which, in a scientific text, expresses uncertainty, without ascribing any level of probability, but in a book for citizens, it dilutes the threat and robs it of its urgency. In fact, even in a scientific text, it is weak writing. The authors continue in the same paragraph to state: "There may be substantial changes in species abundance and some are likely to become extinct. This is most likely in alpine and wetland areas." Again, we note the use of the word "may", and the limit to the extent of the problem with the word "some". These words undermine the imperative to act urgently. Nevertheless, it was a dire warning to the citizens of Australia by authors who understood climate change. Such was the state of play at the end of the 1980s.

1990: The Intergovernmental Panel on Climate Change

In 1990, the Intergovernmental Panel on Climate Change, commonly known as the IPCC, released its first report (Houghton *et al.* 1990). Its first statement was engaging. It said that we are certain that there is a natural greenhouse effect which keeps the Earth warmer than it would otherwise be. They then add that emissions resulting from human activities are substantially increasing the atmospheric concentration of greenhouse gases and that these increases will enhance the greenhouse effect, resulting on average in additional warming of the Earth's surface. Among the many points they raise, in the policymakers' summary, is that changes in the variability of the weather and the frequency of extremes will generally have more impact than changes in the mean temperature at a particular location. To zoologists, this is an important matter because animals have to survive on a daily basis, not on an annual average.

They also point out that, because species respond differently to climate change, some will increase in numbers and/or range while others will decrease, that is, there will be some winners among the losers. Ecosystems will therefore change in structure and composition. They note that some species may be displaced to higher latitudes and altitudes, and some may be prone to local, and possibly even global, extinction, whereas other species may thrive. The tasks for zoologists, ecologists, physiologists, pathologists, and related scientists were identified in 1990. When to start and what to do was yet another matter.

1990: hothouse earth

The engaging science writer, John Gribben (1990), wrote an illuminating introduction with a touch of humour to his book *Hothouse earth*. Gribben's opening statement is that, in 1988, the greenhouse effect moved firmly into the arena of political debate. He noted that although scientists have been concerned for years that the world might be destined for warming caused by human activities, how quickly it might set in and how big this warming is likely to be was, in Gribben's view, not known. Against this background of uncertainty, he noted, even those politicians who were aware of the potential importance of this so-called greenhouse effect for future generations adopted a policy of "wait and see". That evidence, said Gribben, came in with a bang in 1988. One of the elements that shifted the greenhouse debate towards the centre was the state conference on "the changing atmosphere" held in Toronto in May 1988. The picture that delegates were presented with was one in which the average temperatures of the world rise 4°C in the next 40 years, and that the global warming will proceed unevenly with higher latitudes warming more quickly. Both drought in Africa and floods in the other parts of the world were linked by experts to the burgeoning greenhouse effect, already at work. The coverage of the meeting, said Gribben, included front-page stories in the *New York Times* and the *Guardian*, and even a comment in *The Times* as the Toronto meeting called on the wealthy industrialised countries to reduce their emissions of carbon dioxide (the gas chiefly responsible for the greenhouse effect) by 20% by the year 2005. Against this background, says Gribben, Congressional committees in Washington and the environment committee of the House of Commons in London both heard expert evidence on changing climate. Gribben recorded that James Hansen, of the NASA Goddard Institute of Space Studies in New York, told the Senate in June 1988 that the earth is warmer in 1988 than at any time in the history of instrumental measurements and that global warming is now sufficiently large that we can ascribe a high degree of confidence to a cause and effect relationship to the greenhouse effect. Gribben commented that this was a particularly significant statement, because Hansen had been studying the greenhouse problem for years but, until 1988, he also had a reputation of caution and was a proponent of the "wait and see" approach.

To Gribben's amusement, in September 1988, experienced observers of the political scene in Britain were taken aback by an unexpected shift in government comments on environmental issues. Prime Minister Margaret Thatcher made a speech to the Royal Society in which she drew attention to the importance of environmental issues such as acid rain, the damage being done to the ozone layer, and the greenhouse effect. Then, says Gribben, Foreign Minister Sir Geoffrey Howe called on the United Nations General Assembly to hold a serious debate about the threat of climate change. Gribben reported that he said that we are totally dependent on climate, and if we damage it beyond repair then the Earth becomes a lifeless desert, and we cannot leave a problem of this magnitude to technical bodies. Gribben's comment was that this could have come straight from a pamphlet published by Friends of the Earth. He then added that this caused astonishment in Britain because the Conservative government, under Margaret Thatcher and Sir Geoffrey Howe, as a senior member throughout the previous nine years, had an abysmal record on environmental issues.

Gribben said very little of immediate relevance to biologists. He did record that Gregg Marland of Oak Ridge National Laboratory in Tennessee had carried out a major study of what might be involved in any serious attempt to control the greenhouse effect by planting trees. He testified on the subject to the Senate Energy Committee in Washington in 1988. He calculated how many trees would be needed to convert the 5 billion tons of carbon dioxide getting into the atmosphere each year from the burning of fossil fuels. It would need 7,000,000 km^2 of young trees, an area about the size of Australia[2], Gribben commented. He then added that, as it happens, it is also about the area of tropical forest cleared as a result of human activities since the end of the latest ice age, most of it during the past few hundred years. He also noted that saving existing forests from destruction would be just as beneficial. This would also be beneficial for many other reasons, often aired in the debate about the damage we are doing to our planet, said Gribben. In one season in 1988, Gribben commented, an area of rainforest the size of Scotland was burned in Brazil to provide pasture land for cattle. The cattle, in many cases, provide meat for North American hamburgers. Gribben then linked the problem to the crisis of development facing poor regions of the world. Gribben closed his book with a usefully annotated bibliography, where he said that *The coevolution of climate and life* by Stephen Schneider and Randi Londer (1984) was a massive 563 page labour of love from climatologist Schneider and writer Londer, and that it was one of the most complete and accessible single volume guides to the whole business of climate change.

1996: The planetary gamble we cannot afford to lose

Stephen Schneider (1996) subtitled his climate change book *Laboratory earth* with the phrase, *the planetary gamble we cannot afford to lose.* It is a book in the series Science Masters, and the blurb on the back of the book quotes *New Scientist* as saying the series looks set to play a major role in responsible popularisation of science. Schneider has certainly done that. He devoted a chapter to biodiversity. He

2. Mainland Australia has an area of 7.69 million square kilometres.

noted that all responsible ecologists admit to a maddening degree of uncertainty surrounding both the numbers of species and the current extinction rates, and are endlessly frustrated by what they perceive to be the lack of public support to address these data deficiencies. They will no doubt have brought a smile to the face of any ecologist who has read Schneider's book. Schneider says that by far the most serious environmental problems of the 21st century will not simply be habitat loss or ozone depletion or chemical pollution or exotic species invasions or climate change by themselves. Rather, said Schneider, it will be the synergism of these factors. We agree, and that becomes a fundamental position for ecologists, conservation biologists and policy writers to adopt when endeavouring to manage climate change as a theme. Conversely, it also points to the need to take climate change into account even though the basic aim of any study is to focus on a different component of the environment. Schneider encapsulated an important point neatly by saying that it is difficult enough to explain the distribution and numbers of species today, given that the biota has had 10,000 years to settle into their current ranges without overwhelming amounts of human disturbance until recently. Now the experiments being performed on laboratory earth are demanding of the scientific establishment explanations of the detailed responses of species and communities subject to multiple disturbances at potentially unprecedented rates. Schneider continued in a more personal vein to ask what honest scientists can proclaim to have certain knowledge of such a questionable future. One wonders, said Schneider, what honest critic can say the scientists were admitting uncertainty and then use that uncertainty as an excuse to delay action that could lower the risks. Schneider added that this may be good business or political practice for some, but for him it constituted a country gambling with the biological riches of the Earth. Given such intense writing it is not surprising that Stephen Schneider concluded his preface by saying that his children had to live with a father who often would appear at breakfast bleary-eyed from late hours of writing and editing, only to be reminded by them that he had insisted only hours before that they get a good night's sleep to keep healthy and alert. Schneider is an example of his own hope, expressed in the last sentence of his preface, that at least some readers will be motivated to pursue their knowledge of the Earth much further, and that nearly all will resolve to get involved in being part of the solution to Earth's systemic problems.

Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Biodiversity Synthesis

Among the 11 key messages from the Millennium Ecosystem Assessment (2005) on biodiversity, one included climate change. It stated that the most important drivers of biodiversity loss and ecosystem service changes are habitat change (such as land use changes, physical modification of rivers or water withdrawal from rivers, loss of coral reefs, and damage to sea floors due to trawling), climate change, invasive alien species, overexploitation, and pollution. The report also noted that short-term goals and targets are not sufficient for the conservation and sustainable use of biodiversity and ecosystems. Given the characteristic response times for political, socioeconomic, and ecological systems, longer-term goals and targets (such as for 2050) are needed to guide policy and actions. The final key message was that science can help ensure that decisions are made with the best available information, but ultimately the future of biodiversity will be determined by society. We concur, and one of the aims of this book is to help ensure that a much broader spectrum of society than scientists specialising in climate change can see what scientists are saying about the prospects for conserving biodiversity in the face of climate change.

2009: inside the battle to save Earth's climate

In an engaging title, *Science as a contact sport*, Stephen Schneider (2009) subtitled his book, *inside the battle to save Earth's climate*. This book is riveting reading, and one of us (DL) put 'post-it' notes on all relevant pages for zoologists/ecologists and Australians interested in the battle. By the end of the book it was bristling with so many post-it notes that it looked like an echidna. We make a few points here to show the depth of thinking and the scale of the issues being tackled, and the buffeting that Schneider took on both the political front and from the media. Schneider started his academic life as a physicist, but by the time he wrote this book he had understood the fundamental debate about the environment. In his introduction he made a point that consumption and population are the main drivers of environmental stresses. He added that from our current (in 2009) 6.8 billion people (now 7 billion people at the end of 2011) we can expect by the end of the century have grown to 8 or 9 billion. If all these people expect to obtain consumption levels of a typical American today, and at the same time derive energy mostly from fossil fuels, then human-induced climate change is virtually inevitable. He also pointed out in his introduction that the climatic future is already upon us, at least in violent spurts. He cited the case that in 2003 an unprecedented heatwave in Europe killed more than 50,000 people; in August 2005 there was the disaster of hurricane Katrina in the USA. Schneider says that climate change experts have long projected that the strongest hurricanes will intensify as they move over warmer oceans. As predicted, said Schneider, wildfires in the western United States have dramatically increased; sea levels are rising; high mountain and polar glaciers are melting; and Arctic sea ice is rapidly thinning all year long. Schneider says that when he is asked what is the difference between the early, carefully hedged warnings of 30 years ago and now, he replies that it is not that the basic science has changed but that nature is cooperating with the theory.

Schneider (2009) recounted that in 1974 the Global Atmospheric Research Program sponsored an international meeting to discuss what was needed in a transition from weather forecasting to climate forecasting. A major contention at the meeting, said Schneider, was his fault, in that he had been exposed to people in agriculture and ecology. He put forward the point that scientists who are interested in impacts of climate change need to know which specific variables, such as drought

and flood frequencies and temperature extremes, would change because these have major impacts on ecology, water supplies and coastlines. Schneider reported that the modellers were aghast, nobody believed we could produce credible estimates of such extremes.

In his detailed book, in which he recounts the battles, Schneider recorded that the early awareness among scientists in the 1970s was replaced in the late 1980s by an outreach that spread from television shows to the first world conference on climate change. He records that the Reagan administration stoutly opposed any efforts to rein in pollutants because it was anathema to the free enterprise system. He also records that in 1982 he worked with paleo-climatologists, but he added that we do not use paleo-climate, that is, prehistoric situations, to give analogies for the future. That does not work well because land use changes, atmospheric CO_2, and aerosol forcings will be the main drivers of dramatic changes in the near future. These factors are all going to be different from anything that ever occurred in history. Historical information can be employed to study processes and help us build and test the models we use for the near future.

In his chapter, "The battle heats up and so does the world", Schneider recounted the excitement and the intense bargaining around the IPCC assessment report of 1996. He quoted (p 141) what he saw as the single most important paragraph in assessment history: "Our ability to quantify the human influence on global climate is currently limited because the expected signal is still emerging from the noise of natural variability, and because there are uncertainties in key factors. These include the magnitude and patterns of long-term natural variability and the time evolving pattern of forcing by, and response to, changes in concentrations of greenhouse gases and aerosols, and land surface changes. Nevertheless, the balance of evidence suggests that there is a discernible human influence on global climate" (IPCC 1996, second assessment, Climate Change 1995, chapter 8, section 4, 22). Schneider recorded that it was not until the release of the fourth assessment report in 2007 that the IPCC could state with confidence that human induced warming of the climate system is widespread.

Under the heading "The IPCC third assessment report", Schneider recorded that the main friction during the pre-plenary meeting in 2001 resulted from disagreements between the climatologists of a like mind to Schneider, and some economists over the potential seriousness of global warming. Most climatologists believed that no one could precisely quantify the extent of the damage that climate change could impose on nature and society simply by studying markets and other items that were easily quantifiable in monetary terms. In his work with the IPCC, Schneider said that he wanted to value lost biodiversity and heritage sites that would be destroyed if small island states like the Maldives and Tuvalu were flooded by rising sea levels. The economists said that small island states represent only a tiny fraction of the world's gross domestic product, and argued that their demise would have almost no impact on the global economy when considered on a "one dollar, one vote" basis. Schneider added that they were reluctant to assign value to anything not traded in markets, and tended to disagree with using a precautionary approach, such as cutting emissions now.

Of particular relevance to biologists is that, in the plenary meeting of the IPCC in 2001 at the UN headquarters, Terry Root's work was the most controversial issue. From an analysis of the behaviour of some thousand species of plants and animals from around the world, she reported that about 80% of the species exhibited some kind of changes over the past 10 to 40 years, a change in direction that would be expected with warming, for example, trees flowered earlier, birds migrated to their breeding grounds sooner or laid their eggs earlier, and butterflies moved up mountains or to cooler regions closer to the poles. This was, said Schneider, a spectacular conclusion because the Earth had only warmed up by about 0.6°C in the past century. It had been assumed that it would be impossible to detect a correlation between such a small amount of warming and behaviour of plants and animals. The findings were controversial and surprising, and had the potential for political influence because, Schneider reasoned, people care deeply about plants and animals and the loss of biodiversity is often more real to people than some of the other effects of global warming. Schneider then added that those at the IPCC meeting who opposed stringent climate policies wanted to minimise the importance of these findings.

In the lead up, during 2007, to the fourth IPCC report, Schneider included some comments relevant to biologists. He said that examples of unique and threatened systems include Arctic sea ice, mountain top glaciers, threatened and endangered species, and coral reef communities, which would largely disappear from excessive warming and acidification associated with such high atmospheric concentrations of CO_2. Tropical rainforests that were now relatively resistant to wildfire would become much more vulnerable. Extinction of over 40% of known plant and animal species would become much more likely at the level of warming associated with a doubling of CO_2 concentrations.

In his chapter on habitats for humanity and others, Schneider describes the ecology of a little furry relative of the rabbit called the American Pika *Ochotona princeps*. He said that surveys conducted 100 years ago showed pikas at around 7000 feet (2135 m) in altitude, but more recent surveys show the range is now closer to 9000 feet (2745 m), coinciding with a degree or so of local warming over the past century. Because they already live at or near the top of usable habitat of the mountains, the adaptive behaviour of moving further upwards to a cooler spot is often not possible. He compared the pika to the proverbial canary in the coal mine. Schneider recorded that the fourth assessment report in 2007 included serious language about the threat to biodiversity. It stated that, "there is high confidence that climate change will result in extinction of many species and reduction in the diversity of ecosystems" (Schneider 2009, p. 234). Of course, Schneider added, climate is not the only factor threatening species. Land use, exotic invasive species competing with native habitat space, and introduced chemicals have been demonstrated

as interacting pressures by many existing published studies. However, he added, these stresses are not always competitive but can be synergistic, reinforcing each other. He reinforced the point by saying that as the magnitude of climate change increases, further warming will almost certainly cause additional adverse impacts contributing to biodiversity losses. He gave the example that only about half a degree of additional warming can cause harm to coral reefs. Even worse, said Schneider, warming of 2°C above 1990 levels will result in mass mortality of coral reefs globally. Species in one sixth of the planet's ecosystems will be shuffled like a deck of cards, and about one quarter of known species are committed to extinction. Schneider added, that by "committed to extinction", the IPCC meant that a long-term continuation of disruptions to ecosystem structure and functioning could create situations where it will be too late for mitigation or adaptation to save many of those threatened species. Schneider added that we have to take action to prevent that rise in temperature that will exceed the adaptive capacities of many species and the attempts of conservationists to configure biological refuges and interconnections between them to facilitate climate-induced forced migration.

