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National
Climate Change Adaptation
Research Facility

National Climate Change Adaptation Research Plan

Freshwater Biodiversity

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The role of the National Climate Change Adaptation Research Facility is to lead the research community in a national interdisciplinary effort to generate the information needed by decision-makers in government and in vulnerable sectors and communities to manage the risks of climate change impacts.

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National Climate Change Adaptation Research Plan

Freshwater Biodiversity

Contents

Executive Summary

Climate change will alter the basic physical and chemical environment underpinning all life. Species will be affected differentially by these alterations, resulting in changes to the structure and composition of present-day freshwater ecological communities, with the potential to change the ways in which these ecosystems function and the services they provide.

Species and ecosystems will also be modified as climate change affects important underpinning processes such as water flows and rainfall patterns. In turn, communities, industries and regions will be affected by species and ecosystem changes. Some of these effects are already evident.

The role of the National Climate Change Adaptation Research Facility (NCCARF) is to lead the Australian research community to generate the biophysical, social and economic information needed by policy- and decision-makers in government, and in vulnerable sectors and communities, to manage the risks of climate change impacts. A key activity in this role is the development of National Climate Change Adaptation Research Plans (NARPs) for each major sector. As national research plans, NARPs focus on identifying research required for national policy purposes and national industry development and management, but they also provide a key sectoral research investment framework and prioritisation for all stakeholders at the regional and local scales.

The Freshwater Biodiversity NARP is concerned with the identification of climate adaptation research priorities for freshwater species and ecosystems. These research priorities should support governments, conservation agencies, landowners, community organisations and individuals to implement effective climate change adaptation initiatives for freshwater species and ecosystems. These initiatives will take advantage of opportunities for freshwater biodiversity that result from climate change and will reduce unavoidable detrimental climate change impacts.

Climate change will affect Australia's freshwater biodiversity in highly variable ways, depending on the types and locations of both climate impacts, and freshwater species and ecosystems. Adaptation responses to climate change impacts will be required in response to the specific effects experienced, together with the challenges they present in terms of opportunities and detrimental impacts in each location.

The Freshwater Biodiversity NARP identifies a research program for a five to seven year timeframe.

Adaptation research for freshwater biodiversity is fundamentally about generating information, knowledge and tools concerned with determining:

- why and to what extent freshwater species and ecosystems are vulnerable to or able to benefit from climate change,
- what their adaptive capacity might be,
- how their adaptive capacity can be increased,
- how the management of freshwater biodiversity can integrate climate change information, knowledge and tools, and
- what the implications of this integration are for policies, plans and on-ground management of freshwater biodiversity.

Adaptation research is interdisciplinary. It needs to address stakeholder understanding, institutional factors, management practices and end user needs, as well as the biophysical and technical aspects of climate change adaptation. In addition, adaptation must take account of the many factors that already impact on freshwater biodiversity, how they may be affected by climate change, and what new factors may result from climate change impacts and from society's responses to climate change.

Current factors include the effects of water diversion and catchment management projects on water quality and quantity; future factors may include water use by increased forest development associated with carbon sequestration initiatives.

This NARP identifies five broad areas of research:

- incorporating climate change adaptation into the management of freshwater species and ecosystems,
- identifying climate change adaptation options for Australia's freshwater biodiversity refugia,
- understanding climate change adaptation interactions between the freshwater biodiversity sector and other sectors,
- supporting environmental policies and goals to protect freshwater biodiversity under changing climate conditions, and
- ensuring that adaptation initiatives for freshwater biodiversity, and for other sectors, are mutually supportive and integrated where appropriate.

Climate change adaptation research will build on past and current research, particularly research concerned with responses to climate variability or to other external changes. Research outlined in this NARP will further contribute to a considerable existing body of knowledge about adaptation responses available to freshwater biodiversity managers and other stakeholders.

