NCCARF
National
Climate Change Adaptation
Research Facility

National Climate Change Adaptation Research Plan:

Terrestrial Biodiversity

Consultation Draft

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Executive Summary

Increasing concentrations of greenhouse gases in the atmosphere due to human activities are driving changes in global climate. The magnitude of the recent physical changes is greater than at any time during human civilization and, importantly, the *rate* of change is faster. The IPCC (2007) has highlighted that biodiversity is likely to be the most vulnerable sector for the Australia and New Zealand region (as it is in general around the world), largely reflecting the very low adaptive capacity of natural ecosystems compared with other sectors.

The threats to terrestrial biodiversity from climate changes arise from changes in the basic physical and chemical environment underpinning all life, especially CO_2 concentrations, temperature, and precipitation. Species will be affected individualistically by these changes, leading to flow on effects to the structure and composition of present-day communities, and then potentially to changes in how ecosystems function and the services they provide. Changes in CO_2 concentration, temperature and precipitation will have direct impacts on ecosystem processes such as net primary productivity, nutrient cycling, and decomposition. Species, communities and ecosystems will also be affected indirectly, as climatic changes affect important processes such as fire and disease. Some of these changes are already evident.

Individuals, institutions and sectors of the community that will need to adapt include those who govern and manage terrestrial systems, those who have responsibilities for conserving terrestrial biodiversity and those who depend on terrestrial ecosystems for economic or social benefit. High quality, focused research is required to ensure these groups are well positioned to adapt to climate change, either in their own interests or on behalf of the Australian community. Whilst some work has been done aimed at understanding the broad impacts of climate change on the terrestrial environment, adaptation research is less well developed.

This National Adaptation Research Plan (NARP) for Terrestrial Biodiversity identifies research required to assist managers of the terrestrial estate prepare for the consequences of climate change. It provides a framework to guide research funding decisions and key directions for the country's terrestrial research community. In conjunction with research plans in other priority thematic areas, this Plan will guide researchers generating the information Australia needs to develop an effective portfolio of adaptive strategies.

The priority questions identified in the Plan have been organised into four main sub themes that correspond to the main ecological scales of organization and also the main scales of management: national/continental scale, regional scale, local land management, and management of key species. A number of critical information needs and research gaps are identified under each sub-theme. All research issues identified and discussed in this Plan (set out in the table below) are considered to be high priority based on following five criteria:

Essential
- Severity of impact/degree of benefit;
- Immediacy of required intervention/response;
- Need to change current intervention/practicality of intervention;

Desirable
- Potential for co-benefit;
- Potential to address multiple, including cross-sectoral, issues.

The table below lists the high priority research issues.

5.1 National/continental scale issues
5.1.1 How will climate change affect existing conservation goals and how should changed conservation goals be promoted and achieved?
5.1.2 How can the existing Australian legal, policy and institutional architecture for land management and biodiversity conservation respond to changes in conservation goals caused by climate change?
5.1.3 What conceptual models and long-term observation systems are needed to support the design, analysis and assessment of active adaptive management and policy experiments at regional and national scales under climate change?
5.2 Regional issues
5.2.1 What designs of landscapes in intensive and extensive land-use zones confer maximum resilience for biodiversity in the face of climate change, including the uncertainty associated with future climate scenarios?
5.2.2 How will climate change interact with other key stressors such as fire, invasive species, salinity, disease, water extraction, climate hydrology, grazing and clearing and what are the implications for ecosystem structure and functioning?
5.2.3 How can large-scale carbon mitigation initiatives such as revegetation and forest-related mitigation be designed to avoid adverse impacts on biodiversity and to maximise biodiversity conservation benefits?
5.2.4 How can major socio-economic trends occurring in many regions of Australia contribute to effective climate change biodiversity adaptation responses?
5.3 Local land management issues
5.3.1 What are the costs and benefits of different climate change adaptation measures in key vulnerable communities and ecosystems?
5.3.2 How should fire management adapt to climate change?
5.3.3 How can management of local protected areas incorporate and adapt to climate change?
5.3.4 How can we better integrate conservation plans and actions across landscapes, incorporating protected area management, off-reserve conservation measures and other land-uses, to maximise biodiversity conservation benefits/outcomes under a changing climate?

5.4 Managing key species
5.4.1 Which species should be the focus of investment in climate change adaptation?
5.4.2 How will climate change affect current management actions for protecting priority species and what management changes will be required?
5.4.3 How will climate change affect current or potential problem species and what management responses will be required?

Table 1) *High priority research issues*

Implementation

A detailed implementation plan will be prepared upon completion of the Terrestrial Biodiversity NARP, outlining budget, research capacity and funding opportunities. The National Adaptation Research Network for Terrestrial Biodiversity will play an essential role in implementing the research plan, and will contribute greatly to building collaboration, information sharing and research capacity across the Australian research community.

1. Context and objectives

1.1 Introduction

There is now widespread acceptance that human activities are contributing significantly to climate change, and that this change is producing significant physical effects. It is also generally acknowledged that these impacts will become more severe if substantial changes in human behaviour and resource use do not occur.

There are two main themes to such modification. Mitigation strategies involve actions that are intended to reduce the magnitude of our contribution to climate change (primarily by reducing greenhouse gas emissions) or offset or reverse its effects (for example, establishing and maintaining forest areas to sequester carbon). Adaptation strategies involve actions in response to changes that are either inevitable or likely.

The National Climate Change Adaptation Research Facility (NCCARF), established by the Australian Government and hosted by Griffith University, aims to lead the Australian research community to generate the biophysical, social and economic information needed by decision-makers in government, and in vulnerable sectors and communities to manage the risks of climate change impacts.

A key role of the Facility is to coordinate the development of National Adaptation Research Plans (NARPs) that identify critical gaps in the information needed by sectoral decision-makers and set national research priorities. NARPs are being developed in partnership with governments, stakeholders and researchers. Identification of research priorities will enable State and Federal governments and other research investors to fund research over the next five to seven years that can deliver maximum benefit to the Australian community, as well as to provide a broad framework for longer-term research planning.

Biodiversity is widely acknowledged to be one of the sectors most vulnerable to the impacts of climate change. In terms of the projected magnitude and rate of the climate change, Australia's (and the world's) biodiversity is facing a threat equivalent to those of abrupt geological events that triggered the great waves of extinction in the past. The aims of this Plan are to:

1. Identify important gaps in the information needed by sectoral decision-makers to respond to climate change in ways that reduce the vulnerability of terrestrial ecosystems;
2. Set adaptation research priorities based on these gaps; and
3. Identify capacity that can be harnessed or that needs development to perform priority adaptation research.

1.2. National climate change policy context for this Plan

The National Climate Change Adaptation Framework (the Framework) was endorsed by the Council of Australian Governments (COAG) in April 2007 as the basis for government action on adaptation over five to seven years. The Framework includes possible actions to assist vulnerable sectors and regions, such as biodiversity, fisheries and coasts, to adapt to the unavoidable impacts of climate change. It also includes actions to enhance the knowledge base and scientific capacity underpinning climate change adaptation.

In 2007, the Australian Government provided $126 million over five years towards implementing the Framework. The Australian Government established the National Climate Change Adaptation Research Facility (NCCARF, hosted by Griffith University) to coordinate and lead the Australian research community to generate the biophysical, social and economic information needed to adapt to climate change. Up to $50 million will be invested in priority research for key sectors as identified in National Adaptation Research Plans (NARPs), giving effect to Action 1.1 of the Framework, which aims to improve national coordination of climate change adaptation research. The NARPs, that are being progressively developed by the NCCARF in partnership with governments, stakeholders and researchers, set national priorities for adaptation research. The NARPs will be important tools for coordinating adaptation research across Australia and will be implemented by the NCCARF with assistance from a number of National Adaptation Research Networks and through participation across all Australian jurisdictions. Funding of up to $10 million has been provided over five years to support the establishment and operation of these research networks which form an integral part of the National Climate Change Adaptation Research Facility.

An inclusive, multi-disciplinary research network for Terrestrial Biodiversity has been established to collate knowledge, co-ordinate expertise and synthesise these inputs into recommendations and frameworks that will help guide the way forward for Australia to adapt to global climate change. The management node for this network has been established at the Centre for Tropical Biodiversity and Climate Change at James Cook University (JCU). It is convened by Stephen Williams (JCU) and Lesley Hughes (Macquarie University). The network currently includes over 200 researchers from 40 institutions and is continually expanding. The aim is to include members that represent all state and federal government biodiversity and climate change units, major NGOs and stakeholder groups. Members of the network will collectively incorporate knowledge and experience in all major ecosystems and taxonomic groups relevant to designing and implementing adaptation strategies.

The network will work with the Facility to advance regional and sectoral knowledge about climate change impacts, vulnerability and adaptation options for terrestrial biodiversity, and to foster an inclusive and collaborative research environment across Australia, through:

- Collating and synthesising relevant literature, data and resources
- Open exchange of information and sharing of resources
- Contributing to the work of the Facility in synthesising existing and emerging research and in developing and implementing the National Adaptation Research Plan.
- Nurturing the careers of young investigators and research students by promoting a sense of community, collaboration and strong, effective mentoring, and encouraging them to shape the future direction of their research areas.

The development of the NARP for Terrestrial Biodiversity builds on recent initiatives that identified potential climate change impacts on Australian species and ecosystems, and research strategies needed to minimise future biodiversity loss. These initiatives include the National Action Plan for Biodiversity and Climate Change (2003-2007) (NRMMC 2004), and Hilbert et al. (2006). More recently (November 2006), the Natural Resource Management Ministerial Council adopted as a priority action the preparation of a strategic assessment of the vulnerability of Australia’s biodiversity (Biodiversity Vulnerability Assessment, BVA) to climate change. The Australian Greenhouse Office of the former Department of the Environment and Heritage (now part of the Department of Climate Change, DCC) commissioned the BVA with the following terms of reference:

(i) to cover terrestrial, freshwater and marine environments;
(ii) to be strategic in nature and provide policy directions for future adaptation planning (i.e., it will not be a systematic, region-by-region, community-by-community assessment);
(iii) to include an assessment of the scientific observations and predictions around impacts/responses to climate change; and
(iv) to provide comments on ways biodiversity management can adapt to enhance the resilience of Australian biodiversity to the impacts of climate change.

The BVA is the first national assessment of the vulnerability to climate change of Australia’s biodiversity in its entirety (Steffen et al. 2009). This NARP draws heavily on the principles and recommendations of the BVA which were based on the ecological principles that characterise (i) how individual species interact with their environment; (ii) how species interact with each other in communities and ecosystems; (iii) how ecosystems and landscapes are structured; and (iv) how environmental change affects the structure and functioning of ecosystems. These principles underpin the analyses of current biodiversity change and that projected under further climate change, as well as the policy and management principles required to deal with these challenges.

The development of the NARP for Terrestrial Biodiversity was led by the following drafting team: Professor Lesley Hughes, Professor Richard Hobbs, Mr Angas Hopkins (DCC), Dr Mark Stafford Smith, Professor Will Steffen, Associate Professor Stephen Williams and Professor Jan McDonald, with assistance from Mr Frank Stadler (NCCARF).

1.3 Other policy and management drivers and research responses

The National Climate Change Adaptation Framework 2007 and the Biodiversity Vulnerability Analysis interact with a large number of other policy and implementation activities occurring in the government and non-governmental sectors, frequently as part of a wider conservation or management agenda. Appendix 1 summarises activities that define important terrestrial biodiversity and climate change issues or need to respond to them.

1.4 The scope of this National Adaptation Research Plan

The Australian terrestrial biota is extremely vulnerable to the impacts of climate change, as are the human communities that depend on terrestrial ecosystems for essential goods and services. Effective adaptation to unavoidable climate changes is necessary to minimize negative impacts and realise potential opportunities. High quality, focused research is required to support climate adaptation policies and practices that will maximise the resilience of species and ecosystems to change. End-users of this research will include individuals, institutions and sectors of the community who have responsibilities for managing the conservation estate, those who govern or manage the use of terrestrial resources and those who depend on terrestrial ecosystems for economic or social benefit.

This NARP - TB will support adaptation efforts by identifying research priorities that are most relevant to the needs of these stakeholders. The Plan will provide targeted guidance to research investors and research providers about priority information needs and research that is most likely to address those needs. Properly funded and delivered, this research is expected to assist stakeholders effectively meet the challenges of climate change.

The Research Plan is focused primarily on research to inform adaptation actions by Australian governments and communities to climate change impacts on terrestrial biodiversity. Research, observations and measurement systems have been given high priority where they will inform the design of adaptation policies or strategies or help implement adaptation actions by relevant people and organisations. Research on the nature of climate change impacts *per se* is not emphasized unless such research is considered essential to fill a void in understanding adaptation options.

This Research Plan touches on some adaptation issues or options for terrestrial biodiversity important to Indigenous communities around Australia. We recognise that these issues are critical. They will be considered in full as part of a National Climate Change Adaptation Research Plan devoted to the Indigenous communities of Australia.

Adaptation options will apply at different spatial scales. As a *National* Adaptation Research Plan, this Plan gives priority to research needs of national significance either because they are likely to apply over large geographic areas or relate to matters of national importance. The Plan also provides a framework for identifying region-specific research priorities, such as climate change impacts on fire behaviour, and those that address local management issues. Finally, the Plan outlines research priorities related to particular priority species .

Future climate impacts will depend on the future rate of global warming. Thus, the temporal scale relevant to this Plan is relatively unconstrained, potentially extending from issues apparent now to those expected to become important in several decades. Potential longer term impacts are also considered because it may be important to commence research now to inform actions in the near future that will enable us to accommodate or avert negative impacts in the distant future.

Criteria for setting research priorities are set out in Section 1.6. Section 2 outlines the need for adaptation strategies to conserve terrestrial biodiversity. Section 3 describes the ecological context within which adaptation research is set, including the characteristics of Australian's terrestrial biota that will affect its response to climate change, and the interaction of climate change with other environmental stresses. Section 4 describes the primary stakeholders to whom this Plan is aimed, and their information needs. Section 5 sets out the priority research questions under sub-themes which refer to the basic levels of ecological organisation. Table 2 at the end of section 5 indicates the priority ascribed to each question. Section 6 outlines some implementation issues arising from the plan. Except when referring to specific data, most references are not cited in the text. A reading list is included at the end of the Plan.