Schneider's (2009) view of the world was influenced by his wife, Terry Root, an ecologist interested in the consequences of rapid warming for birds and other species around the globe. As zoologists and ecologists we have appreciated the value of the link made by a climate scientist with a physics background seeing the world through ecological eyes. Among Root's studies, said Schneider, was that she used published studies of plant and animal movements from around the globe to see if they showed a consistent pattern worldwide in relation to global warming. The method she used, explained Schneider, was meta-analysis, which is a way of combining results in various studies, whether statistically significant or not. The results from meta-analyses determine whether there is a consistent signal or fingerprint among the studies. The balance of evidence from her meta-analyses done on species from many different animal or plant groups, examined on six continents, suggested that a significant impact from recent climatic warming is discernible in the form of long-term, large-scale alteration of animal and plant populations. Her subsequent work on this theme and information was gathered on species and global warming from 143 studies, each of which spanned at least 10 years. The study showed a common trait of at least one species that exhibited change over time, and found either a temporal change in temperature at the study site or a strong association between the species trait and site specific temperature. To document a strong role for climate change in explaining observed changes in animal and plant populations, Root's team looked for repeated examples occurring over long temporal and broad spatial scales. The study showed that recent temperature change had already had a marked influence on many species, ranging from molluscs to mammals and grasses to trees. Schneider concluded by saying our responsibilities as human stewards of these co-inhabitants are clear and compelling. We agree, and that is the underpinning of this book on climate change and the challenge of arriving at robust conservation strategies for Australian fauna.

A point from Schneider's (2009) inclusion of ecological ideas is that the basis of the meta-analyses relies on effective local studies, a sound knowledge of the natural history of the area and the species being studied, and publishing the work so that others can draw on it. In that role, we point out, the Royal Zoological Society of New South Wales makes a measurable contribution by publishing such local studies, and ensuring that sound science is available to a wide audience in perpetuity. We note too that 10 years was regarded as a minimum to such studies, and this invites additional comment. Firstly, we know that it is hard for any biologist to maintain a sustained effort for a decade or more in one location. Gaining support for such work requires considerable work on the part of the scientist. We can see why 20, 30, or 40 years would be even better. Such studies are rare indeed. There are many reasons for conducting long-term monitoring studies, and there are powerful reasons for the design of such studies to be framed as research questions so the fauna's range advances can be derived from such studies. A number of authors have also made these points, and it warrants a review on its own. We add that the sites where such studies are conducted are also important. Nadgee Nature Reserve on the NSW south coast is one example where long-term research has been conducted, but where a recent management shift in emphasis to wilderness puts up a barrier to potential future studies (Lunney *et al.* 2012). This means that institutional support for those carrying out such research needs to take a long-term view if we are ever to gain a clear grasp of the rate and direction of change from global warming. The researchers too need to publish their work, and contribute to the debate on global warming. We can also see from Schneider's writing that the politics of the matter, and the hostile press because of vested interests, makes working on such topics for a sustained period even harder. This requires resilience by the researchers and their supporters, and without it, caution will continue to surround the global warming predictions because of a lack of evidence. It also makes sense to us that such long-term studies incorporate other questions, and address the outcomes of what may be climate change in terms that are also understandable for people near the study site or in the local district. Also framing the answer as global warming to a rural community could sound a bit distant. It could be easier to point to common Australian phenomena, such as droughts, fires, floods, and heatwaves, as well as to show people what is happening, such as dead animals, dying trees, and bleached coral. We also know, as Schneider pointed out, but which has been a fundamental problem for Australian ecologists and conservation biologists, that there are other factors leading to changes in the numbers and distributions of species and what he called the reshuffling of ecosystems. Disentangling the effects is a major challenge, and this requires patience and a good grasp of the natural history of the animals and plants that you are working with, as well as a sense of experimental design. In our view, this task is as hard as has been the work of Schneider and his many colleagues in the world of climatology, and no less political or no less subject to

misinterpretation by the media, or to a challenge by vested interests if one argues for nature conservation rather than pursuing those short-term, economic goals that, more often than not, trump nature conservation values. Climate change, or global warming, simply adds another dimension to the already challenging task of conserving Australia's biological diversity. In that sense, we have been more forewarned than Schneider and many of his colleagues who were not confronted with difficult social choices until their careers were well advanced.

Some Australian participants in the debate

2000: The scientific committee under the *NSW Threatened Species Conservation Act 1995*: a key threatening process

In a bold move, in 2000, the Independent Scientific Committee under the New South Wales *Threatened Species Conservation Act 1995* made the following determination: Anthropogenic Climate Change – key threatening process listing[3]. After a period of public exhibition, the Scientific Committee produced a final determination, based on a series of findings, including: "There is evidence that modification of the environment by humans may result in future climate change. Such anthropogenic change to climate may occur at a faster rate than has previously occurred naturally. Climate change may involve both changes in average conditions and changes to the frequency of occurrence of extreme events." "4. Response of organisms to future climate change (however caused) is likely to differ from that in the past because it will occur in a highly modified landscape in which the distribution of natural communities is highly modified. This may limit the ability of organisms to survive climate change through dispersal (Brasher and Pittock 1998; Australian Greenhouse Office 1998). Species at risk include those with long generations, poor mobility, narrow ranges, specific host relationships, isolated and specialised species and those with large home ranges (Hughes and Westoby 1994). Pest species may also be advantaged by climate change." "5. Modelling of the distribution of species under realistic climate change scenarios suggests that many species would be adversely affected unless populations were able to move across the landscape (for example, Brereton, Bennett and Mansergh 1995). Examples of species which would be at risk in New South Wales include: Mammals: *Burramys parvus* Mountain Pygmy-possum, *Potorous longipes* Long-footed Potoroo, *Mastacomys fuscus* Broad-toothed rat, *Pseudomys fumeus* Smoky mouse; Birds, *Leipoa ocellata* Malleefowl, *Pedionomus torquatus* Plains-wanderer, *Tyto tenebricosa* Sooty Owl, *Calyptorhynchus banksii graptogyne* - Red-tailed Black-Cockatoo, *Polytelis anthopeplus* Regent Parrot, *Petroica rodinogaster* Pink Robin, *Pachycephala rufogularis* Red-lored Whistler; Reptiles, *Delma impar* Striped Legless lizard; Amphibians: *Litoria spenceri* Spotted Frog, *Litoria raniformis* Southern Bell Frog, *Pseudophryne pengilleyi* Northern Corroboree Frog and *Pseudophryne corroboree* Southern Corroboree Frog."The committee added, as their final point, that: "8. In view of the above, the Scientific Committee is of the opinion that Anthropogenic Climate Change adversely affects two or more threatened species or could cause species, populations or ecological communities that are not threatened to become threatened." Despite the overuse of weak words such as "may", this point confirms the clear link, in this case in legislative terms, between a key threatening process and identifiable species of fauna that are already on the list of threatened species. This also highlights another problem – that the threatening process has to be underway for a species to be listed, so that in turn the process that led to the listing can be included. However, in this case the species were already on the list, so by implication climate change will exacerbate their plight. We can also point out that listing species is important, and to achieve that, some serious science has to be undertaken to study the species in question. Key threatening processes are derived from detailed knowledge of species as well as an appreciation of other elements of science, such as is apparent in climate change. The points are indivisible in our view. We cannot study climate change in the absence of detailed ecological/zoological studies, nor can we press on with studying or monitoring any native animals without paying attention to such rising threats as climate change. The deliberations of the Scientific Committee demonstrate how, in a policy framework, the two are linked.

