1 Introduction

As efforts to reach international agreements on climate change mitigation have made disappointing progress in recent years, there has been increasing interest in many countries in developing adaptations to cope with inevitable climate change. The aim of this paper is to provide an introduction not only to the key policy documents that have been developed in Australia relevant to biodiversity and climate change, but also to recent research aimed at supporting the development of future strategies and plans. Though Australia and China are dramatically different in many respects, such as the size of their human populations, they have much in common from an ecological perspective. With a land area of about 7.6 million km², Australia is the sixth largest country in the world, while China with a land area of around 9.6 million km² is the fourth largest country. Consequently, both experience a wide range of climatic conditions and support a diverse collection of ecosystems. Chapman [2009] has estimated that Australia has around 570,000 species out of a total of approximately 11 million species for the whole world, but only about 150,000 Australian species have been scientifically described. Considering one of the better-known groups there are estimated to be about 18,400 species of native Magnoliophyta (flowering plants) in Australia in comparison to about...
17,300 species of native flowering plants in China. This suggests the levels of terrestrial biodiversity for the two countries are broadly comparable.

In developing climate change adaptation options to protect biodiversity in any country there are a number of key questions which need to be considered including: What is happening to biodiversity now? What will happen to biodiversity in the future? What adaptations are needed? Where are the priority regions for action? What are the priority actions needed? And how can we engage the public?

The following sections examine how various strategies and action plans have addressed the biodiversity and climate change issue, and how recent research is providing answers to the above questions. These answers will help support the implementation of existing plans as well as the development of future plans.

2 Key Australian policy documents and reports


A search of the literature using the terms “Australia”, “biodiversity”, and “climate change” shows that only about five papers a year were published in this area in the five years before the preparation of the National Biodiversity and Climate Change Action Plan 2004–2007 [NRMMC, 2004]. This is in comparison to more than 65 papers that satisfied the same criteria in 2010. Though these key words and phrases would not capture all the relevant literature, this comparison illustrates the relative lack of knowledge available when this plan was prepared. Few studies had examined the effects of climate change on native species and those that had tended to focus on single species.

The seven objectives of the National Biodiversity and Climate Change Action Plan 2004–2007 were to: 1) improve our understanding of the impacts of climate change on biodiversity; 2) increase awareness of climate change impacts and our capacity to respond; 3) minimise the impacts on inland aquatic and semi-aquatic ecosystems; 4) minimise the impacts on marine, estuarine and coastal ecosystems; 5) minimise the impacts on native terrestrial species, communities and ecosystems; 6) minimise the impact of invasive organisms on biodiversity in future climates; and 7) factor impacts of climate change on biodiversity into natural resource management and land use planning. Each of these objectives was backed up by seven and twelve specific actions.

The need to increase understanding reflects the relative lack of knowledge of likely impacts when this document was prepared, while the need to increase awareness reflects the need to engage and inform the public. In addition to highlighting the importance of a range of natural ecosystems in objectives 3, 4 and 5, the plan identified invasive organisms as a particular problem and these continue to be a major problem. For example, there are estimated to be about 2,700 introduced plant species now established in the wild in Australia and 429 of these species have been declared noxious weeds or are under some form of legislative control [NRMMC, 2007].

2.2 Australia’s Biodiversity Conservation Strategy 2010–2030

In 2010, Australia’s Biodiversity Conservation Strategy 2010–2030 [NRMMC, 2010] replaced the 2004–2007 Action Plan as the key Australian Government document on biodiversity and climate change. Though it covers many issues not directly related to climate change, the Strategy reflected the importance of climate change in the second of its three priority areas which involve: 1) engaging all Australians; 2) building ecosystem resilience in a changing climate; and 3) getting measurable results.

Priority 2, which is the most relevant to this paper, includes three sub-priorities with specific time-bound objectives. Sub-priority 2.1 aims at protecting biodiversity with a 2015 national target of increasing native habitat managed primarily for biodiversity conservation by 600,000 km² across terrestrial, aquatic and marine environments. Sub-priority 2.2 involves the restoration of 1,000 km² of fragmented landscapes and aquatic systems by 2015 to improve ecological connectivity, as well as four continental scale linkages
being established and managed to improve ecological connectivity. Sub-priority 2.3 aims to reduce by at least 10% the impacts of invasive species on threatened species and ecological communities in terrestrial, marine and aquatic environments.