1.5 Links to and synergies with other National Adaptation Research Plans

There are clear overlaps between this research plan and research priorities in other National Adaptation Research Plan thematic areas. Of particular importance is the growing body of evidence that adaptation strategies that enhance resilience of natural ecosystems have co-benefits for many other sectors. Some potential areas of synergy, common interest or conflict are set out below.

Water Resources and Freshwater Biodiversity – The Water Resources and Freshwater Biodiversity NARP has clear links to the terrestrial biodiversity NARP in two key respects:

- The Water NARP deals with the specific subset of terrestrial biodiversity located in and around freshwater ecosystems.
- Water availability will be a key conflict and decision issue in climate change policy and actions.

Water is one of the major factors shaping Australia's ecosystems and is therefore particularly relevant to this research plan. For example, adaptive measures in response to water shortage may have significant impacts on terrestrial biodiversity. The construction of new dams and water infrastructure will affect river flows and downstream ecosystems and an increase in farm dams may lead to further increases in feral animal and macropod numbers on farm land and neighbouring bush. Clearly, the adaptive management of the environment at the interface of freshwater and terrestrial ecosystems is critical for both sectors. Adaptation actions that reduce degradation of watersheds, through reduced deforestation, afforestation and soil conservation, can reduce vulnerability to drought, and the maintenance and restoration of wetlands can be important for flood control.

Marine Biodiversity and Resources – The Marine Biodiversity and Resources NARP also has links to the terrestrial biodiversity NARP in two main respects:

- The Marine NARP is concerned with the marine-terrestrial interface and coastal ecosystems.
- Changes to terrestrial ecosystems that result in increased erosion or changes to freshwater productivity will affect coastal and marine ecosystems.

Both sea level rise and increased storm activity will have significant impacts on the marine-terrestrial interface and coastal ecosystems, including the condition and distribution of salt marshes, mangroves, estuaries, beaches and dunes. Higher sea levels will cause coastal erosion and the landward migration of marine ecosystems such as salt marshes and mangroves, at the expense of other coastal ecosystems. There is also growing evidence that resilient coastal ecosystems such as mangroves and saltmarsh can play a role in the protection of coastal infrastructure. The marine NARP deals with coastal issues, but the Terrestrial Biodiversity Plan should also ensure that these key issues are addressed.

Primary Industries – Primary industry and natural systems often compete for the same resources, namely land/habitat and water. Without careful management, climate change will intensify this conflict as agriculture seeks to relocate to regions of reliable rainfall. Relocation of cropping enterprises to higher rainfall regions may lead to habitat destruction and loss of terrestrial biodiversity if these relocations take place without careful management. This management should aim to utilise existing farm land, avoid or minimise any land clearing, ensure that control measures are in place for weeds and pests and that nutrient run-off into waterways is avoided or minimised. In addition, where marginal agricultural land is abandoned, conservation resources may be diverted to stabilise or rehabilitate degraded areas. Motivated by the emergence of carbon markets under an emissions trading scheme, carbon farming is likely to become more widespread in Australia. These initiatives will need careful design to avoid negative impacts on biodiversity and to maximise potential conservation benefits.

Disaster Management and Emergency Services – Natural systems are especially vulnerable to the introduction and spread of invasive species following damaging natural events such as bushfires or cyclones. A key recommendation of the Biodiversity Advisory Committee's 2008 Climate Change and Invasive Species report was that policy frameworks be developed that anticipate the invasive risks posed by cyclones, floods and other extreme events. It suggested that scenario planning be used to predict the outcomes of different events on different regions, and that planning activities consider which actions have the potential to promote invasions after extreme events, and generate plans to mitigate the risks. Emergency plans for cyclones and floods should include protocols for preventing the spread of weed seeds and other invasive organisms during rescue and clean up operations. Pest hygiene practices of fire crews, especially when operating in national parks, are also relevant here.

Settlements and Infrastructure

Current patterns of population growth and urbanisation will increase demands for development of areas that currently serve as habitat. This will exacerbate climate-related pressures on those habitats. Population shifts to less populated parts of Australia in response to a changing climate may lead to habitat disturbance in new locations.

Demographic shifts will require both significant infrastructure and natural resource management planning. Existing infrastructure such as roads, powerlines and pipelines already fragment habitats and may impede the latitudinal or altitudinal movement of species shifting distributions in response to warmer temperatures. Synergies may be exploited where, for example, infrastructure renewal projects concerned with adaptation of the built environment, can facilitate the movement of species through the installation of wildlife corridors or under-/overpasses.

Fire influences Australia’s biodiversity both positively and negatively, and also poses a great risk to human health, settlements and infrastructure. Worsening fire conditions due to drier and hotter summers, combined with ongoing development of the peri-urban environment, will require adaptation options that protect the built environment while safeguarding conservation values.

In the context of this research plan, adaptation research in biodiversity conservation needs to be informed by the adaptation needs of the settlements and infrastructure sectors and vice versa.

Social, Economic and Institutional Dimensions

Responding to the potential impacts of climate change on terrestrial biodiversity will require changes to biodiversity management practices, including an extended role for conservation on private land. Climate change will also cause human population movement and changes to regional socio-economic trends which will affect regional conservation requirements and efforts. The institutional and regulatory arrangements that will be needed and the best mix of economic incentives will be addressed broadly in the Social, Economic and Institutional NARP, but specific issues for terrestrial biodiversity are considered specifically in this plan.

Human Health

As terrestrial ecosystems respond and adapt to the changing climate, so will the complex interactions between disease-causing organisms, vectors and human hosts. The National Adaptation Research Plan for Human Health and Climate Change recognises links with terrestrial biodiversity, especially with regard to vector-borne diseases such as Ross River virus, Barmah Forest virus and environmental pathogens such as *Leptospira*.

Loss of terrestrial biodiversity may also negatively affect the mental and physical health of Indigenous people in remote settlements and those maintaining a close spiritual connection to the land. For example, the demise of culturally significant animal or plant species may cause significant mental distress. Likewise, any shortage of important bush tucker species will further impoverish the diet of remote communities and therefore have negative health outcomes.

1.6 Criteria for setting research priorities in National Adaptation Research Plans

The NARPs developed under the auspices of the National Climate Change Adaptation Research Facility identify critical gaps in the information needed by sectoral decision-makers, set research priorities based on these gaps, and identify capacity that could be harnessed to conduct priority research.

Critical

1. **Severity of potential impact or degree of potential benefit**

   What is the severity of the potential impact to be addressed or benefit to be gained by the research? Potentially irreversible impacts and those that have a greater severity (in social, economic or environmental terms) will be awarded higher priority.

2. **Immediacy of required intervention or response**

   Research will be prioritised according to the timeliness of the response needed. How immediate is the intervention or response needed to address the potential impact or create the benefit? Research that must begin now in order to inform timely responses will receive a higher priority than research that could be conducted at a later date and still enable a timely response.

3. **Need to change intervention or practicality of intervention**

   Is there a need to change the intervention used currently to address the potential impact being considered. If yes, what are the alternatives and how practical are these alternate interventions? Does research into the potential impact of the intervention being considered contribute to the knowledge base required to support decisions about these interventions? Research that will contribute to practicable interventions or responses will be prioritised.

Desirable

4. Potential for co-benefit

Will the research being considered produce any benefits beyond informing climate adaptation strategies?

5. Potential to address multiple, including cross-sectoral, issues

Will the research being considered address more than one issue, including cross-sectoral issues?

2 Terrestrial Biodiversity and Climate Adaptation

2.1 The need for adaptation

Anthropogenic climate change is moving the Earth system out of the envelope of natural variability that the world's ecosystems have experienced over at least the past two thousand years. The present concentrations of CO_2 in the atmosphere are higher than at any other time in the past 650,000 years, and the current atmospheric CO_2 concentrations (>385 ppm) are far above the approximately 300 ppm found during the warm period just prior to the most recent glacial period (IPCC 2007a). The current concentrations of CO_2 also far exceed pre-industrial values, rising from 280 ppm in 1750 to about 385 ppm in 2007, with 70% of the increase occurring since 1970 (IPCC 2007a).

The rate of increase in CO_2 concentrations since the Industrial Revolution is unprecedented in the past 10,000 years (IPCC 2007a). CO_2 concentrations are rising faster than indicated in all previous scientific projections, including those published by the IPCC in 2007 (IPCC 2007a), having almost tripled since the 1990s from 1.1% pa to 3.1% in the 2000s (Canadell *et al.* 2007; Raupach *et al.* 2007). This suggests that the mean projected temperature increases published in that report are highly likely to be underestimates, assuming that the relationship between increases in CO_2 concentration and temperature increases observed over the past two decades continues into the future.

Climate change will affect all sectors, but natural ecosystems (terrestrial, freshwater and marine) are considered to be most vulnerable for two main reasons:

1. the rate of climate change is likely to be too rapid for most species to adapt by genetic change, except possibly for some species with rapid life cycles;
2. climate change is happening in the context of many other pressures on natural systems including habitat loss, degradation and fragmentation, invasive species, over-harvesting and over-allocation of water resources. Climate change will interact with, and exacerbate, many of these other stresses.

The Millennium Ecosystem Assessment (2005) warned that climate change is likely to become the dominant direct driver of biodiversity loss by the end of the century. There is accumulating evidence that climate change is already affecting the distributions, life cycles, genetic makeup, physical characteristics, and populations of species.

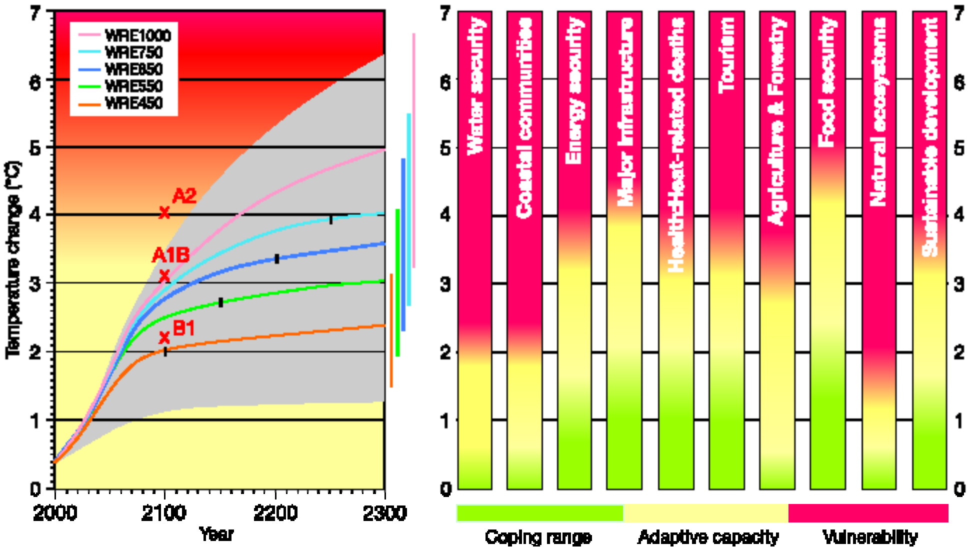

Figure 1) *Vulnerability to climate change aggregated for key sectors, allowing for current coping range and adaptive capacity. Right-hand panel is a schematic diagram assessing relative coping range, adaptive capacity and vulnerability. Left-hand panel shows global temperature change taken from the TAR Synthesis Report (Figure SPM-6). The coloured curves in the left panel represent temperature changes associated with stabilisation of CO_2 concentrations at 450 ppm (WRE450), 550 ppm (WRE550), 650 ppm (WRE650), 750 ppm (WRE750) and 1,000 ppm (WRE1000). Year of stabilisation is shown as black dots. It is assumed that emissions of non-CO_2 greenhouse gases follow the SRES A1B scenario until 2100 and are constant thereafter. The shaded area indicates the range of climate sensitivity across the five stabilization cases. The narrow bars show uncertainty at the year 2300. Crosses indicate warming by 2100 for the SRES B1, A1B and A2 scenarios (Hennessy et al. 2007).*

2.2 What do we mean by "adaptation" in the context of terrestrial biodiversity?

Two main types of adaptation may be distinguished: *autonomous* and *planned*.

(i) Autonomous adaptation

Responses to climate change within terrestrial ecosystems may occur autonomously, through natural physical and biological processes. At a species level, adaptation responses may occur *in situ*, or involve dispersal to new locations. There are four main types of *in situ* responses that may allow an individual or species to meet the challenge of environmental change without dispersing to a new site: (i) *acclimation,* the gradual habituation of an organism to a slowly changing environmental condition by simple physiological or morphological means, (ii) *behavioural change,* including alteration of the use of microhabitat, (iii) *phenotypic plasticity,* the range of variability shown by an organism's phenotype in response to environmental changes and (iv) *genetic adaptation,* in which natural selection among individuals by means of differential survival and/or reproduction alters the relative frequencies of particular characteristics change within the population. Genetic change in response to climate change will be more likely in species with short generation times and large populations. These four types of response are not mutually exclusive.

In addition to *in situ* responses, some species may adapt to climate change by dispersing to new locations. Changes in species distributions can occur in one or both of two ways: (i) in mobile species, changes in geographic range can occur when an environmental change (such as an increase in temperature) cues individuals to disperse to new, more suitable areas and (ii) gradual shifts in the boundaries of species ranges as conditions become more or less environmentally suitable.

Collectively, the combination of these responses amongst individual species will result in changes in structure and composition of ecological communities and ecosystems. Changes in the species composition of ecosystems will affect their provision of services.

(ii) Planned adaptation

Planned adaptation refers to specific decisions and actions taken by humans to modify current practices, with the aim of enabling species and ecosystems to successfully respond to the changing climate. Adaptation by the biota can be facilitated publicly or privately, by individuals or groups. For example, networks of protected areas may facilitate migration and species re-distribution; restoring habitats essential for important life stages may increase biological robustness to climate variability and change. The information needs for effective planned adaptation are the focus of this Plan.

Even more direct action may take the form of engineered strategies designed to increase the ability of species or other ecosystem components to cope with or be more resilient to climate change. Examples might include assisted colonisation of species considered at extreme risk of extinction. There is considerable uncertainty about the effectiveness of such direct interventions and experience shows that they may come with significant risk of unintended or unanticipated consequences.