2001-2010: Clive Hamilton

Australia is fortunate to have a range of thoughtful and outspoken commentators in the climate change debate who are well informed, write well, and work from the science and not political ideology or short-term commercial interests. Clive Hamilton is a shining example of a public intellectual who has mastered both the numbers and the political process. In his book, *Running from the storm*, Hamilton (2001) opened with a statement that climate change is perhaps the most serious environmental threat facing humanity in the 21st century. Progress in preventing it, says Hamilton, has been excruciatingly slow. He pointed out that the issue is so difficult because the main culprit is the combustion of fossil fuels and energy from fossil fuels remains the very basis of industrial and post-industrial economies. As an economist, Hamilton can confidently state that it is no exaggeration to say that rich countries have become rich by burning fossil fuels. Under the heading, "The role of climate science", Hamilton makes the observation that anyone who participates in the greenhouse debate must take a position on the science of climate change, and for those who are not climate scientists, this is not what to believe but whom to believe. Besides summarising the main points of the IPCC reports, Hamilton outlined what he called the cautious predictions by scientists from the CSIRO. These included a substantial reduction in winter snow cover affecting the survival of plants and animals in alpine environments, more days of high

3. http://www.environment.nsw.gov.au/threatenedspecies/HumanClimateChangeKTPListing.htm, last accessed 31.12.11. One of us, PH, was a member of this committee at the time.

and extreme fire danger, permanent damage to the Great Barrier Reef within 30 years, increased intensity of tropical cyclones, and a high incidence of diseases, such as malaria, spreading south. Hamilton identified that ethical undercurrents swirl beneath almost every aspect of the international climate change negotiations. The principal questions, says Hamilton, are distributive, that is, who is responsible for the problem, who will suffer most from climate change, and who will bear the costs of abatement measures? In one sense, Hamilton has reiterated the fundamental ethical issues of so many conservation issues, the ones familiar to zoologists who are trying to conserve Australia's fauna and the ecosystems on which they depend. The climate change debate brings this issue into sharper focus, because it involves more people simultaneously on a global scale.

In *Requiem for a species*, Hamilton (2010) has produced a book that extended his earlier writings, and is rich in both science and the social dimension of the issue, including the politics and the psychology of the subject. When one of us (DL) picked up the book, it was so captivating that it was read from beginning to end at one go. Hamilton, now a professor of ethics at Charles Sturt University, writes forcefully and grimly about prospects for a world where a temperature rise of 4°C is possible. Fortunately, he has not lost his sense of humour or his ability to encapsulate the scientific and moral dimension in his writings. He also willingly speaks about the matter, and it is indeed engaging to listen to him on the subject, for example, at the launch of *Requiem for a species*. (http://www.youtube.com/watch?v=2mccKiZ9AfE.)

2005: Tim Flannery

Tim Flannery is an outspoken scientist encouraging Australians to pay attention to the issue of climate change, such as through his 2005 book, *The weather makers: how man is changing the climate and what it means for life on Earth*. He has a zoological background with a long-term fascination with New Guinea. It was no surprise that he opened his first chapter describing Mt Albert Edward, one of the highest peaks in New Guinea, with its wallaby tracks, scratchings and burrows of Yardlong Rats, and the traces where Long-beaked Echidnas had probed for worms (Flannery 2005). Many of the creatures he saw on Mt Albert Edward were unique to such alpine regions. That was in 1981 when he was in his mid-20s. Even then there was evidence that the forest was colonising the slope from below, and Flannery wondered whether it was a sign of climate change. He then said he forgot about the issue, partly because his generation had inherited seemingly bigger and more urgent issues, such as rainforests being felled for timber and agricultural land, large animal species being hunted to extinction, and, in Australia, rising salt threatening to destroy most fertile soils, and overgrazing, degradation of waterways, and logging forests all threatening their ecosystems and their biodiversity. There are many Australian zoologists who would share that sense from the 1980s, although each would have their own list of threats. Flannery recorded that by 2001, articles in scientific journals indicated the world alpine environments were threatened and he remembered Mt Albert Edward's forest.

2009: Barrie Pittock and the rate of change of the science

In the second edition of his book on climate change, Pittock (2009) said that it was a substantial update since his first edition in 2005. Developments since 2005, he said, in the science, the observations, and the politics of climate change were so substantial that they warranted major changes to the content and tone of the book. The urgency of the climate change challenge was now far more apparent than in 2005, said Pittock, with new observations showing that, on many fronts, climate change and its impacts were occurring faster than expected. In the foreword to the book, Rajendra K. Pachauri, chair of the Intergovernmental Panel on Climate Change, noted that Barrie Pittock has been a leading researcher on climate change. Pittock's book provides information and analysis that will assist decision-makers on what needs to be done. We agree with that view of the chair of the IPCC, but we do note that the book is not about biodiversity, except by way of reference regarding impacts. However, he does provide insights which are relevant in the context of Australia as well as the point we are pursuing about wildlife.

In general, said Pittock taking a world view, warming effects on biological systems include average range shifts polewards of about 5 to 10 km per decade, and events in spring occurring two or three days earlier per decade. Plants and animals will also move to higher elevations, but such movements are limited in many places by coastlines, limited height of mountains or alienation of land due to clearing or other human interference. This particularly affects many biological reserves set up to protect rare and endangered species. Among the reasons for the concern, said Pittock, are the risks to unique and threatened systems. He said that natural systems are vulnerable to climate change, especially where migration to higher elevations or higher latitudes is not possible or too slow, and increasing numbers will be irreversibly damaged as global warming increases. In a box insert to his text, he outlined the threats to coral reefs saying they are severely threatened by global warming and other stresses. He also made the point that extreme climatic events occur naturally in an unchanging but variable climate, virtually by definition. It is now widely accepted, said Pittock, that many extreme events, such as heat waves, heavy rain events, floods and droughts, will increase in frequency and magnitude in many regions with global warming, while others, notably cold days and frosts, will decrease.

Pittock (2009) discussed adaptation as a concept in a way that is easy to understand. He says adaptation is an automatic or planned response to change that minimises the adverse effects and maximises any benefits. It is one of two possible means of coping with human-induced climate change and sea level rise. The other option is to reduce the magnitude of human-induced climate change by reducing greenhouse gas emissions. This is called mitigation. Adaptation is essential to cope with climate change and sea level rise that we cannot avoid now and in the near future, while mitigation would limit the extent of future climate change. Adaptation, he said, is essentially

a local challenge, and mitigation is essentially a global process which will only be achieved by international cooperation and a common commitment. Adaptation, he stated, is necessary because climate change is already happening, and the long time lag in the climate system makes further climate change inevitable. Further climate change, he pointed out, is already built into the system by past greenhouse gas emissions.

Pittock pointed out that natural climate variability, year to year, decade to decade, demonstrates that the biosphere is sensitive to climate and thus sensitive to climate change. But the effects of other stresses, he said such as erosion, fire, sea level rises, salination, and air pollution are also evident. These, he said, can amplify the effects of climate change, or at least add to the stresses on humanity which relies on the biosphere for food, fibre and shelter. He makes an important point about the size of the human population. He records that the 2007 IPCC report indicated that globally the contribution to growth in greenhouse gas emissions from 1970 to 2000 was about equally due to the growth in population and the growth in income per capita. Actual and projected emissions from 2000 to 2030, on the other hand, are twice as much due to growth in income per capita than to population growth. This is a clear numerical link between population growth and the way the world uses its resources. While resources are the common focus, the issue of the growth of the human population demonstrably has a key role in the issue of increasing impact of climate change. This point about population growth is a recurrent theme among a wide range of those who examine the human condition and the state of the world's ecosystems. Ecologist Charles Krebs (2008), in the closing paragraphs of his book, *The ecological world view*, stated that human impacts on ecosystems are rooted in the continuing increase in world population. Krebs concluded his book by stating his views, and commenting on the issue of climate change. He said that because many geographical distributions are limited by climate, climatic warming in the next century will have dramatic effects on native animals and plants, including disease-causing organisms. Ecological restoration, he mused, may be the major global conservation problem of the next century. His final remark was that we do not yet know how to construct intact ecosystems that can support human life, so we should take care of the Earth and vigorously guard the services it now provides us all for free.