A couple of examples serve to illustrate innovative ways that areas managed primarily for nature conservation are being increased. In July 2011, it was announced that the Henbury property, an area of more than 500,000 ha in Australia’s arid central region, was being purchased for addition to the National Reserve System (NRS). The property will be managed by a commercial company, but cattle will be removed and the land will be managed to encourage natural revegetation with the aim of sequestering up to 1.65 million t CO$_2$ over the next 10–15 years. The management objective is to generate biodiverse carbon credits to fund ongoing conservation management.

In May 2011, the Federal Court of Australia granted Native Title rights to the Wunambal Gambera people over a large area of coastal land in the northern Kimberley region of western Australia. The traditional owners have declared 343,515 ha of this region as the Uunguu Indigenous Protected Area. The Area, which is now part of the NRS, includes a great diversity of habitats and is home to many threatened species, including the smallest rock wallaby (*Petrogale barbridgei*).

Work is also progressing on extending marine reserves in areas controlled by Australia’s Commonwealth Government. Waters immediately adjacent to the coastline are controlled by Australia’s states and territory governments. So, marine reserves usually begin about three nautical miles from the coast and extend to the limits of Australia’s Exclusive Economic Zone some 200 nautical miles from shore. Proposals for new Commonwealth marine reserves in the South-west, North-west, North and East marine regions will be released for public consultation in 2011.

The Great Eastern Ranges and Gondwanalink projects are two of the most important initiatives aimed at improving connectivity across fragmented landscapes. The Great Eastern Ranges project includes the mountainous ranges and escarpments in a broad strip running down eastern Australia and has a current focus on a 1,200 km section in the state of New South Wales. The Gondwanalink project is concerned with protecting and restoring native vegetation over a 1,000 km band of south-western Australia. Both projects operate excellent websites providing a wealth of information about the projects, including information relevant to climate change, while some of the scientific issues behind the projects have been discussed by Soule et al. [2004].

The Department of Sustainability, Environment, Water, Population and Communities is responsible for reducing the impacts of invasive species. Some current concerns include the Chytrid fungus, which is a worldwide problem for amphibious species and Guava rust (*Puccinia psidii*), which threatens Myrtaceous species including eucalypts. Feral animals, such as feral cats, are a particular threat to small marsupial species. Insects, marine pests and weeds are other areas of concern. For example, invasive grass species are a problem in northern Australia and a climate change adaptation study aimed at controlling buffel grass (*Pennisetum ciliare*) was part of the NRS study outlined below in section 3.2.

### 2.3 Australia’s Biodiversity and Climate Change

Australia’s Biodiversity and Climate Change [Steffen et al., 2009a] is a report that was prepared for the Natural Resource Management Ministerial Council to provide a strategic assessment of the vulnerability of Australia’s biodiversity to the impacts of climate change. This report provides a very useful overview of Australia’s biodiversity today, impacts of climate change, responses to climate change, and current management. A concluding chapter identifies five key messages and policy directions, which are also outlined in a summary for policy makers [Steffen et al., 2009b]. These key messages are to: 1) Reform our management of biodiversity — while some existing policy and management tools remain effective some new approaches will be needed to enhance the resilience of our ecosystems. For example, the NRS (Australia’s
network of protected areas) needs to be enhanced substantially. 2) Strengthen the national commitment to conserve Australia’s biodiversity — wide public discussion is needed on a new national vision for Australia’s biodiversity under climate change and the resources to implement it. 3) Invest in our life support system — our environment has suffered from low levels of investment for decades. We must renew public and private investment in this natural capital. 4) Build innovative and flexible governance systems — agile governance systems will be needed to cope with climate change. 5) Meet the mitigation challenge — strong emissions mitigation actions are needed globally, but these must be carried out in ways that deliver both adaptation and mitigation benefits. For example, favouring the establishment of complex diverse ecosystems rather than monocultures of fast-growing trees.