Projections of climate change become increasingly uncertain at more local scales and it is therefore difficult to predict specific impacts with certainty. Rather than contemplating all possibilities and attempting to design a myriad of targeted adaptation actions, a more effective strategy will be to enhance the resilience and flexibility of both social and ecological systems, providing them with the capacity to adapt autonomously or to respond as likely changes become more clearly understood. Building general resilience by promoting diversity and flexibility within ecosystems, and by reducing the impacts of other stresses, is generally advocated in preference to specific, prescribed adaptation measures targeting specific impacts of unknown likelihood.

2.3 The value of terrestrial biodiversity

Adaptation strategies that promote the maintenance of terrestrial biodiversity in the face of climate change have two important benefits: (i) protection of ecosystem services and (ii) contribution to adaptation in other sectors, known as “ecosystem-based adaptation”.

2.3.1 Ecosystem services

Climate change will affect the goods and services provided by terrestrial biodiversity and ecosystems to human systems. There are three main categories of ecosystem service:

- Supporting services such as nutrient cycling, soil formation and primary production;
- Provisioning services, including food, fresh water, wood, fibre and fuel; and
- Regulating services for climate, flood, disease and water purification.

While food, fibre and wood are ecosystem goods in their own right, their provision in turn depends on supporting ecosystem services and functions such as soil fertility, nutrient cycling and pest control.

The relationships between production systems, land capability and climate are relatively well understood in Australia because the success of our agricultural systems has relied on such knowledge. Human systems and economic sectors that are particularly dependent on functional, productive and sustainable terrestrial ecosystem services and biodiversity include:

- primary industry and forestry
- the catchment management and water supply sector
- tourism
- Indigenous communities
- the pharmaceutical and engineering sectors which harness biological compounds and technologies.

Primary industry in Australia is driven by economic imperatives that result in low cultivar/breed diversity and reduced genetic diversity. The loss of genetic and species diversity of crops and livestock is a threat to long-term food security. International efforts are being made to preserve as much agricultural diversity as possible, for example in seed banks. Conservation of global livestock genetic diversity, although of equal importance, has not been as successful. Primary industry in Australia has an opportunity to contribute to long-term food security through both production and by investigating the opportunities for maintaining and developing genetic diversity in crops and livestock to provide resilience to the impacts of climate change.

The tourism industry in Australia is heavily dependent on natural environments with high iconic or biodiversity values, such as the Queensland Wet Tropics, Kakadu National Park, the Kimberley, karri forests and the Gondwana Rainforests of Australia (SE Qld and NE NSW).

Indigenous people have a deep traditional and spiritual connection with country. Many Indigenous communities obtain traditional foods, fibre and other biomaterials from the bush to meet their nutritional, physical and spiritual needs, and sustain economic activities.

Modern bio-prospecting involves the sampling of wild organisms and the testing of compounds derived from these organisms for their medicinal, chemical or perhaps technical properties.

2.3.2 Ecosystem-based adaptation

Maintaining biodiversity and healthy ecosystems is also a critical component of adaptation to climate change in other sectors. For example, in the face of sea level rise and the projected increase in extreme events such as storm surges, healthy coastal wetlands can provide protection for human infrastructure. Research into how biodiversity can contribute to societal adaptation to climate change is in its infancy in Australia. However there is growing evidence in the international literature that incorporating ecosystem management into broader cross-sectoral adaptation policies as a complement to technological and structural measures, is likely to result in more sustainable adaptation in many sectors.

3 Ecological context of this Plan

The adaptation research needs outlined in this Plan have been developed in light of the broader ecological context for Australian terrestrial biodiversity. This context is summarised briefly below, but is elaborated in more detail in the Biodiversity Vulnerability Assessment (Steffen et al. 2009). A summary of key messages and policy directions emerging from the BVA is shown in Appendix 2

3.1 Significance of the rate of environmental change

As noted above, the *rate* of climate change experienced currently, and that expected over at least the next century, is almost certainly unprecedented since the last massive extinction event 60 million years ago. The incidence and severity of extreme events is expected to increase even more rapidly than mean climatic conditions. The current and expected rate of change is almost certainly too rapid for many (perhaps most) species to adapt to new environmental conditions via genetic change, particularly long-lived species that reproduce slowly. Such dramatic rates of change have prompted suggestions that the Earth will experience a massive wave of extinctions this century, with rates of species loss about 1000 times background levels.

3.2 Climate change in the context of other stresses

Climate change is a new stressor that adds to, and interacts with, a range of existing stressors that have already significantly changed and diminished Australia's biodiversity. Viewing climate change in isolation from other stressors, is misleading and counterproductive in terms of policy and management. The most important proximate drivers of change in Australia's biodiversity that will interact with climate change include loss and fragmentation of habitat associated with land clearing, redistribution of water resources, and changes in nutrient distributions in soil and water, changes in fire regimes, mining, introduction of exotic species and salinity. Several other drivers that act mainly through socio-economic forces and institutional arrangements at a national and a global level and which have indirect impacts on organisms include human population growth, global markets and globalization, primary industries, and perverse incentives including subsidies for fisheries, forestry, land clearing, agriculture, and grazing.

3.3 Uniqueness of the Australian biota

Adaptation planning to minimise future losses of biodiversity needs to take account of the unique features of the Australian biota, the organisation and structure of Australian ecological communities, and of biological and climatic uncertainty. Research to assist adaptation of biodiversity in the face of climate change should be particularly responsive to the way that these features affect how impacts play out in Australia, since these are the effects for which we are least likely to be able to draw on overseas research. The most important features of the Australian continent and its biota relevant to adaptation planning for climate change are outlined below.

(i) *Biogeographic history and degree of endemism:* The Australian continent has been isolated from other land masses for over 45 million years. Today, Australia has 7-10% of all species on Earth and the majority of these species occur nowhere else, with some groups having 80% or higher levels of endemicity. Many endemic species are isolated, are already considered threatened, and/or have small geographic and climatic ranges, factors which indicate high vulnerability to rapid climate change.

(ii) *Aridity and rainfall variability:* Australia’s climate is characterised by a high degree of variability, with extremes in temperature and precipitation (droughts, floods and storms). These episodic climate events are extremely important in driving the structure and function of Australian ecosystems. If Australia’s climate becomes drier, the pre-adaptation of some species to high aridity environments could bestow a degree of resilience not found in many other parts of the world suffering similar drying conditions. However, it is also likely that many species are operating close to their physiological limits and therefore even small changes could have large impacts.

(iii) *Infertile soils*: Australian soils are some of the oldest and most nutrient-poor in the world. Nutrient limitations may constrain the responses of many Australian vegetation types to the fertiliser effect of rising atmospheric CO_2 levels. In addition, significant soil changes over small distances and highly specific soil and nutrient requirements could limit establishment opportunities for many species dispersing to more climatically-suitable areas.

(iv) *Flat topography*: Australia has limited topographic relief with less than 5% of the land more than 600 m above sea level. Lack of topographic variability will limit the opportunity for many species to migrate to higher elevations as

temperatures increase. This could require species in flat areas to migrate long distances if they need to stay within a narrow climate envelope.

(v) Role of fire: The combination of aridity, high temperatures and sclerophyllous vegetation means that fire plays an important role in determining community composition and function in all but the wettest areas. Climate-associated changes in fire regimes may be one of the most significant drivers of ecosystem change in many regions.

3.4 Climate change and terrestrial biodiversity: assessment of vulnerability

The impacts of climate change on biodiversity will be both direct (such as effects of changes in temperature, rainfall and atmospheric CO_2 concentration) and indirect (impacts on ecosystem processes such as fire, or on interactions between species and consequent effects on communities and ecosystems).

Changes in the physical environment affect physiological processes in plants and animals such as respiration, photosynthesis, metabolic rate, and water use efficiency. Individuals may also respond to environmental change by altering their behaviour or the timing of life cycle events (phenology) such as flowering, dispersal, migration and reproduction. All organisms are able to cope with some degree of variability in their environment, and to maintain homeostasis and reproduction within the bounds of that variability. Beyond some physiological threshold, however, responses change quite dramatically and death may result.

The response of plants to rising CO_2 will also be important, especially coupled with warming and/or altered rainfall patterns, as any differential responses between plant species could have large secondary impacts on plant community structure, net primary productivity, animals that use plants as habitat or food, and even nutrient cycles in ecosystems.

Individualistic responses of species to climate change will result in changes to both the structure and composition of many communities and ecosystems. Differential rates of dispersal as climate zones shift, for example, mean that ecological communities will not “move” as units across a landscape. With the current rapid rate of climate change, novel combinations of species will appear in the future, creating communities that have no present day analogue. Flow-on effects to ecosystem services on which humans depend are potentially significant. Such ecosystem services include provision of food, fibre, and water; pollination; pest control; purification of water; and biogeochemical (nutrient) cycling. The impact of climate change on the provision of ecosystem services is largely unknown. Many of the changes are expected to be non-linear and there may be thresholds where rates of change alter or even jump to different levels. This behaviour inherently increases uncertainty in predictions.

Responses of species to rapid climate change will vary, with both winners and losers. Adaptation management of species requires objective prioritisation based on assessment of their relative vulnerability in order to allow the efficient allocation of management resources and avoid wasting resources on species that can adapt on their own. Assessing the relative vulnerability of an individual species requires consideration of both the sensitivity of the species and the degree of regional and microhabitat exposure, followed by consideration of the ability of the species to adapt via evolutionary or ecological shifts:

(i) *Species traits including life history and geographic range characteristics:* These traits include the ability to disperse and thus migrate to more suitable locations, and the presence of opportunistic reproductive strategies.

(ii) *Degree of exposure:* The degree and rate of climate change in the future will vary from region to region. Relatively more warming is expected for the inland, compared with coastal regions. Within a habitat, some species may have more opportunity than others to take advantage of differences in microhabitats. Regions with high topographic relief, such as dissected plateaus with cool, moist gorges, may continue to provide refugia for some species as the regional climate warms. Species restricted to high elevations or high latitudes, to low-lying islands, or to ephemeral habitats such as intermittent streams and inland wetlands will be particularly at risk in the near term.

(iii) *Adaptive potential:* Some species may adapt genetically, or have sufficient phenotypic plasticity to tolerate new conditions *in situ.* Others may be able to cope, at least in the short- to medium-term, by altering their use of microhabitats, or by shifting their geographic range. For mobile species physically capable of travelling some distance to more suitable areas, their capacity to do so will depend on the "permeability" of the landscape matrix between suitable habitats. Some species, although capable of shifting their range, will be prevented from doing so by physical barriers such as coasts or extensively cleared land. Species that are currently restricted to Tasmania, southern parts of the continent, isolated lakes and waterways or to mountaintops, will simply have nowhere to go.

Further detail about the potential vulnerability of species and ecosystems may be found in Steffen et al. (2009)

3.5 Complexity of potential impacts

Predicting the *future* effects of climate change on Australia's terrestrial biodiversity is complicated for a number of reasons:

- Climate change will interact with other drivers that are currently affecting biodiversity.
- Responses to physical and chemical changes will occur at the level of the individual, and be reflected in population dynamics of individual species. The component species or functional groups within an ecosystem will therefore not respond as a single unit, and interactions among species will have the potential to modify outcomes, sometimes in unpredictable ways.
- Many properties of biological and ecological systems are inherently difficult to track. For example: (a) a change in the average value of a continuous environmental variable (such as temperature) may not be as important biologically as a change in variability or extremes of that variable and (b)

responses of biological systems may be non-linear, with thresholds or "tipping points" not yet identified.
- Basic knowledge about limiting factors, genetics, dispersal rates, and interactions among species that make up Australian communities and ecosystems is generally lacking.
- Management actions taken to adapt to and/or mitigate the impacts of climate change on human systems could have further adverse impacts on biodiversity (see below).

The current state of knowledge about future climate conditions, species climate dependencies and thresholds, and climate-ecosystem interactions will only support the most general guidance on potential vulnerability, adaptation responses and management initiatives. This inadequacy highlights the need for better understanding in key areas. Pervasive uncertainty in detailed climate scenarios, biotic responses to them, and feedbacks from human land use and management will be an unavoidable feature of the next few decades, so management and policy decisions must be undertaken in the face of this uncertainty. There will need to be a strong focus on "learning by doing" through adaptive policy and management experiments. This will require approaches that employ risk management and robustness analysis rather than waiting for certainty. In many cases, adaptation actions will be aimed at managing for transformation, whilst minimising loss of biodiversity and ecosystem function.

3.6 Observed trends: species and communities are already responding to climate change

Australian average temperatures on land have increased 0.9^{o}C since 1950, although with significant regional variations (CSIRO/BoM 2007). Minimum temperatures have been increasing faster than maximum temperatures. The rate of warming is accelerating, with twice the warming experienced since 1950 as in the first half of last century (CSIRO/BoM 2007). 2005 was the warmest year on record in Australia, with an average temperature over 1.0^{o}C above the long term mean. 2007 was the sixth warmest year on record, and the warmest ever in southern Australia; 2008 was the 14th warmest year, 0.41°C above the 1961-90 average. The frequency of extreme hot and cold temperatures has also been changing. There has been an increase in hot days (over 35^{o}C) since the late 1950s, as well as an increase in hot nights (>20^{o}C) and a decrease in cold days (<15^{o}C) and cold nights (<5^{o}C).

Concomitant changes in intensity, distribution and seasonality of rainfall, snow cover and precipitation run-off, increasing acidity of oceans and changes in extreme events such as floods, droughts and fire have also been documented.

On other continents, particularly in the northern hemisphere, the availability of long-term biological datasets has enabled the extensive documentation of recent climate and biological trends. The clearest evidence for such changes comes from observations of phenology (mostly advances in life cycle events) and geographic range shifts (mostly polewards and to higher elevations). Expansions at the colder edges of ranges appear to be occurring more rapidly than retractions at warmer edges. It is not yet clear whether this is just a lag effect (colonisations occurring faster than local extinctions), or because minimum temperatures in many regions are increasing faster than maximum temperatures, or simply because instances of colonisation are easier to observe than confident detection of local extinctions. There is also evidence that some organisms are responding genetically to the strong selective pressures imposed by climatic changes.