2009: the first major treatise on Australia's biodiversity and climate change

Will Steffen (2009), with seven other of Australia's leading ecologists, has produced a landmark book on *Australia's biodiversity and climate change*. The book is intellectually engrossing and a challenge to read because it compresses into one modest-sized book a great deal of description of Australia's biodiversity and the latest in ecological thinking, combined with how to understand the impact of climate change on Australia's plants and animals and the ecosystems that support them. One of us (DL) read it in a day, but it was a long day. The book will serve many purposes, one being an outstanding textbook, another being a professional's guide to managing the issues of climate change and biodiversity in the context of all the other issues that are already being faced, and it should provide the basic advice for the next policy steps to conserve Australia's biodiversity in the context of climate change. There is nothing that resembles it – it is the book that we should rely on to see the context of climate change across Australia. One can note hundreds of little points that are really worth citing if one were to compress the book into a modest number of pages. What follows in the next few paragraphs are some highlights, partly because of their relevance to what we are writing here, but mainly to draw attention to this critical addition of a link between ecological thinking and managing the biodiversity of Australia in the context of climate change. Early in the book is the heading: "Utilitarian values of individual species". The first example was the Koala, which alone, they state, is estimated to be worth over $1 billion annually to the Australian tourism industry. They cite the Australian State of the Environment Committee 2001, although Koala buffs will know that the source is Hundloe and Hamilton (1997). The point, however, is that if the Commonwealth government acknowledges the value of this one species as being that high, then it would be good to see some economic analysis as to what effort is being invested to maintain Koala populations to sustain that income. The point can be immediately expanded to argue for more substantial economic analyses, and ones with much longer time frames that have been customarily used in economic analysis (Lunney *et al.* 1997). Such analyses also work on a smaller scale, for example Hamilton *et al.* (2000) identified that the economic cost of a plan of management to conserve Koalas in Coffs Harbour on the north coast of New South Wales was far outweighed by the economic benefits, particularly those arising from tourism. That study was a crucial step in Coffs Harbour City Council adopting the first-ever Comprehensive Koala Plan of Management for a local government area in New South Wales (Lunney *et al.* 1999, 2000, 2002). Consequently, it is no surprise that an economist, Ross Garnaut (2008, 2011), was called on by the federal government to produce a review of Australia in the global response to climate change. The purpose, as Garnaut (2011) explained in the second edition of his book, was to examine how developments in science, diplomacy, political culture and the economy have affected the national interest case for Australian climate change action.

Steffen *et al.* (2009) emphasised that returning to fundamental ecological principles is necessary because Australia's environment, and the Earth's environment as a whole, is now operating under conditions not experienced previously. The nature of changes occurring simultaneously across the continent, their magnitudes and the rate of change, is unprecedented. The consequence, they say, is that the past is no longer a reliable guide to the future. Understanding and applying ecological principles is essential to maintain or enhance Australia's biodiversity after a century of rapid environmental change. They concluded that there are no shortcuts to sound and effective management. We agree, and that too was an underlying principle in the Royal Zoological Society forum on *Wildlife and climate change*, and this book which follows the forum, in meeting the challenge to develop robust strategies for Australia's fauna.

Steffen *et al.* (2009) also make the point that historical and existing drivers of change to biodiversity remained substantially more important, even today, than climate change. However, the impact of climate change will grow in importance as the century progresses. Climate change should not be viewed as a new, independent driver, but rather as the latest in a number of significant, human-related drivers of change. They warned to "expect the unexpected" and "prepare for surprises", then added that non-linear responses to drivers of any kind of environmental change are common, and that this is well grounded in ecological science. Schneider (2009) had a neat phrase here to explain non-linear responses: he said that a non-linear response was like the slope of a skateboard rink where the wall got steeper as the skater got higher and the parents watching became more fearful.

Steffen *et al.* (2009) summarise some relevant ecological research. They point out that modelling suggests that several factors are significantly related to the loss of mammal species. These factors are rainfall (with more loss in arid areas), environmental change (with more loss in areas where habitat has been lost or degraded), mammal bodyweight (with medium-sized mammals from 35 to 5500 g being the most affected), whether a species shelters on the ground or in trees and burrows or rock piles (with on-ground species being the most affected), the density of introduced herbivores, such as sheep and cattle (the areas with higher densities having lost more mammal species), and the length of time since foxes and cats first arrived in a region (with longer time since arrival leading to more species loss). They also note the ranges of many Australian animals and plants have expanded through deliberate or accidental introduction outside the natural range, with examples including Koalas on Kangaroo Island in South Australia and yabbies in Western Australia. The above examples are terrestrial, and we made a positive effort to include marine examples in the forum and this book.

In a chapter on the rate and magnitude of climate change, Steffen *et al.* (2009) stated that the frequency of extreme hot and cold temperatures has also changed. There has been an increase in hot days over 35°C since the late 1950s, as well as increases in hot nights over 20°C. There are fewer days below 15°C and a decrease in cold nights (< 5°C). They point out that droughts have become more severe with higher temperatures and increased evaporation. They note that the effects of reduced rainfall and drought on fire frequency, duration and seasonality have not yet been detected, although hotter and drier years are generally associated with increased fire risk. In a chapter on the response of Australia's biodiversity and climate change, they noted that, in the past, species persisted in localised refugia rather than moving long distances. This emphasises the importance of maintaining a mosaic of habitats, thereby increasing opportunities for species to persist through changing conditions. Under the heading "averages vs extremes", they state that extreme climate and weather events are infrequent events at the high and low range of values of a climatic or weather variable. They then added that a small change in the average of a climate variable can accompany a large change in the frequency of extreme events. Projections of the future point to increases in the frequency and intensity of many extreme events, such as drought, storm surges and fire. Later they make the point that modelling needs to be better integrated with observations and experiments. We agree, and that is the point of this book and the Royal Zoological Society NSW forum that led to it, namely to assist in moving towards that goal. They also covered what they call "knowledge gaps", but while the phrase could imply that we know the structure, we just lack detail, that is not what they are driving at. Their examples ask such broad questions that it is more than a gap in our knowledge, it is an unfolding array of questions of increasing complexity that will need substantial research, and not a set of minor questions which can be addressed later to fill in some missing details.

In their concluding chapter, Steffen *et al.* (2009) state that although many people are familiar with the historic record of change in Australia's biodiversity, the fact that changes continue to unfold is fundamental to assessing the impact of climate change. The additional effects of climate change will exacerbate current threats and cause unprecedented additional stresses on Australia's biodiversity in their own right. They point to the logical conclusion that without an effective integration of knowledge about present stresses on biodiversity into climate change adaptation strategies and approaches, such efforts are certain to fail. By the end of the book, too, they are crisper and firmer in their statements than at the beginning. They state that the Earth is warming rapidly with human-driven increases in atmospheric greenhouse gas concentrations being the prime cause, with climate change being likely to accelerate in the future. They add that Australia is currently experiencing climate change consistent with the global pattern: high temperatures, altered patterns of precipitation, sea-level rise, and changes in the magnitude and frequency of extreme events. Biodiversity, they state, is much less able to adapt to these changes than human systems. They also point to the need to build innovative and flexible governance systems. They note that while primary responsibility for biodiversity conservation resides with each state and territory, over the past two decades many biodiversity conservation policies and approaches have been developed nationally through Commonwealth-State processes. We note, as long-term New South Wales public servants, that much of the infrastructure for conserving biodiversity in the face of existing threats and the rising impact of climate change are State matters. These include museums, conservation reserves, such as National Parks and Nature Reserves, legislation, decisions on resource use such as logging, and land management decisions from land clearing and the management of invasive species to fire management and planning law. We are also mindful that some institutions that were well suited to handling many of these matters, such as the CSIRO Division of Wildlife Research, no longer exist (Krebs 2012). At its zenith, this division was the premier wildlife research institute in Australia and a leader in global wildlife conservation. Consequently, we agree with the thread running through their argument that a diversity of institutions involved in the governance of this

issue will be essential to ensure the survival of Australia's biodiversity. Unfortunately, just as the impacts of climate change intensify, governments throughout Australia are withdrawing from involvement in nature conservation and important institutions such as museums, parks and wildlife services, and the CSIRO are being constrained by budgets that diminish their ability to contribute to conservation initiatives.

In conclusion, Steffen *et al.* (2009) state the expected minimum global average temperature increases of 1.5 or 2°C above pre-industrial levels will likely lead to a massive loss of biodiversity worldwide. Thus, mitigation is central to biodiversity conservation under climate change. They are categorical in saying that to avoid ever-wider extinctions in the second half of the century, deep cuts in global greenhouse emissions are required by 2020 at the latest. They reiterate an important point from their book that societal responses to the mitigation challenge could have significant negative consequences on biodiversity, including planting of monocultures of fast-growing trees rather than establishing more complex ecosystems that support biodiversity and store more carbon, and inappropriate development of Australia's north in response to deteriorating climatic conditions in the south. Not surprisingly, the last sentence in the book says that with flexible, integrated approaches to mitigation and adaptation, many opportunities will arise for solutions that deliver positive mitigation/adaptation outcomes and enhance biodiversity values.