2.4 Other policy documents and reports

The previous sections outlined three key Australian Government documents relevant to biodiversity and climate change. Several other government documents touch on biodiversity and climate change less directly. For example, Australia’s Native Vegetation Framework [NVFRTG, 2009] is aimed at achieving a reversal in the long-term decline of Australia’s native vegetation and an improvement in the condition of existing vegetation. It recognises not only the threat that climate change poses to native vegetation, but also the important role that native vegetation plays in carbon storage. Similarly, Australia’s strategy for the NRS 2009–2030 [NRMMC, 2009] recognises the need to consider climate change. In the following sections we’ll look at how research studies of the NRS and other important biodiversity issues are providing knowledge to support the implementation of current plans as well as the development of future strategies.

3 CSIRO Climate Adaptation Flagship

The CSIRO is Australia’s national science agency and one of the largest and most diverse research agencies in the world. Its work is increasingly organised around a small number of “flagships” which are designed to address issues of national importance. For example, the Climate Adaptation Flagship became fully operational in July 2008 with the goal “to equip Australia with practical and effective options to adapt more effectively to climate change and variability and in doing so create 3 billion $A a year in net benefits by 2030”. It is organised around four research themes: pathways to adaptation, cities and coasts, natural ecosystems, and adaptive primary industries. Research relevant to biodiversity in both Australia’s terrestrial and marine environments takes place in the natural ecosystems theme (managing species and natural ecosystems).

The following sections describe how the natural ecosystems theme has endeavoured to answer the questions raised in the introduction. One of the great achievements of the theme in its first three years of operation has been to assess potential climate change impacts and adaptations across the whole of Australia’s vast terrestrial and marine environments. The Marine Report Card and the NRS studies outlined below help to answer the questions: “what is happening to biodiversity now?”, “what will happen in the future?”, and “what adaptations are needed?”.

A trial application of a systematic regional approach to adaptation helps to answer the questions “where are the priority areas for action?” and “what are priority actions in particular areas?” while CSIRO’s CarbonKids initiative provides an example of engaging the public.

3.1 Marine climate change in Australia report card

The 2008 workshop “In Hot Water” [Poloczanska et al., 2008] showed convincingly that the marine environment was responding to climate change and that this message needed to be disseminated to the Australian public and policy makers. Elvira Poloczanska, Anthony Richardson, and Alistair Hobday scoped, then coordinated the development of a report card that summarises our current knowledge of impacts, key knowledge gaps and recommended adaptation options in terms of six marine environment issues (e.g., temperature, ocean acidification) as well as eleven
major biodiversity groups (e.g., phytoplankton, coral reefs, temperate fish, seabirds) [Poloczanska et al., 2009]. Seventy individuals from 35 organisations contributed to the preparation of the card, which was launched in November 2009 as a printed three A4-page foldout, a website and a 289 page book for libraries (Fig. 1). The foldout version is written in plain English suitable for the general public, while the website and book provide access to state-of-the-art knowledge about climate change and marine systems. Copies of the foldout are available from the website by clicking on an option towards the bottom of the opening page. For example, the foldout entry for coral reefs is as follows.

Figure 1 Current knowledge of marine climate change impacts for Australia, highlighting key knowledge gaps and adaptation responses

(1) What is happening? Sea surface warming has led to extensive coral bleaching and declines in coral condition on the Great Barrier Reef and on northwestern reefs (high confidence). Ocean acidification and increased thermal stress are the likely causes of a reduction of more than 10% in the growth rates of massive Porites corals on the Great Barrier Reef (medium confidence).

(2) What is likely to happen this century? Frequency and severity of mass coral-bleaching events will increase as temperatures warm, leading to declines in coral reef health (high confidence). Ocean acidification will reduce coral growth rates making reefs more susceptible to erosion and disturbance from storms (high confidence).

(3) Addressing knowledge gaps. Undertake experimental studies to strengthen predictions of thresholds for coral-algal phase shifts and loss of ecosystem function under climate change.

(4) Key adaptation options. Improve and maintain coastal water quality and healthy populations of herbivorous reef fishes to help sustain the resilience of coral reefs.

To complement this plain English summary the detailed article on coral reefs in the book [Anthony and Marshall, 2009], which is similar to that on the

\[www.oceanclimatechange.org.au\]
website, provides a scientific review of over 15 pages and includes 88 references. As shown above the sections in the report card discussing “what is happening” and “what is likely to happen” each include an assessment of the level of confidence in the statements given. While this is a subjective assessment made by the authors of each section, examining the detailed article provides an indication of how much published information is available to back up each statement.