To the extent that similar organisms respond to climate change in similar ways in Australia, we have confidence that many changes in species' life cycles and distribution recently observed in Australia can also be attributed to climate change, at least in part. Many of these changes are likely to have significant non-climatic causes and the precise role of different factors may continue to be almost impossible to quantify in most cases. Nevertheless, an increasing number of the changes in Australian biodiversity documented in recent times are consistent with changes which would be anticipated from recent changes in climate conditions, mainly in temperature and rainfall. Most of the recently observed changes in biodiversity have been at the species level, due partly to the visibility of larger mobile species such as birds, and partly to the nature of biological organisation itself. "Fast" processes such as dispersal, migration, and population growth in small organisms will be more obvious in many species. Greater time lags are predicted in responses of "slow" processes such as vegetation change, reef building, or reproduction in large organisms. Some of the best documented changes observed in the terrestrial biota to date include: allele frequency shifts in wild populations of the fruit fly *Drosophila melanogaster*, equivalent to a 4^{o} shift in latitude (about 400 km) over 20 years (Umina et al. 2005); increased penetration of feral and native mammals to higher elevations in alpine and sub-alpine areas; range shifts and expansions of bird species to higher elevations or higher latitudes; earlier arrival and later departure times of migratory birds in Australian breeding and feeding grounds; and expansion of rainforest at the expense of eucalypt savanna woodland and grassland in Northern Territory.

What is most noteworthy about the observations both in Australia and elsewhere, is that in many cases, significant impacts are apparently occurring with *extremely modest increases* in temperature compared with those expected over coming decades.

3.7 Potential impacts on terrestrial biodiversity of mitigation strategies and adaptation in human systems

Management actions taken to adapt to and/or mitigate the impacts of climate change on human systems could have further adverse impacts on biodiversity. Biofuel production has considerable impacts on biodiversity when it results in direct conversion of natural ecosystems and indirect displacement of agricultural land into natural ecosystems. Birds can be affected by wind turbines through collision with turbine blades, displacement from migration routes, and direct habitat loss. The biodiversity impacts of hydro-electric dams include habitat destruction, terrestrial barriers to fish migration, reduced sedimentation and changes in flow-altering downstream ecosystems, and fish mortality in turbines. Changes in the nature, intensity, and/or geography of agricultural practices in response to the changing climate (such as intensifying development in the north west of the continent where rainfall is increasing) have the potential for negative biodiversity impacts. Land-based mitigation strategies such as monoculture plantations for carbon sequestration may also result in biodiversity loss.

Adaptation actions aimed at conserving biodiversity must take place in this context of changing human systems. In particular, the important role of ecosystems in the carbon cycle means that the potential exists to develop 'win-win' mitigation policies that are beneficial for both climate change mitigation and biodiversity.

4 Stakeholders and their information needs

The role of the National Adaptation Research Plan is to ensure that the policy, management and research communities, in government and in private capacity, are able to effectively collaborate in their efforts to manage Australia's terrestrial biodiversity through the impacts of unavoidable climate change.

A collaborative research approach, of which this Plan is the first element, will comprise national, state and territory, regional and local partnerships between researchers, policy analysts, managers, interested citizens and others. While all stakeholders need to be involved in a co-ordinated response to climate change adaptation, these stakeholder groups also have distinct roles:

- Only commonwealth agencies can ensure a comprehensive and effective national response to unavoidable climate change.
- State and territory biodiversity management agencies have a significant role in leading regional collaborations because they have both extensive on-ground presence and considerable management and research capacity.
- Local government plays a key role in forming and supporting local responses and collaborations.
- Citizens individually and in groups, private entities, regional bodies and peak organisations are able to provide insights which are cross-sectoral while frequently being focused on particular issues in particular places, and are able to mobilise considerable effort to respond to them.
- Researchers, in tertiary institutions, research organisations or government agencies or in a private capacity, provide a creative and committed resource for gaining the necessary data, knowledge and insights to underpin the activities of the other stakeholders.

Information needs for these stakeholders play out at two main scales – national-to-regional policy-making and planning, and regional-to-local implementation of conservation management. Understanding the details of local conservation management activities often plays an important part in informing the development of policy (for example, the questions around the possible invasive behaviour of native species locally will inform how the definition of weeds might need to be changed nationally), so research on management responses is often just as important for policy-makers as research directly on the policy instruments themselves.

In summary, there are three broad groups of stakeholders having specific information needs.

- Commonwealth agencies responsible for managing climate change impacts and protecting biodiversity values at the national scale, and state and territory government agencies responsible for managing climate change impacts and protecting biodiversity values at the sub-national scale, need information that will support sound policies, programs, plans and on-ground initiatives. Examples include information to project species adaptation and ecosystem resilience thresholds, future reserve system representativeness, and instances where establishing dispersal corridors or translocation initiatives would be effective. Information about potential indirect impacts from climate change and effective management responses will be required for changes to ecosystem processes such as changes to water availability, fire behaviour, salinity and other existing stresses to landscapes, ecosystems or species.

- Private organisations will have a similar hierarchy of information needs. National conservation, industry and community groups will require information which enables them to develop and evaluate policy proposals related to climate change adaptation. Natural Resource Management agencies such as catchment management authorities, regional or local community groups, businesses, and landholders, will require information that is biologically and geographically relevant to their responsibilities and interests. In many instances this information will be similar to that required by their state and territory government colleagues, though it will normally be more heavily focussed on supporting the inclusion of climate change risks in regional, local or site planning and on-ground projects. Local governments will have similar information needs.

- Research scientists need to understand the broader context in which their research activities occur, and particularly the potential applications of their research. This is also a critical requirement for research investors seeking to make informed decisions about allocation of research funding.

4.1 Information needs for national to regional planning and policy

Commonwealth decision-makers are responsible for compliance with international agreements, set national environmental policies and regulations, implement quarantine protection, manage national reserves, administer the species and other conservation provisions of the Environment Protection and Biodiversity Conservation Act (EPBC Act), and provide funding for sustainable land management under programs such as Caring for Our Country (see Appendix table 1). The agencies responsible for these activities also play a major role in promoting coordinated action across the nation.

State and Territory decision-makers set the policy, planning and regulation context for regional natural resources management, while agencies at this jurisdictional level directly manage biota and the conservation reserve estate, and monitor activities of other government agencies and industry, including those that operate via development assessment and environmental impact assessment processes. State and territory agencies also support public and stakeholder actions to achieve environmental outcomes.

State, Territory and Commonwealth cooperation, for example through the Council of Australian Governments (COAG) and its committees, is essential for coordinated adaptation climate change responses in the future. Effective involvement of other relevant stakeholders will also contribute to environmental objectives. Stakeholders concerned with regional, state and national scale biodiversity management include multi-sectoral stakeholders and land management groups such as NRM groups and Landcare and non-government organizations such as the Australian Conservation Foundation (ACF), World Wide Fund for Nature (WWF) – Australia, and the National Farmers Federation (NFF).

There are significant challenges for policy and management in re-defining goals for biodiversity conservation in the light of the impacts of climate change on species distributions, reviewing the compatibility of these with all current instruments and revising conservation and related legislation (BVA, Steffen et al. 2009). In governance terms, there is a need for better, faster-reacting and more flexible intergovernmental arrangements at state and national levels, coupled with flexible regional approaches which may require relinquishing more rights and resources to regions within effective coordination frameworks. There needs to be a strong emphasis on avoiding perverse outcomes from interacting instruments, including current and future international agreements. All these activities need to be undertaken on the basis of the best intersection between planning and policy research and the ecological understanding of the impacts of climate change.

Adaptation actions and decisions addressing impacts at the regional, state and territory, and national levels require specific research support, most of which will be common in nature to all parties though possibly required at differing scales.

The common information requirements are:

- Information that supports planning as well as observation, analysis and reporting of future policy and management initiatives which operate at a national, state or regional level.
- Information that supports the tuning of biodiversity-related policy instruments such as legislation and regulations as required by climate change impacts or risk management.
- Options for promoting investment in biodiversity protection under climate change conditions.

4.2 Information needs for regional to local conservation management

Much of the Australian landscape is managed at the spatial scale of communities and ecosystems, especially protected areas and catchments. Managers at this scale are frequently guided by management plans that focus on retaining present day natural communities and ecosystems. That is, plans are grounded either explicitly or implicitly in the notion that *resisting* change is desirable. Managers need information to guide more flexible approaches to maximise biodiversity and avoid negative consequences to ecosystem services. Policy analysts need sound science about on-ground management to understand how to set the appropriate policy context that will enable management to develop new objectives, including changes to ecosystem composition or vegetation type, even where such changes cannot be predicted with precision.

The complexities inherent in understanding and predicting the responses of communities and ecosystems to multiple interactive stressors mean that policy and management imperatives need to be oriented towards *enhancing the resilience* of communities and ecosystems, and in facilitating their capacity to transform into new assemblages and patterns of functioning. Some specific policy and management imperatives include maintaining well-functioning ecosystems and their ecosystem services, removing or minimising existing stressors such as land clearing, salinity, weeds and predators, and investigating options for assisting the transformation of ecological communities to minimise biodiversity loss as a result of climate change.

Shortcomings in available knowledge at the community scale flow directly from the limitations in our existing knowledge outlined above regarding species and population responses. Of particular importance is our lack of understanding of changes to trophic relationships within communities. Decision-makers also face constraints that are beyond their jurisdiction or control. For example, efforts to facilitate natural adaptation by allowing for migration of a particular ecological community may be constrained by planning regulations and private land tenure on neighbouring sites.

A greater understanding of how processes play out at a local scale will also inform national, state and territory policy stakeholders. Commonwealth Government agencies responsible for threatened species protection, the identification of invasive species (in terms of definitions such as the Weeds of National Significance), and the management of quarantine programs, need information about species-level responses to changes in climate. This type of information will also be required by state and territory government agencies responsible for threatened and other species protection and for undertaking or regulating ecological rehabilitation, by managers of repositories of biological material such as botanic gardens, germplasm stores and zoos and by non-Government conservation organizations with a focus on particular species, often iconic and charismatic vertebrates. Information about community or ecosystem scale impacts will be sought by managers of economically significant vegetation, including vegetation which contributes to agriculture, water security, forests and tourism. Agencies and organizations, including mining companies, tasked with restoration and rehabilitation, will seek information about climate change implications for population genetics and local adaptation in species currently or potentially used for restoration and rehabilitation of degraded lands.

The common information requirements are:

- Information that supports species, community and ecosystem conservation policy development and planning that takes account of climate change;
- Information that supports the protection of species or maintenance of ecosystem functions and services under climate change;
- Information that enables rehabilitation and similar activities to take account of climate change risks.

5 Policy needs and priority research topics

This Plan provides guidance for research programs aimed at supporting informed adaptation policy and management responses to present and future climate change impacts. It is critical now to avoid investments that will be futile or counter-productive as climatic changes continue, and to maximise potential benefits through early adaptation initiatives. In the medium-term (5 to 10 years), the research will also inform policy and strategic planning and will enable sound adaptation responses and observation, analysis and reporting systems to be conceptualised, tested, implemented and improved on a continuous cycle. Outcomes of these medium-term research activities will underpin Australia's climate change adaptation policy responses for several decades, and thus will be key elements of the nation's policy environment.

Because ecological systems are complex and dynamic, and because future social and climatic conditions cannot be predicted with precision, decision-makers and managers will inevitably need to participate in an action learning cycle, with thoughtful implementation of well-monitored management interventions at all scales. Active adaptive management uses information derived from targeted interventions to revise successive interventions and improve policy. This approach to combining research with management has been advocated for several decades as an approach to natural resource management that maximises the rate of learning and progressive improvement in management responses to problems. To support this, research needs to focus on contributing the knowledge for identifying management interventions that are most likely to yield useful outcomes, the current lack of which hinders confident management decisions and initiatives. Basic biodiversity science remains vital, but the priorities of specific programs will be established by considering whether enough is known to define appropriate adaptive interventions. Likewise, applied science should be focused on how to implement those interventions.

Figure 2 provides a conceptual outline of the iterative process by which research addresses all aspects of environmental management and identifies key research priorities through an active adaptive management approach.

1. An assessment of existing knowledge about an environmental system and its current management reveals both prospective environmental management options (policy, planning and on-ground initiatives) and also key areas of uncertainty about the environmental system being managed.
2. Where uncertainty about the environmental system is constraining the definition of effective management initiatives, basic research is undertaken to generate the necessary understanding.
3. Where the potential outcomes of management initiatives are uncertain, further research is undertaken into management options, leading to appropriate initiatives being identified.
4. Once there is sufficient understanding about the environmental system and the impacts of potential management responses to support management interventions, these are applied as well-controlled experiments.
5. Where observation, analysis and reporting practice and analysis is not well developed, as for emerging issues such as climate change impacts, research on observation, analysis and reporting is undertaken.

6. The effects of the management initiatives (on the environment being managed and on other relevant factors such as local employment) are monitored, enabling the value of the management actions to be assessed and also leading to a better understanding of the system being managed.

This iterative process leads to both an improved understanding of the environmental system and also of the various potential management interventions for it.