2011: The priorities in dealing with the interaction between existing threats and climate change

In a wide ranging review that is international in scope but immediately applicable to Australia, Driscoll *et al.* (2011) considered priorities in policy and management to deal with the acceleration of the biodiversity crisis from the interaction between existing threats and climate change. They note that, despite popular opinion, climate change alone is not the greatest near-term threat to biodiversity. It is, they argue, the interaction between climate change and existing threats to biodiversity, such as habitat loss and fragmentation, invasive species and resource exploitation that is set to be the main driver. The sweep of their approach to the subject is evident in such statements as that there is an opportunity to substantially ameliorate climate change impacts by conserving and re-establishing native vegetation, that large-scale restoration of native vegetation and the re-establishment of large-scale conductivity are recognised as essential responses to the biodiversity crisis and are the most frequently recommended actions to counter climate change impacts on biodiversity. They state that, given the increased impacts of invasive exotic species that are expected with climate change, adaptation to climate change is contingent on better management of invasive species than has been achieved to date. They add that with an expected delay between the time of arrival and the time of becoming invasive, research is needed to identify species that have already been introduced, but which have not yet become invasive. They also comment on the importance of monitoring changes in the distribution of species. It would, they point out, be most useful if monitoring is able to detect range declines in species that are not compensated for by range expansion at a different range margin, followed by subsequent research to determine why species fail to expand. With respect to resource extraction and climate change, they re-iterate the accepted views that, in addition to land clearing, water extraction, livestock grazing and forest logging are well-recognised threats to biodiversity. Although they use the word "likely" to state that forest logging is likely to interact with the effects of climate change to reduce biodiversity, their next statement – that climate change will cause large disturbance events to become more frequent, widespread and intense – identifies that the word "likely" was an understatement, typical of science writing but less than what is needed in common speech. This becomes even more apparent in their next statement that climate change will magnify the threat to biodiversity posed by exploitative forestry operations, particularly the widespread post-logging (salvage) timber extraction that increases the area of disturbed forest. They conclude their review by saying that they do not see climate change mitigation and biodiversity preservation as an either/or trade-off, nor uncertainty as a reason for delaying action. In short, they are asserting that we need to preserve biodiversity while reducing the causes of climate change and we cannot delay action on either front. This is an important point, especially as so much of the politics of climate change is directed towards mitigation of the causes and, by implication, either the issue of conserving and managing our wildlife can wait, or we just accept that resources should be directed to mitigation, not adaptation of our management actions to conserve our fauna. As many authors have said before them, there needs to be a global response to the worsening biodiversity crisis by addressing the fundamental drivers of global change, namely increasing human population, increasing rates of resource consumption and increasing greenhouse gas emissions. However, they add, there are critical responses that policymakers and land managers can take now to reduce some of the worst impacts of climate change on biodiversity. Their paper enlarges on Steffen *et al.* (2009) in identifying actions to combat existing threats, and thereby diminish the interactions between them and climate change. Such review papers are most welcome, and we shall need many more of them that also begin to focus on local areas and species.

2011: Climate change in Australasia and the Pacific

At the end of 2011, as we were finalising this book, Kingsford (2011) edited an edition of *Pacific Conservation Biology* on the theme "Climate change in Australasia and the Pacific". This was timely and welcome because it demonstrated that there is an ever-increasing number of researchers focussed on this matter within our region. Kingsford and Watson (2011) provided a valuable overview in their closing paper. They made many points common to other studies, but reinforced them for those who were not certain of the implications previously. They made the

useful distinction between acute impacts that are discrete, such as storms, droughts, fires and extreme rainfall events, and continuous, chronic impacts, such as gradual increases in mean temperatures, decreases in seasonal rainfall and rises in sea level, occurring over decades. They also distinguished among the projected impacts in three realms: terrestrial, marine and freshwater, with a table and a figure showing the components of environmental change with the projected impacts on biodiversity. As others have stressed, and Kingsford and Watson reaffirm, impacts other than climate change threaten biodiversity, including habitat loss and degradation, invasive species, over-harvesting, pollution and disease. They point out that the most obvious way to increase resilience for an ecosystem is to reduce or eliminate these threats. The example that reflects Kingsford's particular expertise is the section on freshwater systems where they state that freshwater habitats are in severe decline with the development of water resources for human use significantly contributing to this problem.

Kingsford and Watson (2011) point out that some of the impacts are known, including alterations to the length of the growing season, changes to the timing of season events, and the stratification period in lakes. They make the point that these impacts are hard to predict and require detailed knowledge of the ecology of each of the species, but for most species, this does not exist. They emphasise this by stating that, except for a few well-known charismatic species, the knowledge base is particularly low. They then point out that little is known about the persistence of species confronted by climate change, particularly given the current extinction crisis. We note their strong language with words such as "extinction crisis", meaning that before climate change emerged as a distinct impost on biodiversity, an extinction crisis was already underway.

Kingsford and Watson (2011) state that methods need to be developed quickly to allow the assessments of climate change impacts on particular species and the relative importance of climate change compared to the other drivers of extinction. They then say that once the relative importance of the threats is identified, well targeted adaptation measures can be implemented. This is a logical and intelligent sequence of ideas and actions, and by articulating it, others can then see the value of local studies of individual species, and the need to add climate change in as an extra dimension that will enable adaptation measures to be planned, implemented, and examined through what they label an 'adaptive management framework'. For many, the phrase "adaptive management framework" is jargon, and jargon is one of the communication blocks in any discipline. In this instance, the authors point out that in this framework, the conservation objectives are measured, such as through monitoring, to determine if they are being met. Monitoring, they say, lags in resources, including in some of the more significant restoration efforts. That Kingsford and Watson are fearful that this might not occur emerged when they stated that the $12.8 billion spent on buying back environmental water and improving the efficiency of irrigation works in the Murray-Darling Basin has had no monitoring program with resources. They state that measuring the success or otherwise of our adaptations will provide much needed knowledge about responses of organisms to climate change and other threats, and guide future efforts that are cost effective. Kingsford and Watson portray climate change and biodiversity in a way that links them via an understanding of ecology and management responses. In short, Kingsford and Watson and their fellow authors, as well as those in this book from the Royal Zoological Society of NSW, concur that climate change does not sit there on its own as an isolated problem if conserving biodiversity is your aim, it is part and parcel of all the issues that face our fauna, which is fading in the face of the ever-increasing list of threats.

Are robust strategies for Australian fauna possible?

In 1990, Charles Birch won an international award – the Templeton Prize – for his contribution to affirming life's spiritual dimension, whether through insight, discovery, or practical works. How, you might ask, does that influence the discussion? Birch was keen on looking at what lay at the heart of the matter in those minds that craved meaning in life. He understood the ecological crisis, he set students in the late 1960s to study DDT, a chemical pollutant, and how it worked its way through the ecosystem. At about this time, Birch began his long journey to look at meaning in science and nature. One of us (DL) was an undergraduate at the time. Birch enjoyed giving lunchtime talks to students and staff. In one series, which packed the Wallace Theatre, Birch presented a sparkling scientific talk. On another day, and at another venue, he gave a talk where he tackled the spiritual side of his enquiries. Three people attended, DL was one of them. Few people seemed interested in a scientist searching for meaning. The importance here is that Birch was interested in human motivation, feelings, and passions as to what drove people to think, to act and be part of the world. He revelled in the journey. Its lesson for fellow ecologists and scientists is to cross the divides of the disciplines, not only those in universities, but also in understanding the driving forces for life. He remained a scientist, so his quest was far more individual than one would experience if one joined a group of like-minded souls, such as a religious group where illogical, untestable answers and superstition can be accepted explanations for the sake of group unity and a sense of security. The lesson that can be drawn from Birch's search, in the current context, is that climate change is a challenge to the meaning of life, what we value, and how we can live our lives. As Birch's car sticker said, "Live simply, so that others can simply live." The other part of the lesson is that Birch remained a scientist and was not swayed to abandon evolution, ecology or the rigorous pursuit of questions and answers in a scientific forum.

The point we now have reached is that climate change does challenge fundamental values, and demands an adherence to clear-thinking. That point also applies to the media and how we evaluate what we read or see on TV, and what we note is missing from the media.

It also applies to the way scientists communicate how they work, how they think, and how they write. Pittock (2009) and Steffen *et al.* (2009) have produced texts that answer the questions that any reasonable person might ask of a scientist. Steffen *et al.* particularly speak to those scientists who are skilled in understanding the Australian environment and the ecological principles that underpin the options for conserving biodiversity in the face of existing threats and the overwhelming threat of climate change. We have benefitted from Birch's writings because they are rich in values and unabashed in their desire to conserve the natural world.