The Marine Report Card has played a significant role in increasing public awareness of marine climate change issues through the high use of its website (around 1,800 unique visitors per month with each unique visitor being responsible for many “hits”), considerable media coverage around its launch, and by being one of three finalists in the 2010 Eureka Prizes (the major Australian science awards). A user survey indicated that about 90% of users rated the design, content and usefulness of the card as either “very good” or “good”. As the report card concept has been very successful, it is planned that it will be updated every three years and a terrestrial version is also in development.

3.2 NRS studies

Two phases of studies on the NRS and climate change have been completed. The NRS includes about 98 million km² in 9,300 protected areas covering about 13% of the country. The aim of the first NRS study [Dunlop and Brown, 2008a; 2008b] was to investigate the impacts of climate change on Australia’s formally-protected conservation areas and on their management. A detailed report outlined key threats, including water availability, species movements (both native and exotic), changes in land use and altered fire regimes. The report recognised that change is inevitable and some species are likely to go extinct in the wild. It suggested that facilitating natural changes and protecting habitat were appropriate ways to minimise negative impacts. The report included an analysis of climatic impacts, but this was relatively simple, considering only 10 major bioclimatic regions across the whole country.

The second NRS study [Dunlop et al., 2011], led by David Hilbert and Michael Dunlop, explored likely impacts and adaptations in much greater detail. This included the development of a 1 km resolution database for the current climate (based on the 1960–1990 period) as well as for 2030 (A1B medium emissions), 2030 (A1FI high emissions), 2070 (A1B medium emissions) and 2070 (A1FI high emissions) projected climate change scenarios across the whole country. Details of the study will be provided in a series of reports, which cannot be described in detail here as they have not yet been made public. However, one of the analysis methods used is particularly worth noting. Most of the analysis methods used in the past have examined impacts of climate change on single species or small groups of species. As mentioned in the introduction, it is estimated that there are about 570,000 species in Australia’s terrestrial environments, so clearly there is a need to analyse how large numbers of species may be affected by climate change. As part of the second NRS study, Simon Ferrier et al. [2010] developed tools to analyse the impacts of climate change on large numbers of species in major groups, including plants, mammals, birds, reptiles, and frogs based on Generalised Dissimilarity Modelling (GDM). GDM is a statistical technique for analysing and predicting spatial patterns of turnover in community composition (beta diversity) across large regions [Ferrier et al., 2007]. In the second NRS study nearly three million distributional data points were used for 13,000 vascular plant species (Fig. 2). The GDM analyses carried out in this study were helpful in showing regions likely to be under high ecological stress under climate change.

3.3 Adaptation a systematic regional approach

Chapter 7 of “Australia’s Biodiversity and Climate Change” [Steffen et al., 2009a] outlined a proposed method to help answer the questions “where are the priority areas for action?” and “what are priority actions in particular areas?” This is based around the need to consider social and economic as well as environmental factors. A trial application of this method has been completed in Vietnam [Miller et al., 2009]
using social and economic data for 12 years from 65 provinces to assess current status and trends for factors such as biodiversity, human population, average income and agricultural productivity. These data were related to 13 ecological regions. A table was prepared identifying for each ecological region the status and trends and climate change scenario. Additional information included descriptions of climate change implications, governance and investment sources, and education needs, as well as key features for an integrated response package and action plan.

3.4 CarbonKids

CarbonKids is a CSIRO initiative aimed at providing an educational program that combines the latest in climate science with education in sustainability. It is providing to registered schools in Australia: 1) a set of integrated curriculum units for the primary and middle years of schooling with associated resource pages; 2) supporting climate change information sheets including critical questions and interesting facts; 3) suggested opportunities and activities for classes and individuals that lead to staff and students taking action at school and at home to combat climate change; 4) promotional tools including a CarbonKids Media Kit; 5) an invitation to send student delegates and a teacher to annual CarbonKids Climate Science workshops; and 6) regular e-newsletters.