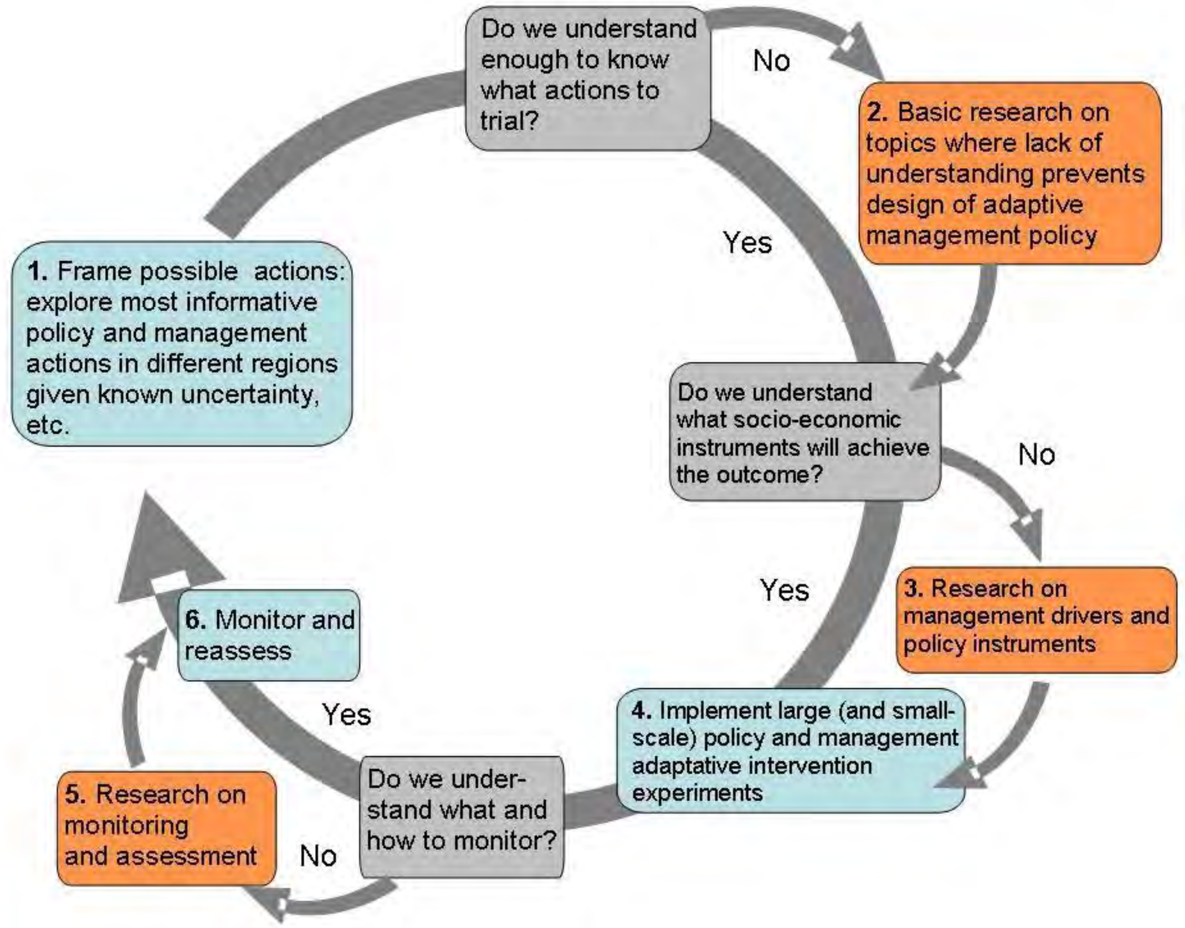

Figure 2) *The iterative process by which research addresses all aspects of environmental management and identifies key research priorities through an active adaptive management approach.*

While fundamental knowledge in many areas is still required, most of the research suggested below is focused on the knowledge needed for specific adaptation actions. This section is organised around four sub-themes, reflecting the scale at which information is required for management decisions to be made effectively. The first three sub-themes correspond broadly to three different spatial scales at which management decisions take place (i) National (ii) Regional (iii) Local. The fourth sub-theme includes questions relating to critical management issues at a species level. Many of the questions identified below, however, are relevant to more than one sub-theme and could easily be included in more than one section and likewise, there will be many stakeholders interested in research questions at multiple levels. Collectively, the overall aim of the research questions is to focus research effort on how we can incorporate risk and vulnerability assessment at all levels of environmental management with future climate scenarios, to support informed decisions about the timing and cost/benefit tradeoffs of adaptive management options. Under each sub-theme, several overarching policy questions are outlined, then a number of specific research questions or research strategies are described that will provide the information to advance the policy.

A research question which lies over all sub-themes concerns the capacity of Australian institutions to meet the challenge of managing the nation's natural heritage, conservation values and ecosystems as changes to climate parameters affect species and ecosystems in unpredictable ways. *Reducing society's vulnerability to the challenges of climate change requires proactive management and rapid institutional learning. Governance and management strategies and practices need to be regularly tested and adjusted in an adaptive management framework. Research must be focussed on critical issues for developing and implementing action under such a Framework (Figure 2).* This issue is shared with other sectors, such as marine resources and biodiversity, health, primary industries and water resources, and will also be addressed substantively within the Society, Economic and Institutional National Adaptation Research Plan.

5.1 National/continental scale issues

Continental-scale national policies will facilitate strategic climate adaptation initiatives that take account of the inherent uncertainties of future social and economic forces and options. For instance, changes in land use driven by factors unrelated to biodiversity that alter threatening processes may also create opportunities for new synergies between ecological protection and agriculture or water provision. To achieve effective outcomes at this scale, governance institutions need to incorporate effective communication and collaboration between jurisdictions and stakeholders. Key stakeholders at this scale are national and state policy makers and programme delivery agencies. They need to understand how policy goals and program design must change to recognise the impacts of climate change on biodiversity, and to handle the uncertainty of future climates.

The key issues at this scale are:

- Defining new conservation goals appropriate in a changing climate
- Designing the best institutional architecture for conservation
- Observation, analysis, reporting and evaluation.

5.1.1 Conservation goals for the 21st century

Question 5.1.1 *How will climate change affect existing conservation goals and how should changed conservation goals be promoted and achieved?*

A cornerstone of conservation policy both in Australia and elsewhere is to conserve species and ecological communities where they are thought to have occurred historically. In Australia, the notion of a species' historic range or the location of a community generally extends back to the time immediately preceding European settlement, 220 years ago. Under rapidly changing environmental conditions, this “preservationist” goal will become increasing difficult to achieve as moving climate zones lead to new environments and cause species to respond differentially. This research priority invites a reconsideration of the over-arching objectives of current conservation goals under climate change, driven by research into both scientific understanding of projected changes and community expectations of how we protect biodiversity.

The overall goal of conservation in Australia will continue to include (i) maintenance of well functioning ecosystems; (ii) protection of a representative array of ecosystems (iii) removal or reduction of existing stressors; (iv) building and restoration of habitat connectivity; and (v) identification and protection of refugia. (BVA SPM4). But as the climate changes rapidly, our traditional conservation focus on preventing ecological change will shift toward the management of change to minimize loss of biodiversity and maintenance of ecosystem function. The criteria of comprehensiveness, adequacy and representativeness (CAR) currently underpin the protected area estate and inform national approaches to conservation. The existing debate over the meaning and utility of CAR and other criteria will become more pressing under climate change.

Conservation goals will need to reflect public and private attitudes to conservation, but there is also a critical role for enhanced community appreciation of the importance of biodiversity conservation under a changing climate. An important component of this will be to better quantify and communicate the value of ecosystem services. Improved techniques for community education and attitudinal change are needed to provide the political impetus for enhanced attention to biodiversity conservation. The precise objectives of conservation initiatives will vary from region to region, and must also be informed by enhanced understanding of what is ecologically achievable. Conservation managers will need guidance on the most appropriate timing to move to new management goals and interventions at the same time as reinvigorating efforts to overcome existing stressors.

5.1.2 Institutional architecture

Question 5.1.2 *How can the existing Australian legal, policy and institutional architecture for land management and biodiversity conservation respond to changes in conservation goals caused by climate change?*

This question is aimed at ensuring that the current suite of policy instruments for biodiversity conservation, and the institutional arrangements by and within which they are deployed, are prepared for climate change. A systematic and comprehensive approach is required to enable a joint legal/ecological review of all policy instruments (legislation, regulations and institutional arrangements) at state and national levels. This will identify which tools remain appropriate under climate change, which are outmoded and which require modification (and how) to meet anticipated new biodiversity conservation goals in a changing world. This review would encompass issues such as reserve selection, the definition of invasive species, park management plans, EPBC Act declarations and actions, etc, as well as the handling of new priorities such as *ex-situ* conservation, species translocation, and eco-engineering.

There is current debate about what nationally consistent models of institutional architecture for conservation and land management at a regional to local scale are most likely to be flexible, adaptable and tuned to local/regional conditions. Research to develop these models is increasingly urgent under climate change, both for interactions among multiple scales of government, and for developing further models to support public-community-private partnerships for conservation. This must be informed by a better quantification of the value of private and community-based conservation actions, particularly by Indigenous people, in contributing to conservation goals under climate change.

A key new policy issue is the potential for synergies and perverse outcomes for biodiversity from new non-conservation legislation and regulations. A systematic and on-going review process is needed to maximise benefits and minimise future risks from these interactions, particularly for climate change mitigation-related instruments such as the proposed Carbon Pollution Reduction Scheme (CPRS) and any proposed adaptation instruments. Policy tools or market-based instruments (e.g. ‘biodiversity credits’) need to be identified that are capable of promoting synergies between climate change mitigation, adaptation and biodiversity conservation. (See question 5.2.3 for some on-ground parallels to this policy-level issue)

Adaptation policy and management initiatives require clarity as to what conceptual models will underpin large scale experiments designed to better inform future responses to climate change and other stressors.

5.1.3 Observations, experiments and analysis for adaptation management

Question 5.1.3 *What conceptual models and long-term observation systems are needed to support the design, analysis and assessment of active adaptive management and policy experiments at regional and national scales under climate change?*

Successfully responding to the complex and uncertain interactions of climate change, human activity and ecological functioning requires the application of active adaptive management and adaptive policy development approaches. Research must provide clarity on what conceptual models will underpin large scale adaptive experiments, and how they should be designed to better inform future responses to climate change and other stressors.

To be effective active adaptive approaches also depend on well-targeted observation, analysis and reporting systems, which provide information about how species and ecosystems are responding to climatic change, and how management practices are influencing these responses. Selection of the most cost-effective and information-rich natural systems to observe, analyse and report on is critical. Research must determine which species, habitats, ecosystem processes and ecological gradients are the best candidates for observation, analysis and reporting programs to assess the rate at which species, communities, ecosystems and landscapes are responding and to detect trends or thresholds that will trigger policy and management actions.

5.2 Regional issues

National and state policy makers set the context for regional planning, and are seeking an understanding of how planning at this scale should change to promote flexibility, and create effective landscape architectures for the future. Regional bodies such as catchment management authorities and industry groups require guidance on how their planning processes can allow for climate change. Climate change impacts at the regional scale are subject to the influence of many other sectors, such as catchment management, agriculture and forestry.

The key issues at this scale are:

- Maximising landscape resilience
- Climate interactions with other stresses
- Interactions between mitigation and adaptation
- Integration of biodiversity conservation with regional socio-economic trends

5.2.1 Landscape architecture / matrix

Question 5.2.1 *What designs of landscapes in intensive and extensive land-use zones confer maximum resilience for biodiversity in the face of climate change, including the uncertainty associated with future climate scenarios?*

Landscapes are being managed increasingly for multiple ecosystem services, such as for biodiversity conservation, carbon storage, and agricultural or forestry production. This management approach could yield either positive synergies or perverse outcomes as other sectors or ecosystem services respond to the climate change challenge through mitigation and adaptation. Climate change will force significant changes in the distributions and types of resource use, with substantial yet poorly understood consequences for environmental management.

Increased understanding of how landscape configuration could be modified and managed to optimise biodiversity conservation and promote productivity in other land uses such as agriculture is urgently needed. In particular, an important task is to determine how agricultural and other human uses of ecosystems can be managed to retain and enhance biodiversity in a changing climate, and what economic or policy instruments are needed to support this goal. Are there particular designs, or sets of design principles, that can be applied to groups of landscapes across Australia that maximise resilience for biodiversity?

Further research is needed to manage productive landscapes for multiple benefits. For example, as climate change favours agricultural pests, strips of native vegetation between fields may have the potential to provide refugia to birds and invertebrate biocontrol organisms that protect the crops and buffer the impact of increased pest activity. It is important to consider the interplay between crop and livestock diversity and other on-farm biodiversity in the context of a changing climate.

Changing landscape management objectives from maximizing production to developing ‘resilient’ landscapes will become increasingly important as climate change affects progress. In particular, a better understanding of the role of refugia in maintaining biodiversity during climate changes in the past, could inform contemporary and future management under climate change. In addition, there may be generalised approaches that can be developed for identifying refugia within landscapes, estimating their buffering capacity and planning protective management for multiple species.

The concept of “appropriate connectivity” is also important in a climate change context. Enhancing connectivity has become conventional wisdom for supporting biodiversity adaptation to climate change, and is frequently linked to other benefits such as carbon sequestration, salinity reduction, water provision and biomass production. While connectivity between habitats can allow adaptive movement of native species, it may also facilitate the spread of weeds, disease and fire. Decision-makers therefore need a more nuanced understanding of the potential benefits and problems likely to result from changes to connectivity, since this varies greatly amongst species and communities at local and landscape scales. A key task is thus to determine what types of landscape connectivity will have positive impacts for biodiversity conservation by facilitating adaptive capacity, while minimizing the risks (such as enhanced disease, weed or fire impacts).

5.2.2 Climate change interactions with other stresses

Question 5.2.2 *How will climate change interact with other key stressors such as fire, invasive species, salinity, disease, water extraction, hydrology, grazing and clearing and what are the implications for ecosystem structure and functioning?*

Many of the most significant impacts on species and ecosystems in the future are expected to occur as a result of the interactions of climate change with other threatening processes (BVA SPM2). Understanding such impacts will assist in allocating resources between mitigating existing stressors and implementing new adaptive strategies that specifically incorporate climate change as a factor.

For example, Australia’s agricultural regions and many conservation areas are already stressed from drought, rising water tables and/or salinisation. Competition for increasingly scarce water resources has become an important issue for biodiversity conservation. Climate change is further affecting surface and groundwater flows across the landscape. Thus climatic change impacts on hydrology will be a key factor for the ongoing health of many terrestrial and all aquatic ecosystems. However, it is important to know which regions are most likely to be affected by changes to water availability, in what way, and what management responses might be effective.

Management responses to climate change interactions with other stresses will be better focussed once the relative vulnerability of Australia’s ecosystems and regional vegetation types to such changes has been assessed, and the potential utility of broad scale conservation and restoration management and policy approaches have been tested and evaluated. Conceptual models, policy and management tools that take account of climate change will also be required.