We gain immensely from the writings by scientists such as Birch, who was willing to confront the future, Hamilton who was willing to name those people and organisations who would manipulate science for their personal gain and to the detriment of humanity, Flannery who uses his high public profile to make the message personal, and Schneider who was bold and witty in describing the extreme difficulty of getting past vested interest, ignorance, and the unwillingness to understand science. We have also benefitted from the science writers who pick up ideas and examine them in a way that others can understand. Ehrlich and Ehrlich, Claiborne, Bernard and Gribbin are but five of a much larger list of writers who have captured the essence of the issue, explained it in plain English, and in fact have been clearer, quicker and bolder than the scientific community in getting the message across. However, it is the scientific texts that compress the discipline of climate and climate change that make it possible for ecologists and conservation biologists to grasp the main points without having to be physicists, meteorologists or climatologists. Linacre and Hobbs (1977), Pearman (1988) and the IPCC reports are key documents so that those of us who look down a microscope in a museum or radio-track a native mammal in a forest can grasp the significance of the work of colleagues in separate disciplines. We also need those texts that put together the latest ideas and ecological thinking, climate change thinking, and what might be done to manage it in the face of such a global problem where, as Hamilton has said, the responses have been excruciatingly slow. As Steffen *et al.* (2009) point out, it will be harder to manage the adaptation of Australia's fauna than it will be for the human population to adapt to climate change, which means it is a challenge that will need more resources, more imagination, and more consistency of effort than we have so far witnessed in the conservation of our native fauna and the natural areas and ecosystems that support all of Australia. That is not to say that a great deal has not been done to conserve biodiversity. The fact that the problem can now be so clearly articulated bears witness to the personal integrity and effort of many Australian scientists and their institutional support, as well as support from professional societies and other NGOs that work to conserve our fauna and draw the attention of a wider audience to the issues. We are simply saying we need more of this effort and commitment, along with a sense of values that does not allow the future to be diminished through wilfulness, including wilful denial, and presumed short-term gain.

This question of facing the issues of climate change is now drawing professional philosophers into the debate. Jamieson (2008), in his book *Ethics and the environment*, summarised the situation by saying that, as emissions of carbon dioxide and other climate-changing gases continue to increase, we are bequeathing to future generations the most extreme and rapid climate change since the age of dinosaurs. He then bluntly added that, although the problem has been mostly caused by the residents of industrialised countries, to some extent everyone has contributed, and he made the point that it is nonhuman nature and the descendants of today's poor people who will suffer most from this problem. In his closing chapter on nature's future, Jamieson opens with the phrase "nature is in trouble: biodiversity is under siege, the climate is changing, and the ozone hole has not yet healed". Jamieson notes that while many people are aware of some or all of these problems, there is a tendency to see them in isolation. Environmental science texts, he says, give long lists of maladies, as if each entry were a name of a separate plague that is befalling us. He then proceeded to say that environmental organisations often specialise in a single issue, while ignoring its neighbours; government officials, charged with protecting the environment, issue reports or commission studies instead of writing regulations and enforcing laws, while their colleagues in other agencies do everything they can to encourage drilling and digging, as if these activities had no environmental consequences. Even the newspapers, said Jamieson, reinforce this separation among environmental problems, as well as between environmental and other human concerns. He continued his relentless criticism to say that while the science section (*e.g.* of a newspaper) tells us that fossil-fuel-driven climate change threatens both nature and human societies, the business section treats modest increases in the price of oil as if they were catastrophes. In such social and political circumstances, said Jamieson, it is no wonder that it is difficult for us to think clearly about nature's future. Jamieson also wryly noted that what counts as an environmental catastrophe also depends on what one values. Many ecologists, Jamieson noted, feel that species extinction and biodiversity losses, that are now under way, are the early stage of an environmental catastrophe but, he added, not everyone thinks that these things matter. He concluded by saying the case for prioritising economic growth over other values must rest on a supposed special relationship to human happiness. Yet, he pointed out, it is surprisingly difficult to make that case and it is increasingly clear that wealth is not a good indicator of happiness, either for countries or for individuals. He stated that philosophers have, for a long time, said that treating wealth or economic growth as surrogates for happiness is a mistake.

James Garvey (2008), in his book *The ethics of climate change*, makes the point that it is more to do with the fact that science alone cannot help us with the answers we need. In his introduction, he made the point that the first chapter of his book is about the settled scientific opinion on the climate of our warming world. You hear the word "settled" more from philosophers than you do from scientists. It is a different paradigm in the way of thinking, the idea that something is settled, and then you work from that point. From our overview of the last 42

years of writing on climate change from the world's best scientists and science writers, the word "settled" is not one that comes readily to mind. However, to make headway with the argument, or the debate, or the philosophical wrangle, or to make a strong philosophical point, there is a case to say that aspects of the issue are settled. Such phrases as "may", and "suggest", or "likely", so much overused by scientists, give plenty of room for others not to feel challenged enough by the issue to think about it seriously. With that point settled, we can now look again at the writings of philosophers. It is worth noting that Garvey stated that he relied a lot on the work of the IPCC, so these scientific summaries do reach across disciplines in ways that their authors hoped they might. Such a thought underpins our reason for the Royal Zoological Society of New South Wales organising a forum and pressing on to produce this book. In his epilogue, Garvey said that when he started researching his book, he carried a little notebook around and jotted down references to climate change in the national press. The stories started appearing about once a week, he said, then twice a week, and just about daily, and by mid-2006 the world had suddenly noticed climate change, making headlines on a regular basis. He said that he almost came to the conclusion that a clutch of arguments about the effects of climate change were not really necessary because people were coming around to conclusions on their own. That thinking, he said, was too quick. The momentum is still out there, he said, but it has yet to translate into meaningful action. In his view, world leaders have done nothing morally adequate about climate change in the 20 years since the first warnings of the IPPC and others. He added that we have done nothing much about our individual actions either, despite changing attitudes. He does also note that individual people and individual states and cities have taken impressive action, but he added, it is just nowhere near enough. He said, that despite this, and despite himself, he was hopeful. That is the sort of writing that adds a critical dimension to the debate. We need the ethicists to help frame the climate change debate for society so that all the creatures we call wildlife are considered, and locations, the ecosystems, on which they depend can benefit from the hope that Garvey expressed.

We asked at the outset: are robust strategies for Australian fauna possible? Our answer from our review of science writers, and ecologists in particular, both across the globe and in Australia, is that it is possible. All the authors of the papers in this book are testament to the view that we can undertake the science, we can see the ecological implications of local, detailed studies and we can see the significance of the work of others. What also emerges is the importance of remaining focussed on the ecosystem and the animals that you work with. The case for remaining specialised is strong, and that means that co-workers in adjacent disciplines, such as taxonomy, pathology, physiology, modelling, let alone those with skills in the array of Australia's fauna and the ecosystems in which they dwell, need support in the greater exercise of conserving Australia's fauna in the light of existing threats and the threat of climate change. So yes, it is possible, and we look forward to listening to the next forum on this issue, or the next papers or books that move us forward, given that we are dealing with environmental problems that are growing faster than we are resolving them as a nation.

Acknowledgements

We are indebted to Chris Moon for his editing and constructive comments on the manuscript, to Clive Hamilton for comments on parts of the ms, and to Harry Recher for his critical reading of the ms from beginning to end.

References

Andrewartha, H. G. and Birch, L. C. 1954. *The Distribution and Abundance of Animals*. University of Chicago Press, USA.

Arnold, G. W. 1988. Possible effects of climate change and wildlife in Western Australia. Pp 375-386 in *Greenhouse: planning for climate change,* edited by G. I. Pearman. CSIRO, East Melbourne, Victoria, Australia.

Australian Greenhouse Office 1998. *The National Greenhouse Strategy*. Commonwealth of Australia, Canberra. (Reference in the final determination [Climate Change] of the New South Wales Scientific Committee.)

Bee, C., Furler, W. and Quinn, N. 1988. Greenhouse: international and national policy approaches. Pp 725-735 in *Greenhouse: planning for climate change,* edited by G. I. Pearman. CSIRO, East Melbourne, Victoria, Australia.

Bernard, H. Jr. 1980. *The greenhouse effect.* Harper Colophon Books, Cambridge Massachusetts, USA.

Birch, C. 1975. *Confronting the future: Australia and the world: the next hundred years*. Penguin, Ringwood, Victoria, Australia.

Birch, C. 1993. *Confronting the future: Australia and the world: the next hundred years*. New edition. Penguin, Ringwood, Victoria, Australia.

Brasher, R. E. and Pittock, A. B. 1998. Australasian Impacts of Climate Change. An Assessment of Vulnerability. In Watson, R.T., Zinyowera, M.C., Moss, R.H. and Dokken, D.J. The Regional Impacts of Climate Change. An assessment of Vulnerability, IPCC Report. Australian Greenhouse Office, Canberra. (Reference in the final determination [Climate Change] of the New South Wales Scientific Committee.)