4 Carbon tax and biodiversity inquiry

On 10 July 2011, the Australian Government announced its intention to introduce a carbon tax of 23 A$ per tonne of carbon (equivalent to 20.87 A$ per ton of carbon) to begin in July 2012. This plan includes 1 billion A$ over six years for a biodiversity fund “to establish, restore, protect or manage biodiverse carbon stores”.

It is also worth noting that the Australian Government is conducting an inquiry into “Australia’s biodiversity in a changing climate” especially in relation to nationally important ecosystems. The inquiry will have particular regard to connectivity between ecosystems and across landscapes, how climate change impacts on biodiversity may flow on to affect human communities and the economy, strategies to enhance climate change adaptation, mechanisms to promote the sustainable use of ecosystem services in a changing climate, governance arrangements, and mechanisms to

[Figure 2] Generalised Dissimilarity Modelling combines large amounts of biological and environmental data to assess how whole plant communities are likely to be affected by climate change.
enhance community engagement.

5 Conclusions and discussion

The policy documents that have been developed, such as Australia’s Biodiversity Conservation Strategy 2010–2030 [NRMMC, 2010], provide examples of how major priorities relevant to biodiversity and climate change can be identified. They also show how these can be backed up by specific time-bound actions. However, the policy documents all emphasize the need for improved knowledge so that policies can be more clearly evidence-based.

Part of the role of CSIRO Climate Adaptation Flagship is to provide evidence to support policy development. In relation to the key questions raised in the introduction, the Marine Report Card and the NRS studies are both helping in different ways to answer the questions “what is happening to biodiversity now?”, “what will happen to biodiversity in the future?”, and “what adaptations are needed?”. Creating marine and/or terrestrial report cards would be useful for any country wanting to review biodiversity and climate change issues. The simple foldout report card is an appropriate way of communicating with the public, while preparing the more detailed web pages and book are very effective ways of bringing together knowledge from experts concerned with biodiversity and climate change and providing information in a succinct form for policy makers. The Generalised Dissimilarity Modelling carried out for the second NRS study is particularly important in allowing impacts to be measured together for very large groups of species, so that regions likely to be under high stress under climate change can be identified and adaptation policy responses developed. These broad regional analyses enabled some regions to be identified that were not previously considered vulnerable to climate change.

The systematic regional analysis provides a more structured way of identifying “where are the priority regions for action?” and “what are the priority actions needed?”. The summary table produced provides a useful strategic overview across broad regions, but it should only be seen as a preliminary step and more work would be needed with local communities to develop detailed plans for particular areas.

The need to engage the public in biodiversity and climate change issues was stressed in several of the policy documents mentioned here. There is probably no better place to start than with schoolchildren and the CarbonKids initiative provides some ideas on how this can be done.

There will be many future challenges in developing appropriate adaptations to protect biodiversity under climate change. More reliable estimates of future climatic conditions are needed at finer (sub-kilometre) scales. However, high levels of uncertainty are likely to remain as climatic changes in decades to come will be influenced not only by biophysical conditions, but also by policy action or inaction at the global scale. A study of the effects of climate change on the growth of plantation forests in Australia has shown how ranges of uncertainties in different factors can be included in a forest growth model [Battaglia et al., 2009]. About a million simulation runs of the model were then used to explore the possible range of outcomes. The results showed that despite the uncertainties there were some regions where growth was very likely to increase and others where it was very likely to decrease. Using multiple simulation runs with biodiversity problems may also help to deal with uncertainties and produce policy relevant results.

In this paper, there has only been space to outline some of the most relevant activities of the Natural Ecosystems theme of CSIRO Climate Adaptation Flagship. There are many other relevant studies, for example, major studies of fire and biodiversity [Williams et al., 2009] and invasive plants [Kriticos et al., 2010], as well as important papers in key journals on protected areas [Fuller et al., 2010], defining native and alien species under climate change [Webber and Scott, 2011] and marine systems [Richardson and Poloczanska, 2008]. Current work includes a major biodiversity and climate change study for the Queensland Government, which is the state in the northeastern part of Australia that occupies a land area

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Climate change poses obvious and great threats for the world’s biodiversity, which is already under considerable stress from loss of habitat and invasive species. No country is doing a perfect job in meeting the climate change threat to biodiversity, but all countries can learn from sharing their experiences and knowledge about useful approaches for dealing with the challenge.

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