5.2.3 Interactions between mitigation and adaptation

Question 5.2.3 *How can large-scale carbon mitigation initiatives such as revegetation and forest-related mitigation be designed to avoid adverse impacts on biodiversity and to maximise biodiversity conservation benefits?*

Carbon trading and offset schemes, which are probably the most common climate mitigation approaches in landscapes, offer an opportunity to promote sequestration in biomass while simultaneously contributing to the conservation of biodiversity under a changing climate. There is, however, a real danger of perverse outcomes, depending on the degree to which biodiversity conservation and adaptation issues are explicitly considered in the design of the sequestration scheme. All biomass sequestration/carbon offset projects should therefore be comprehensively assessed before they are approved, to ensure that such projects maximise biodiversity conservation and do not result in perverse outcomes.

For example, the importance of old-growth forests for both adaptation and mitigation needs to be recognised. Old growth forests have very high carbon stores as well as being very important for biodiversity conservation. In addition, long-lived trees, which are key structural elements in forest ecosystems, may be more resilient to climate change in the medium term than fast-growing regeneration or exotic species. A system of market-based instruments and other incentive approaches, such as biodiversity credits, could be established to ensure that adaptation to climate change is not adversely affected by mitigation activities. Research into the design of such instruments is urgently required.

Considering the mitigation-adaptation relationship from an adaptation perspective, properly designed adaptation strategies may produce co-benefits by reducing net greenhouse gas emissions through sequestration of carbon. Adaptation approaches such as the expansion of corridors, the building of appropriate connectivity, and the restoration of degraded ecosystems usually involve extensive revegetation. Research is required to ensure that the types of vegetation, including critical species such as long-lived trees, are appropriate for the location under changed climate conditions. The levels of ecotypic variation and genetic variability in species used in restoration programs will often also need to be considered.

5.2.4 Integration of biodiversity conservation with regional socio-economic trends

Question 5.2.4 *How can major socio-economic trends occurring in many regions of Australia contribute to effective climate change biodiversity adaptation responses?*

Innovative regional approaches to build adaptive capacity for more effective biodiversity conservation can take advantage of some of the major socio-economic trends sweeping across Australia (BVA SPM 4). For example, in parts of the south-east, an influx of retirees from urban areas to marginal agricultural areas provides new opportunities for integrating biodiversity values into these changing landscapes. More generally, integrated response packages – in terms of governance, education, investment sources and action plans for biodiversity conservation – can be tailored to the demographic, land use, climatic and socio-economic trajectories of specific regions around the country. These trends will need to account for potential population shifts driven by the impacts of climate change, especially in coastal regions.

The impacts of climate change on terrestrial biodiversity will have a range of cultural, social, and economic impacts. For Indigenous people the loss of biodiversity might mean the loss of connection to the land, the loss of culturally significant species including regionally important bush tucker, medicinal plants, art and craft resources, or the loss of important ancestral connections. Wildlife and nature-based tourism operators may have to change locations or realign activities to adapt to the changed visitation patterns caused by the impact on biodiversity. Biodiversity will also be affected by adaptation strategies pursued in other domains, such as bushfire control around human settlements, and changes to agricultural locations and methods, including abandonment of marginal agricultural land and increased demand for irrigation water.

5.3 Local land management issues

Local land and biodiversity managers, including park managers, farmers, tourism operators, and local community groups, often manage areas at the level of species, ecological communities and ecosystems. This scale and type of activity needs information that supports on-ground management at these levels. Understanding the way in which climate change is likely to affect the structure and functioning of communities and ecosystems will be important for effective management responses to be developed and implemented.

Changes in composition and structure will occur as species respond differentially to various aspects of climate change, in combination with other stressors. Gaining or losing even a single species could affect a community to varying degrees depending on the biological and ecological characteristics of the species and its role in the larger assemblage. Knowledge about what combinations of functional groups may be required to sustain a community and the associated ecosystem processes provides a basis for identifying indicators of change in response to rapidly changing climate. (BVA SPM4). However management planning will need to be predicated on an acceptance that most communities and ecosystems will change in response to climate change in ways that are difficult to predict with certainty.

Important ecosystem processes, such as production, nutrient cycling, decomposition, and energy transfers across trophic levels are highly dependent on both biotic and abiotic factors. These factors are influenced by climate change, such as temperature, water availability and substrate acidity (pH). Changes in these factors can change ecosystem functioning substantially.

Episodic disturbance events such as fires, cyclones, floods and droughts drive the structure and functioning of many Australian communities and ecosystems. Improved understanding of how climate change will affect the timing and intensity of such events is highly desirable, but given that such understanding will always be inadequate, designing management practices that are robust to this uncertainty is critical (BVA SPM4).

The key issues at this scale are:

- Identifying vulnerable communities and ecosystems
- Fire management under climate change
- Local protected areas management
- Whole-of-landscape management.

5.3.1 Identifying vulnerable communities and ecosystems

Question 5.3.1 *What are the costs and benefits of different climate change adaptation measures in key vulnerable communities and ecosystems?*

Most adaptation actions will be highly community- or ecosystem-specific. For example, suppressing fire in sensitive vegetation types in the alpine zone will require very different management strategies from those facilitating landward migration of endangered saltmarsh communities in the coastal fringe.

Ecosystem models are the most appropriate available research tool for exploring the extent of knowledge about the sensitivity of ecosystems to a changing climate interacting with other stresses (sensitivity studies). Examples of such models are gap models for forest dynamics and state-and-transition models for savanna dynamics. The approach is to vary key climate parameters systematically, in combination with other stresses (e.g., fire frequency, grazing pressure) to search for thresholds or other non-linear, indirect or unexpected effects. The research should be extended to address the implications for policy and management (most of which is implemented at a landscape scale) including cost/benefit analyses where possible.

While these models are useful for carrying out sensitivity studies, they need to be tested by experimental or observational data. Ecosystem-level experiments are notoriously hard and expensive to carry out, so a useful approach is to search for “natural experiments” – where observed changes in climate over the past half-century might be associated with changes in ecosystem structure and functioning. It is particularly important to search for natural experiments in which changes to other stressors have been measured or can be estimated, and their interaction with climate can be explored. Determining how communities and ecosystems respond to multiple disturbances could inform how these and other natural systems might respond to climate change.

5.3.2 Fire management under climate change

Question 5.3.2 *How should fire management adapt to climate change?*

Fire is a key determinant of community composition, structure and functioning in many parts of the continent. Quantifying the risk of changes in fire regimes to regional and local biodiversity values, and to ecosystems and their services, is essential. Climate change will affect all aspects of fire regimes both directly (via warming, and changes in precipitation) and indirectly (e.g. via changes in rates of fuel accumulation). Translating these projected system effects into more specific impacts on local fire regimes is difficult because of the inherent variability of these patterns, the uncertainties surrounding the impact of climate change on other critical drivers of fire events (such as droughts and ignitions), and the effects of increased CO_2 on vegetation. Given competing demands on resources, a pragmatic approach to this complexity is to embed climate change-oriented research within existing fire management programs. This would involve clearly defined premises based on current best knowledge, and well conceived observation, analysis and reporting , review, evaluation and reconceptualisation based on new data and improved understanding. Such an approach would also support another goal: to assess the capacity of current fire management frameworks and institutions to deal with uncertainties associated with climate change and to improve them where necessary. A cost benefit approach to evaluating differing management responses would help society decide how future fire risks should be managed, in light of likely greater large fire risk, impact on human health and other effects.

5.3.3 Local protected areas management

Question 5.3.3 *How can management of local protected areas incorporate and adapt to climate change?*

Incremental changes to climate parameters will result in incremental changes to local ecosystems and communities within the boundaries of the resilience of those entities. Once the limits of resilience have been exceeded, significant changes to ecosystem processes and community structure and composition are likely to result with small additional changes in climate. In such instances, adaptation responses will aim to *manage the affected areas for transformation from one ecosystem and community to another*, whilst minimising overall loss of biodiversity and ecosystem functioning.

This objective is in marked contrast to most current biodiversity policies, which are concerned with protecting existing biodiversity values and preserving current ecosystems and communities in their current form and location. It is necessary to better understand what policy guidelines can effectively support planning and management initiatives concerned with maintaining biodiversity values and ecosystem functioning while component species, and community composition in general, are changing in response to the unavoidable impacts of climate change. A specific issue that needs to be resolved is how the concept of an ‘invasive’ species might be redefined to deal with the reality that many native and introduced species will be moving around the landscape in response to the changing climate, and how this new concept might be applied in day-to-day planning and management for conservation.

5.3.4 Whole-of-landscape management

Question 5.3.4 *How can we better integrate conservation plans and actions across landscapes, incorporating protected area management, off-reserve conservation measures and other land-uses, to maximise biodiversity conservation benefits/outcomes under a changing climate?*

Climate change will affect the species, communities and ecosystems currently located within the existing protected areas system, and so will affect the conservation value of the system as it is currently constituted. Prior to European settlement and the resultant fragmentation and degradation of natural habitats, species could more readily migrate to suitable locations as local climate conditions became less favourable to them.

Australia’s protected areas system is already augmented with off-reserve conservation investment and initiatives. These and additional complementary measures are likely to become increasingly important as climate change affects biodiversity. More work will be needed to enhance these complementary measures, to ensure they are effective into the future under differing scenarios, including via planning that considers all dimensions of the landscape.

5.4 Managing key species

Climate change is altering population sizes, the timing of life cycles, the size, location and nature of geographic ranges, allelic frequencies within populations, and the intensity of interactions between species. The magnitude and speed of these changes in the future are uncertain. Fundamental understanding of what factors limit geographic ranges and population sizes, even under present day climate, is lacking for the vast majority of species. Further, it is likely that many of the most important impacts of climate change in the future will arise from indirect changes (such as the interaction between climate and exotic species, or habitat loss), rather than from direct physiological impacts (such as increasing temperature).

The primary challenge for decision-makers at the species and genetics level is to devise adaptation strategies that minimize loss of species and genetic diversity in the face of uncertainty about detailed responses. Research is needed that can assist them in making decisions with the best evidence available but which provides a buffer that allows for pervasive and irreducible uncertainty.

There are three key issues:

- Choice of species on which resources should be focused
- How to manage species at risk?
- How to manage problematic species?

5.4.1 Identifying key species

Question 5.4.1 Which species should be the focus of investment in climate change adaptation?

At all scales of management, certain species are of higher priority than others, whether threatened, threatening, key to ecological functioning, migratory, or charismatic to humans. Understanding how to identify these species and manage their future trajectories is a specific requirement of biodiversity management.

Detailed modelling of individual species responses to future climate change will not be feasible for all species. Therefore, research aimed at improving the level of generalization is critical for improved decision-making. Much of the research on potential climate change impacts in Australia has focused on climate envelope modelling, used to project likely changes in geographic range under future climate scenarios. While these modelling exercises have become significantly more sophisticated over the past decade, there are still limitations in their applicability and utility and a more multi-disciplinary approach is needed to extend their use. Functional frameworks that identify species characteristics to enable us to generalise about climate change responses for multiple species also need to be developed and tested.

Efficient prioritisation of the resources for adaptation management requires more robust, multi-disciplinary impact models that combine bioclimatic distributions, physiology, microhabitat bio-energetics, demographic and population viability, evolutionary potential, ecological plasticity, species resistance and resilience, and potential for successful adaptive management (Figure 2). Since targeted management of individual species is expensive, it is vital to have robust estimates of the cause and degree of vulnerability. We need information about which life history and other characteristics of species will enable us to make generalisations about the likely impacts of climate change, and the likely efficacy of alternative management options. In many assemblages there are known ‘keystone’ species that are sufficiently important for structuring communities where further research will be justified. Any assessment of impacts and design of adaptive management actions will need to consider the potential for threshold values where the impact of key species will have serious negative impacts beyond the species themselves.

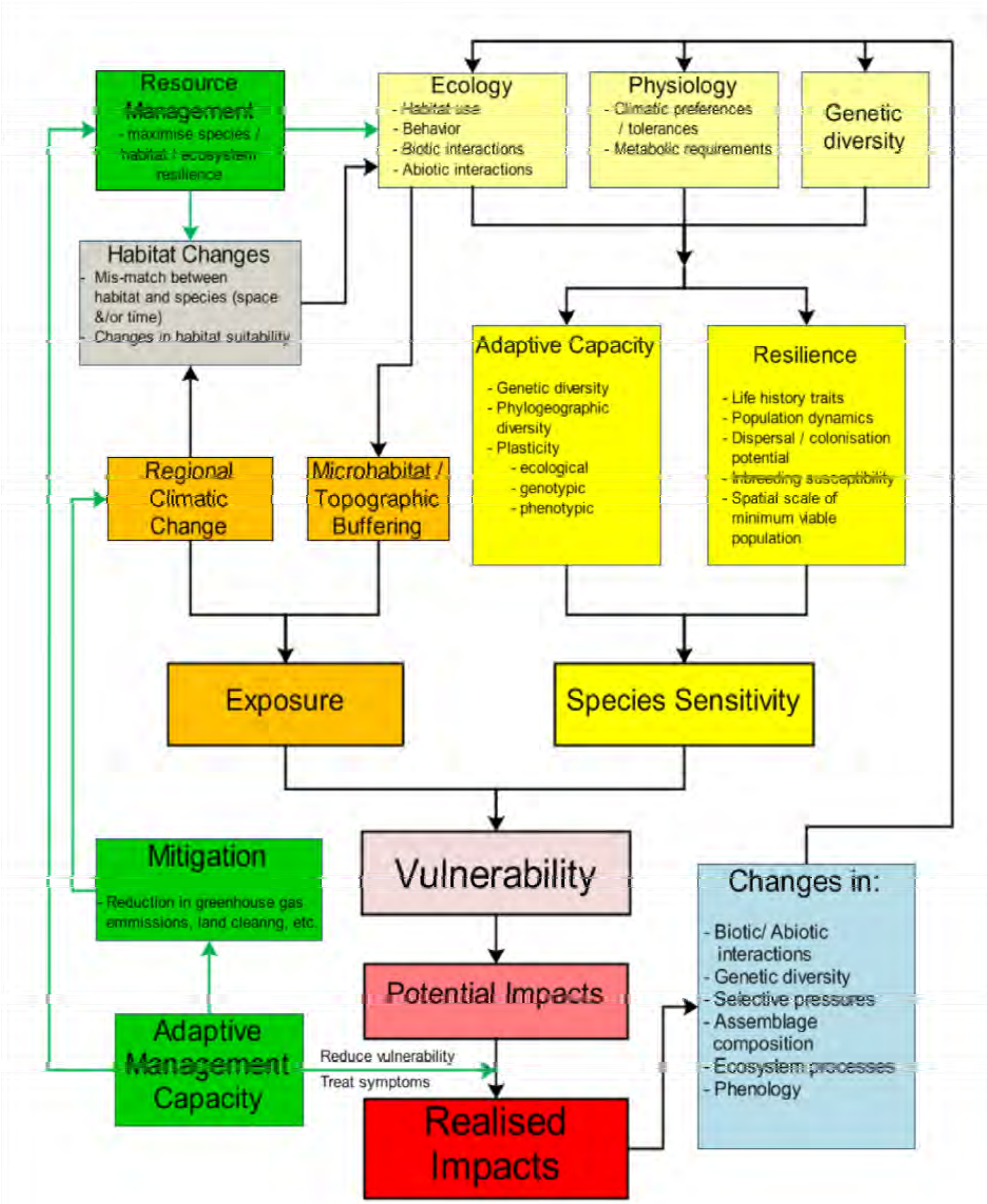

Figure 3: *Prioritising species based on relative vulnerability and adaptive potential: a general framework to assess the vulnerability of species to global climate change. Vulnerability is a function of the sensitivity and the exposure to the climatic change but mediated by the adaptive potential of the species (both ecological and evolutionary), the resilience of the species and the capacity for adaptive management to either reduce vulnerability, treat the impacts, mitigate regional exposure or maximise the system resilience via resource management to increase buffering or reduce other threats. Any realised impacts are likely to cause feedback effects due to changes in biotic/abiotic interaction, loss of genetic diversity and*

changes in/or loss of ecosystem processes. These feedback effects could result in cascading impacts through the ecosystem. All elements of this framework need to be considered in a comprehensive evaluation of vulnerability (Williams & Shoo et al. 2008).