Brereton, R., Bennett, S. and Mansergh, I. 1995. Enhanced greenhouse climate change and its potential effect on selected fauna of south-eastern Australia: a trend analysis. *Biological Conservation* 72: 339-354. (Reference in the final determination [Climate Change] of the New South Wales Scientific Committee.)

Busby, J. R. 1988. Potential impacts of climate change on Australia's flora and fauna. Pp 387-398 in *Greenhouse: planning for climate change,* edited by G. I. Pearman. CSIRO, East Melbourne, Victoria, Australia.

Claiborne, R. 1970. *Climate, man and history.* Angus and Robertson (UK), London, UK.

Driscoll, D. A., Felton, A. Gibbons, P., Felton, A. M., Munro, N. T. and Lindenmayer, D. B. 2011. Priorities in policy and management when existing biodiversity stressors interact with climate-change. On line *Climatic Change* DOI 10.1007/s10584-011-0170-1

Ehrlich, P. R. and Ehrlich, A. H. 1970. *Population resources environment. Issues in human ecology.* W. H. Freeman and co., San Francisco, USA.

Flannery, T. 2005. *The weather makers: how man is changing the climate and what it means for life on Earth.* Atlantic Monthly Press, New York, USA.

Garnaut, R. 2008. *The Garnaut climate change review.* Cambridge University Press, Melbourne, Victoria, Australia.

Garnaut, R. 2011. *The Garnaut review 2011. Australia in the global response to climate change.* Cambridge University Press, Melbourne, Victoria, Australia.

Garvey, J. 2008. *The ethics of climate change. Right and wrong in a warming world.* Continuum International publishing group, London, UK.

Gribbin, J. 1990. *Hothouse Earth: the greenhouse effect and gaia.* Grove Weidenfeld, New York, USA.

Graetz, R. D., Walker, D. H. and Walker, P. A. 1988. The consequences of climate change for 70% of Australia. Pp 399-420 in *Greenhouse: planning for climate change,* edited by G. I. Pearman. CSIRO, East Melbourne, Victoria, Australia.

Hamilton, C. 2001. *Running from the storm: the development of climate change policy in Australia.* UNSW Press, University of New South Wales, Australia.

Hamilton, C. 2010. *Requiem for a species.* Allen and Unwin, Crows Nest, NSW, Australia.

Hamilton, C., Lunney, D. and Matthews, A. 2000. An economic evaluation of local government approaches to koala conservation. *Australian Journal of Environmental Management* 7: 158-69.

Hare, F. K. 1977. Foreword, in Linacre, E. and Hobbs, J. *The Australian climatic environment*. John Wiley & Sons, Milton, Queensland, Australia.

Houghton, J. T., Jenkins, G. J. and Ephraums, J. J. 1990. (eds). *Climate change. The IPCC scientific assessment.* Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

Henderson-Sellers, A. and Blong, R. 1989. *The Greehouse effect*. NSW University Press, Kensington, NSW, Australia.

Hughes, W. and Westoby, M. 1994. Climate change and conservation policies in Australia: coping with change that is far away and not yet certain. *Pacific Conservation Biology* 1: 308-18. (Reference in the final determination [Climate Change] of the New South Wales Scientific Committee.) (Note, the reference is to Hughes, W. in the final determination, but it should have been Hughes, L.)

Hundloe, T. and Hamilton, C. 1997. *Koalas and Tourism: An Economic Evaluation.* Discussion Paper Number 13. The Australia Institute. July 1997, ISSN 1322-5421.

IPCC. 1996. Second assessment: climate change 1995. A report of the Intergovernmental Panel on Climate Change. Geneva IPCC.

Jamieson, D. 2008. *Ethics and the environment. An introduction*. Cambridge University Press, Cambridge, UK.

Kellogg, W.W. and Schneider, S.H. 1974. Climate stabilization: for better or worse? *Science* 186: 1163-1172. (reference from Linacre and Hobbs 1977.)

Kingsford, R. (ed.). 2011. Climate change in Australasia and the Pacific. *Pacific Conservation Biology* 17 (3). (Special issue.)

Kingsford, R. T. and Watson, J. E. M. 2011. Climate change in Oceania – a synthesis of biodiversity impacts and adaptations. *Pacific Conservation Biology* 17: 270-284.

Krebs, C. J. 2008. *The ecological worldview*. CSIRO publishing, Collingwood, Victoria, Australia.

Krebs, C. J. 2009. *Ecology: The Experimental Analysis of Distribution and Abundance* (6th edition). Benjamin Cummings, San Francisco, USA.

Krebs, C. 2012. What good is a CSIRO division of wildlife research anyway. Pp. -- in *Science under siege: zoology under threat*, edited by P. Banks, D. Lunney and C. Dickman. Royal Zoological Society of NSW, Mosman, NSW, Australia. In press.

Linacre, E. and Hobbs, J. 1977. *The Australian climatic environment*. John Wiley & Sons, Milton, Queensland, Australia.

Lunney, D. 2012. "What's the difference between climate science and climate journalism?" Pp -- in *Science under siege: zoology under threat*, edited by P. Banks, D. Lunney and C. Dickman. Royal Zoological Society of NSW, Mosman, NSW, Australia. In press.

Lunney, D., Pressey, B., Archer, M., Hand, S., Godthelp, H. and Curtin, A. 1997. Integrating ecology and economics: illustrating the need to resolve the conflicts of space and time. *Ecological Economics* 23: 135-42.

Lunney, D., Moon, C., Matthews, A. and Turbill, J. 1999. *Coffs Harbour City Koala Plan of Management*. Parts A&B. NSW National Parks and Wildlife Service, Hurstville, NSW.

Lunney, D., Matthews, A., Moon, C. and Ferrier, S. 2000. Incorporating habitat mapping into practical koala conservation on private lands. *Conservation Biology* 14: 669-80.

Lunney, D., Matthews, A., Moon, C. and Turbill, J. 2002. Achieving fauna conservation on private land: reflections on a ten-year project. *Ecological Management and Restoration* 3: 90-96.

Lunney, D., Fox, A., Catling, P., Recher, H. and Lunney, H.W.M. 2012. The ecological significance of 1954 in the history of Nadgee Nature Reserve in the Eden region on the south coast of New South Wales. Pp -- in *Australia's ever changing forests*, edited by B. Stubbs. Australian Forest History Society…in press.

Main, A. R. 1988. Climate change and its impact on nature conservation in Australia. Pp 361-374 in *Greenhouse: planning for climate change,* edited by G. I. Pearman. CSIRO, East Melbourne, Victoria, Australia.

Massachusetts Institute of Technology. 1971. *Inadvertent climate modification. Report on the study of man's impact on climate (SMIC)*. Massachusetts Institute of Technology, USA.

Millennium Ecosystem Assessment, 2005. *Ecosystems and Human Well-being: Biodiversity Synthesis.* World of Resources Institute, Washington, DC.

Oreskes, N. and Conway. E. M. 2010. *Merchants of doubt: how a handful of scientists obscured the truth on issues from tobacco smoke to global warming.* Bloomsbury Press, New York, USA.

Pearman, G. I. (ed.). 1988. *Greenhouse: planning for climate change*. CSIRO, East Melbourne, Victoria, Australia.

Pearman, G. I. 1988a. Greenhouse gases: evidence for atmospheric changes and anthropogenic causes. Pp 3-21 in *Greenhouse: planning for climate change*, edited by G. I. Pearman. CSIRO, East Melbourne, Victoria, Australia.

Pittock, A. B. 2009. *Climate change: the science, impacts and solutions.* (2nd edition). CSIRO publishing, Collingwood, Victoria, Australia.

Schneider, S. H. 1996. *Laboratory earth. The planetary gamble we can't afford to lose.* Weidenfeld and Nicolson, London, UK.

Schneider, S. H. 2009. *Science as a contact sport: inside the battle to save Earth's climate.* National Geographic Society, Washington DC, USA.

Schneider, S. and Londer, R. 1984. *The coevolution of climate and life.* Sierra Club, San Francisco, USA. (Reference from Gribben 1990.)

Steffen, W., Burbidge, A. A., Hughes, L., Kitching, R., Lindenmayer, D., Musgrave, W., Stafford Smith, M. and Werner, P. 2009. *Australia's biodiversity and climate change.* CSIRO, Collingwood, Victoria, Australia.