Learning from the past: Understanding ancestral patterns of diversity is one of the keys to predicting responses of species to climate change. This is particularly important in regions where persistence has been a key feature of biotic responses to climate change because it indicates adaptation and/or phenotypic plasticity as the main mode of response to changing conditions rather than tracking of shifting climate zones. Research describing the characteristics of species that enabled them to cope with rapid or abrupt climate change in the past will help inform future adaptation options. This research will include studies of the effects of historical biogeography, species biological characteristics, paleo-modelling of habitats and distributions, phylogeography and evolutionary dynamics.

Means vs extremes: It is now widely acknowledged that in many cases, thresholds and extreme events may be much more important than gradual increases in climatic means. The limits of species distributions, and their population sizes, are frequently limited by climatic extremes, yet most modelling of species impacts under climate change uses climatic averages as input. Further, the role of biotic vs abiotic factors in determining species distributions and populations is still debated and few generalizations have been developed.

Future research needs to also focus on shifts in the spatial and temporal regimes (intensity and frequency) of extreme events (heat waves, fire, floods, drought, cyclones, storm surges) and how these events affect species distributions and populations. The importance of biotic interactions in determining species distributions and what characteristics can indicate susceptibility to impacts due to change in these interactions will continue to be an important research topic.

5.4.2 Protecting important species at risk

***Question 5.4.2** How will climate change affect current management actions for protecting priority species and what management changes will be required?*

Significant loss of biodiversity, at both the genetics and species level, is expected to result from climate change, with global species extinctions as the most extreme negative consequence. This will have economic implications for a range of industries, including agriculture, tourism and bio-prospecting. Each species will respond differently to the diverse impacts of climate change and conservation planners face the challenge of predicting multiple species trajectories.

The species at most risk of negative consequences in the short to medium term are likely to be those that have already suffered losses in range size or abundance due to other human-induced stresses. Many, though by no means all, of these species are listed as threatened under various types of conservation legislation in the states and territories, and at the federal level. Formal recovery plans are available for some of these species, listing specific conservation actions, although in many cases resources to fund such actions are lacking.

The protected areas system will remain the cornerstone of *in-situ* species management and conservation. Management of these areas, however, will need to be flexible in the face of differential responses to climate change of the species within these areas. In particular, understanding how some species will adapt to climate change by undergoing shifts in their geographic distributions will need to be part of the adaptive management cycle. Some species will move into reserves where they previously did not occur as part of this adaptive process. Research is needed to assist managers reassess what constitutes an “invasive” species and how to manage reserves to minimize biodiversity loss but facilitate adaptive transformation see also Question 5.3.3).

Ex-situ conservation strategies include translocation to potentially suitable environments or habitat that is suitable but currently unused by the translocated organism, germplasm storage and maintenance for future use and protection in herbaria and zoos. Conservation strategies such as translocation tend to be costly and without a high success rate. However, in certain circumstances (such as the use of isolated islands for conserving species that have gone extinct on the mainland), some types of *ex situ* conservation can be effective. We need further research to determine under what circumstances, in a climate change context, *ex situ* conservation will be effective and appropriate. Research could help develop nationally consistent protocols to determine the circumstances in which interventionist strategies such as translocation are justified, and for resolving potential conflicts with quarantine measures.

5.4.3 Problem species management

Question 5.4.3 *How will climate change affect current or potential problem species and what management responses will be required?*

Weeds and pests have significant impacts on both native biodiversity and commercially important species under current climatic conditions. Some introduced species are likely to expand in range and cause more damage in the future, whilst the impacts of others may decline. Further, some native species may become advantaged under climate change to the point where they are considered undesirable. On the other hand, some of the species that may become invasive as the climate changes may become important for the provision of ecosystem goods and services, for example, by taking the place of keystone species displaced by climate change. Another key issue is that some areas may be subject to invasion by multiple species, each of which requires its own control strategy.

Despite the existing levels of resources invested in efforts to control pests and weeds, these species continue to be a serious threat to biodiversity. Understanding the characteristics of those species that are going to become either greater or lesser problems in the future is therefore critical to prioritize management strategies and actions: what are those characteristics for each region, and how can we use this knowledge for management? Identifying invasion hotspots where intensive management may be applied to deal with multiple species in a cost effective way will also be important.

5.1 National/continental scale issues
5.1.1 How will climate change affect existing conservation goals and how should changed conservation goals be promoted and achieved?
5.1.2 How can the existing Australian legal, policy and institutional architecture for land management and biodiversity conservation respond to changes in conservation goals caused by climate change?
5.1.3 What conceptual models and long-term observation systems are needed to support the design, analysis and assessment of active adaptive management and policy experiments at regional and national scales under climate change?
5.2 Regional issues
5.2.1 What designs of landscapes in intensive and extensive land-use zones confer maximum resilience for biodiversity in the face of climate change, including the uncertainty associated with future climate scenarios?
5.2.2 How will climate change interact with other key stressors such as fire, invasive species, salinity, disease, water extraction, climate hydrology, grazing and clearing and what are the implications for ecosystem structure and functioning?
5.2.3 How can large-scale carbon mitigation initiatives such as revegetation and forest-related mitigation be designed to avoid adverse impacts on biodiversity and to maximise biodiversity conservation benefits?
5.2.4 How can major socio-economic trends occurring in many regions of Australia contribute to effective climate change biodiversity adaptation responses?
5.3 Local land management issues
5.3.1 What are the costs and benefits of different climate change adaptation measures in key vulnerable communities and ecosystems?
5.3.2 How should fire management adapt to climate change?
5.3.3 How can management of local protected areas incorporate and adapt to climate change?
5.3.4 How can we better integrate conservation plans and actions across landscapes, incorporating protected area management, off-reserve conservation measures and other land-uses, to maximise biodiversity conservation benefits/outcomes under a changing climate?
5.4 Managing key species
5.4.1 Which species should be the focus of investment in climate change adaptation?
5.4.2 How will climate change affect current management actions for protecting priority species and what management changes will be required?
5.4.3 How will climate change affect current or potential problem species and what management responses will be required?

Table 2: *Summary of research priorities*

6. Implementation strategy

This section highlights the broad strategy required for effective implementation of this National Adaptation Research Plan for Terrestrial Biodiversity. The section outlines the principles on which effective adaptation research should be carried out rather than a detailed blueprint for specific adaptation projects and programs. The research will be carried out by a wide range of researchers and institutions, often with their own funding sources and modus operandi. Nevertheless, this Research Plan aims to provide a framework for achieving a higher level of coherence and effectiveness in the implementation of adaptation research than would have been previously possible. Implementation of this research plan will be facilitated by the NCCARF- Terrestrial Biodiversity research network. The network brings together people from a wide diversity of sectors and disciplines relevant to adaptation of terrestrial biodiversity and provides a focus for integration, synthesis, review, communication and distribution of knowledge, experience, data resources and information. Wide involvement of researchers and stakeholders in the network will ensure that research priorities and actions are relevant and have the highest potential to produce successful adaptation outcomes.

Given that climate adaptation research is a new and challenging area of work, this NARP focuses on learning-by-doing, with ongoing assessment of success/failure and a redirection of research, as appropriate, based on these assessments. This section also provides a broad overview of the resourcing issues – both financial and human - that are likely to arise in the implementation of this research plan.

6.1 Research principles

6.1.1 Emphasis on local/regional scale – "bottom up" approaches

Adaptation to climate change is fundamentally different from the underlying physical climate science and to the impact studies derived from that science. Practical adaptation in the field must be driven by the key sector groups, peak bodies, natural resource-based industries, communities and regions that will contribute to the adaptation effort. In this Plan, the groups include those that traditionally have been concerned with biodiversity conservation, but also an increasing number of groups from other areas, such as agriculture, forestry, water management and tourism, whose activities affect biodiversity.

This bottom-up approach brings a broad community of both practitioners and scholars to bear on the climate adaptation problem, some of whom have not previously been connected with climate change research or with biodiversity conservation – business managers, farmers, natural resource managers, regional planners, water engineers, political scientists, lawyers, economists, sociologists, geographers, national park managers, foresters, conservation biologists, agricultural scientists, and so on.

Many of the researchers, communities, and organizations interested in biodiversity conservation operate at regional or local levels, and would rely on knowledge focused on the species/genetic, ecosystem/community and landscape scales described in the previous sections to implement adaptation actions. That said, policy development at the larger regional scales (often across state borders) and at the national level is central to dealing with climate adaptation, and research questions aimed at these scales must not be left behind in the emphasis on lower scales. An upwards and downwards exchange of information is required to deliver effective adaptation.

6.1.2 Participatory research and adaptive learning

To generate the new knowledge needed to support adaptation action, the various stakeholders concerned with biodiversity conservation need to be involved in the research itself, from the formulation of the questions to be addressed to the implementation of the results. Co-production of knowledge is a commonly used phrase to describe this type of research.

To ensure that research outputs are capable of easy and prompt up-take, it is essential that the needs of stakeholders be taken into account early in the design of adaptation research. Understanding the context and manner in which research will be used will help determine what modes of dissemination and uptake are most appropriate. Few stakeholders will access research through traditional academic publications, preferring instead toolkits, presentations and workshops, interactive web-based material, CDs and DVDs and so on (although traditional academic publication is still important in terms of quality control).

A critical starting point in deciding how best to disseminate information and promote uptake is to identify relevant primary and secondary end-users for particular research priorities. Some work, for example, may directly inform the operational decisions of biodiversity conservation agencies and organisations. Other research, however, may directly address policy-makers at regional and national levels, informing their choice of policy intervention.

6.1.3 Interaction with the global change research community

The approach to adaptation research described above, with its emphasis on experts in biodiversity conservation, terrestrial ecology and institutional design, is in strong contrast to climate impact research, which is often driven by climate scenarios and thus begins with change in the physical climate system. The bottom-up approach thus often demands new and different types of climate information, complementary to knowledge of potential impacts.

The risk management approach to adaptation drives the need for new types of climate information and other global environmental change. Climate risks are treated in the context of multiple other risks to an ecosystem, landscape, region, or the continent. The types of knowledge needed to evaluate the risks of a changing climate are driven by the practitioners themselves, and are created by collaborative research involving the stakeholders, ecologists, appropriate social scientists and economists, and the more traditional climate change research community.

6.2 Financial resources

Rather than developing a comprehensive and detailed budget to underpin the implementation of this Research Plan, this section sets out the various types of funding that could contribute to a broadly-based and locally/regionally sensitive implementation strategy.

Seed funding will be provided under the Commonwealth Department of Climate Change Adaptation Research Grants Program, in response to proposals aimed at addressing the research priorities described in this Plan. However, to fully address the key research questions described above, it will be necessary to access additional funding sources. Particularly relevant to the National Adaptation Research Plan for Terrestrial Biodiversity are key government organisations such as DEWHA, and the state and territory agencies entrusted with conservation and parks management. Likewise, collaborative research with local governments can attract local government co-funding. Furthermore, the growing private conservation sector and some non-government organisations have a strong interest in this research and may contribute to the research effort both financially and through in-kind support such as knowledge exchange.

Funding and resources may also be accessed through Cooperative Research Centres with research agendas relevant to climate change adaptation research in line with this research plan. The CSIRO Adaptation Flagship will also be a major contributor to terrestrial biodiversity adaptation research.

For university-based researchers, the Australian Research Council grants program is probably going to be the first port of call for many researchers and research institutions that seek additional support. Relevant grants offered by the ARC include Discovery Projects; Future and Laureate Fellowships; Linkage Infrastructure, Equipment and Facilities; and Linkage Projects. The latter supports collaborative research and development projects between universities and other stakeholders/user groups, which may be especially relevant for adaptation research

For adaptation studies with a focus on impacts on Indigenous cultural heritage, funding may be obtained through the Indigenous Heritage Program. Research undertaken by Indigenous students or early career scientists may also attract funding from the ARC Discovery Indigenous Researchers Development grant program.

In summary, a wide range of funding sources is possible, with the potential to give a strong multiplier effect to the core NCCARF funding.

6.3 Research capacity

A number of research planning, funding and implementation activities are already responding to biodiversity issues in general, and climate change issues in particular. The Commonwealth Environment Research Facilities (CERF) Programme co-funds multi-institutional environmental research across environmental, economic and social disciplines to support environmental policy development and decision-making, including responding to effects of climate change. A number of Cooperative Research Centres are also engaged in research on climate change impacts and adaptation. Many university-led projects are funded through the State, territory and Commonwealth governments, the Australian Research Council (ARC), and various Research and Development Corporations that are targeting either the impacts or responses to climate change. Government agencies are working together to develop targeted outcome-based research programs to address climate change in terrestrial systems. On the implementation side, research institutions and programs across Australia are also already responding to the widespread, high-risk impacts that climate change will bring and are focusing on targeted research which is of relevance to this Plan. CSIRO has focused existing and new research on climate change impacts and adaptation in a new Climate Adaptation Flagship, including a specific theme on *Managing species and natural ecosystems*. CSIRO's climate-related research is often undertaken in collaboration with key agencies such as the Bureau of Meteorology. Various universities are establishing climate change-oriented units or centres that similarly signal a new focus on these issues.

All these activities signal increasing capacity and focus in Australia on research to support climate change adaptation, either directly or indirectly. The vast majority of this work is biophysical, with relatively little focus on social science or adaptation by people. A consequence of this rapid expansion in research effort is the potential for duplication of both research efforts and capability development. Ensuring clear links among these multiple processes and activities will provide for greater efficiency in the allocation of limited research funds. The Terrestrial Biodiversity NARP has identified the most important adaptation research to assist the management of terrestrial biodiversity in a changing climate and will thereby seek to align research priorities relevant to climate change adaptation across all or most of the above initiatives. The Adaptation Research Network for Terrestrial Biodiversity plays a significant role in the implementation of the Research Plan through information dissemination and collaboration among its growing membership which includes researchers, state and federal government biodiversity and climate change units, major NGOs and other stakeholder groups.

Finally, there is scope to enhance Australian adaptation research capacity through international collaboration, as has happened with climate change science. Research institutes and programs focusing on climate adaptation have been established in many parts of the world – the Tyndall Centre in the UK and the Potsdam Institute for Climate Impact Research in Germany are two prominent examples. Interaction with such institutes and the international community more broadly ensures that Australian adaptation research maintains its position at the forefront of the international effort.

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CSIRO Adaptation Flagship: http://www.csiro.au/org/ClimateAdaptationFlagship.html

Adaptation Research Network Terrestrial Biodiversity:
www.nccarf.edu.au/terrestrialbiodiversity

NCCARF: http://nccarf.edu.au

Appendix 1 Terrestrial biodiversity related activities in the conservation sector

Table summarising the types of activities occurring within different levels of government and the non-government conservation sector that either define important issues with respect to terrestrial biodiversity and climate change, or need to respond to them

Scale	Key examples
International policies, multilateral Conventions and agreements, bilateral agreements and memoranda of understanding to which Australia is a party influencing Australian biodiversity policy	Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention) (1971) Convention on International Trade in Endangered Species (CITES) (1973) Convention Concerning the Protection of the World Cultural and Natural Heritage (World Heritage Convention) (1975) Convention on the Conservation of Migratory Species of Wild Animals (CMS/Bonn Convention) (1979) Japan–Australia Migratory Bird Agreement (JAMBA) (1981) China–Australia Migratory Bird Agreement (CAMBA) (1988) Convention on Biological Diversity (CBD) (1992) Rio Declaration on Environment and Development (1992) United Nations Framework Convention on Climate Change (UNFCCC) (1992) The Partnership for the Conservation of Migratory Waterbirds and the Sustainable Use of their Habitats in the East Asian–Australasian Flyway (Flyway Partnership) (2006) Republic of Korea–Australia Migratory Bird Agreement (ROKAMBA) (2007)
National frameworks, legislation and policies	*Quarantine Act (1908)* *Great Barrier Reef Marine Park Act 1975* *Antarctic Treaty (Environment Protection) Act 1980* National Conservation Strategy for Australia (1984) National Forest Statement (1992) National Strategy for Ecologically Sustainable Development (1992) Intergovernmental Agreement on the Environment (1992) *Wet Tropics of Queensland World Heritage Area Conservation Act 1994* Council of Australian Governments Water Reform Framework (1994) Commonwealth Coastal Policy (1995) National Strategy for the Conservation of Australia's Biological Diversity (1996) Nationally Agreed Criteria for the Establishment of a Comprehensive, Adequate and Representative Reserve System for Forests in Australia (JANIS criteria) (1997) *Natural Heritage Trust of Australia Act 1997*

	Wetlands Policy of the Commonwealth Government (1975) National Weeds Strategy (1997) *Quarantine Proclamation 1998* National Water Quality Management Strategy (1998) National Greenhouse Strategy (1998) Strategic Plan of Action for the National Representative System of Marine Protected Areas (1999) National Local Government Biodiversity Strategy (1999) National Framework for the Management and Monitoring of Australia's Native Vegetation (1999) National Principles and Guidelines for Rangeland Management (1999) *Environment Protection and Biodiversity Conservation Act 1999* National Objectives and Targets for Biodiversity Conservation 2001-2005 Coastal Catchments Initiative (2001) National Approach to Firewood Collection and Use in Australia (2001) State of the Environment reports (2001, 2006) Biodiversity Conservation Research: Australia's Priorities (2001) *Regional Forest Agreements Act 2002* National Framework for Environmental Management Systems in Australian Agriculture (2002) National Framework for NRM Standards and Targets (NRMMC 2002) Framework for a National Cooperative Approach to Integrated Coastal Zone Management (2003) National Water Initiative (2004) National Biodiversity and Climate Change Action Plan 2004-2007 Farm Forestry National Action Statement (2005) Australian Weeds Strategy (2006) Australian Pest Animal Strategy (2007) *Water Act 2007*
State and Territory policies for biodiversity	All states and territories have some form of conservation strategy that guides their policies and programs; they all also implement conservation through a formal array of conservation reserves of differing natures, most of which possess some form of plan of management, and which are managed day-to-day by government conservation agency staff. The conservation strategies include: ACT: The ACT Conservation Strategy 1997 Vic: Victoria Biodiversity Strategy 1997; Victorian Biodiversity Strategy White Paper (in progress) NSW: New South Wales Biodiversity Strategy (1999); New South Wales Biodiversity and Climate Change Adaptation Framework (2007) Qld: Queensland Biodiversity Framework 2003; Wet Tropics Conservation Strategy 2004; The Regional Nature Conservation Strategy for South East Qld 2003–2008 Tas: Nature Conservation Strategy 2002–2006

	SA: No Species Loss 2007–2017 WA: A 100 Year Biodiversity Conservation Strategy for Western Australia: Blueprint to the Bicentenary in 2029 NT: Draft Northern Territory Parks and Conservation Masterplan
Local government activities	Many local governments around Australia have adopted conservation strategies of varying complexity, for example: Liverpool City Council Biodiversity Strategy which aims to "*provide for the conservation of native plants, animals, habitat and ecological processes in the Liverpool LGA*" (http://www.liverpool.nsw.gov.au/biodiversitystrategy.htm
Some non-government organisation activities aimed at conservation	*Advocacy*: some NGOs (e.g. The Wilderness Society, Australian Conservation Foundation, WWF-World Wide Fund for Nature) mainly focus on political advocacy, community awareness and campaigns targeting specific sectors or high profile issues (e.g. WWF-Australia report on biodiversity and climate change). Many smaller NGOs operate at national or local levels and influence more local conservation *Research and monitoring*: many NGOs actively promote research on biodiversity conservation through data collection and monitoring (e.g. Birds Australia, Earthwatch, Conservation Volunteers Australia) *Land acquisition*: more recently, organisations such as The Nature Conservancy and Australian Bush Heritage have supported the purchase of private land with high conservation value, in some cases returning it to the government estate while in others taking an active management role themselves

Appendix 2 Biodiversity Vulnerability Assessment (BVA) - Key messages and policy directions

The impacts of climate change on Australia's biodiversity are now discernible at the genetic, species, community and ecosystem levels across the continent and in our coastal seas. The threat to our biodiversity is increasing sharply through the 21st century and beyond due to growing impacts of climate change, the range of existing stressors on our biodiversity and the complex interactions between them.

A business-as-usual approach to biodiversity conservation under a changing climate will fall short of meeting the challenge. A transformation is required in the way Australians think about biodiversity, its importance in the contemporary world, the threat presented by climate change, the strategies and tools needed to implement biodiversity conservation, the institutional arrangements that support these efforts, and the level of investment required to secure the biotic heritage of the continent.

The key messages coming out of the assessment, presented further on, comprise an integrated set of actions. The order is arbitrary; they are highly interdependent and of similar priority. Taken together, they define a powerful way forward towards effective policy and management responses to the threat to biodiversity from climate change. The task is urgent. All key messages should be well towards full implementation within two years. Most need to be ongoing.

Reform our management of biodiversity

We need to adapt the way we manage biodiversity to meet existing and new threats – some existing policy and management tools remain effective, others need a major rethink, and new approaches need to be developed in order to enhance the resilience of our ecosystems.

As we are moving rapidly into a no-analogue state for our biodiversity and ecosystems, there is a need to transform our policy and management approaches to deal with this enormous challenge. Climate change presents a 'double whammy' – affecting species, ecosystems and ecosystem processes directly, as well as exacerbating the impacts of other stressors. Many effective management approaches already exist; the challenge is to accelerate, reorient and refine them to deal with climate change as a new and interacting complex stressor. The National Reserve System, the pillar of current biodiversity conservation efforts, needs to be enhanced substantially and integrated with more effective off-reserve conservation. Acceleration of actions to control and reduce existing stressors on Australian ecosystems and species is essential to increase resilience. However, there is a limit to how far enhancing resilience will be effective. Novel ecosystems will emerge and a wide range of unforeseen and surprising phenomena and interactions will appear. A more robust, long-term approach is to facilitate the self-adaptation of ecosystems across multiple pathways of adaptation that spread risk across alternative possible climatic and socio-economic futures. Active adaptive management – backed by research, monitoring and evaluation – can be an effective tool to support self-adaptation of ecosystems. An especially promising approach is to develop integrated regional biodiversity response strategies, tailored for regional differences in environments, climate change impacts and socio-economic trends.

Strengthen the national commitment to conserve Australia's biodiversity

Climate change has radical implications for how we think about conservation. We need wide public discussion to agree on a new national vision for Australia's biodiversity, and on the resources and institutions needed to implement it.

If the high rate of species loss and ecosystem degradation in Australia is to be slowed and eventually reversed, a more innovative and significantly strengthened approach to biodiversity conservation is needed. To meet this challenge – particularly under a rapidly changing climate – perceptions of the importance of biodiversity conservation and its implementation, in both the public and private sectors, must change fundamentally. A national discourse is therefore required on the nature, goals and importance of biodiversity conservation, leading to a major rethink of conservation policy, governance frameworks, resources for conservation activities and implementation strategies. The discourse should build a much broader and deeper base of support across Australian society for biodiversity conservation, and for goals that are appropriate in a changing climate. In particular, biodiversity education, policy and management should be reoriented from maintaining historical species distributions and abundances towards: (i) maintaining well-functioning ecosystems of sometimes novel composition that continue to deliver ecosystem services; and (ii) maximising native species' and ecosystem diversity.

Invest in our life support system

We are pushing the limits of our natural life support system. Our environment has suffered low levels of capital reinvestment for decades. We must renew public and private investment in this capital.

There is as yet no widely accepted method – be it changes in natural capital, adjusted net savings or other indicators – to account for the impact of changes in Australia's biotic heritage due to human use. However, by any measure, Australia's natural capital has suffered from depletion and under-investment over the past two centuries. Climate change intensifies the need for an urgent and sustained increase in investment in the environment – in effect, in our own life support system. The challenge is to establish an enhanced, sustained and long-term resource base – from both public and private investment – for biodiversity conservation. In particular, significant new funding strongly focused towards on-ground biodiversity conservation work – carried out within an active adaptive management framework – is essential to enhance our adaptive capacity during a time of climate change. Monitoring the status of biodiversity is especially important, as without reliable, timely and rigorous information on changes in species and ecosystems, it is not possible to respond effectively to growing threats. An effective monitoring network would be best achieved via a national collaborative program with a commitment to ongoing, adequate resourcing.

Build innovative and flexible governance systems

Our current governance arrangements for conserving biodiversity are not designed to deal with the challenges of climate change. We need to build agile and innovative structures and approaches.

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. There has also been a recent trend towards devolution of the delivery of NRM programs to the level of regional catchment management authorities and local landcare groups. Dealing with the climate change threat will place further demands on our governance system, with a need to move towards strengthening and reforming governance at the regional level, and towards more flexibility and coherence nationally. Building on the strengths of current arrangements, a next step is to explore the potential for innovation based on the principles of: (i) strengthening national leadership to underpin the reform agenda required; (ii) devolving responsibilities and resources to the most local, competent level, and building capacity at that level; (iii) facilitating a mix of interacting regional governance arrangements sensitive to local conditions; and (iv) facilitating new partnerships with other groups and organisations, for example, with Indigenous and business entities. In addition, improved policy integration across climate change, environment protection and commercial natural resource use is required nationally, including across jurisdictional boundaries.

Meet the mitigation challenge

Australia's biodiversity has only so much capacity to adapt to climate change, and we are approaching that limit. Therefore, strong emissions mitigation action globally and in Australia is vital – and this must be carried out in ways that deliver both adaptation and mitigation benefits.

There is a limit above which biodiversity will become increasingly vulnerable to climate change even with the most effective adaptation measures possible. Global average temperature increases of 1.5 or 2.0°C above pre-industrial levels – and we are already committed to an increase of around 1.2 or 1.3°C – will likely lead to a massive loss of biodiversity worldwide. Thus, the mitigation issue is central to biodiversity conservation under climate change. To avoid an inevitable wave of extinctions in the second half of the century, deep cuts in global greenhouse gas emissions are required by 2020 at the latest. The more effectively the rate of climate change can be slowed and the sooner climate can be stabilised, the better are the prospects that biodiversity loss will be lessened. Societal responses to the mitigation challenge, however, could have significant negative consequences for biodiversity, over and above the effects of climate change itself. Examples include planting monocultures of fast-growing trees rather than establishing more complex ecosystems that both support more biodiversity and store more carbon, and inappropriate development of Australia's north in response to deteriorating climatic conditions in the south. However, with flexible, integrated approaches to mitigation and adaptation, many opportunities will arise for solutions that both deliver positive mitigation/adaptation outcomes and enhance biodiversity values.