This NARP has very close links with the *National Water Knowledge and Research Strategy* being developed by the Commonwealth Department of Sustainability, Environment, Water, Population and Communities (previously the Department of Environment, Water, Heritage and the Arts (DEWHA)) and climate research being undertaken under Australia's Climate Change Science Program. This NARP also relates strongly to the NARPs developed for the other priority thematic areas; together, the NARPs will guide researchers to generate the information that Australia needs to develop an effective portfolio of adaptive strategies.

Murray River. Image: Nick James.

Research will gain greatest stakeholder acceptance and provide the greatest benefit where the end users of the research products – that is, the people and organisations who will use the research – are involved in the research planning process. End user involvement is also likely to enhance the relevance of research projects and the capacity of end users to understand how research outputs can best be applied to their concerns, thus increasing the success of adaptation initiatives.

This NARP proposes four principles to guide climate change adaptation research for freshwater biodiversity:

- an emphasis on end user engagement,
- participatory research and adaptive learning,
- building on national and international research, and
- dealing with uncertainty.

The NARP identifies a set of 17 priority research questions. As with all NARPs, these research questions are prioritised according to:

- the severity of the potential impact to be addressed,
- the immediacy of the response required,
- the need to change current interventions and the practicality of alternative interventions,
- the potential for the research to produce benefits beyond informing climate adaptation strategies,
- the extent to which the research addresses more than one issue or sector, and
- the extent to which the research addresses the needs of the most vulnerable groups.

As a result of these criteria being applied, six research questions were identified as being of very high priority and four research questions were identified as high priority . The very high and high priority research questions are listed in Table 1.

Table 1: Summary of very high priority and high priority research questions for freshwater biodiversity

Goal 1: Incorporate climate change adaptation into management of freshwater species and ecosystems

- What management options will conserve freshwater species and ecosystems that are currently at or near their climate limits? (Very high)
- What attributes will enable freshwater species to adapt and ecosystems to successfully change autonomously in response to climate change? (Very high)
- How will climate change alter current freshwater biodiversity management effectiveness, and what management changes will be required, including for poorly understood species and ecosystems?

Goal 2: Identify climate change adaptation options for Australia's freshwater biodiversity refugia

- How can the climate resilience of freshwater biodiversity refugia be increased? (Very high)
- What changes to Australia's conservation reserve system are required to improve protection of current and projected climate refugia and to support connectivity for freshwater biodiversity? (Very high)
- What adaptation options will facilitate the type and level of connectivity and dispersal required under climate change impacts?

Goal 3: Understand climate change adaptation interactions between freshwater biodiversity and other sectors

- How will climate change impacts on other sectors affect existing stressors on freshwater biodiversity?
- How can current non-climate stressors on freshwater biodiversity be managed or reduced to minimise the synergistic effects of climate and non-climate stressors? (Very high)
- What integrated climate change adaptation response plans at the local, landscape, catchment and regional scales will build the resilience of freshwater biodiversity, and also terrestrial biodiversity, primary industries, water resources, and associated communities and industries?

Goal 4: Understand the role of environmental policies in protecting freshwater biodiversity under changing climate conditions

- How will climate change affect existing conservation goals, policies and programs for freshwater biodiversity, including meeting Australia's international obligations? (Very high)

Goal 5: Cross-cutting theme: Ensure that adaptation initiatives for freshwater biodiversity and other sectors are mutually supportive and integrated where appropriate

- What climate change adaptation and mitigation actions taken in other sectors will benefit freshwater biodiversity?

Implementation

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

1. Introduction

1.1 Background

There is now widespread acceptance that human activities are contributing significantly to climate change, and that climate change is producing observable physical effects. It is also generally acknowledged that these impacts will become more severe if substantial modification to human behaviour and resource use does not occur, whether through:

- *mitigation*, which involves actions that are intended to reduce the magnitude of our contribution to climate change (primarily by reducing greenhouse gas emissions) or offset or even reverse its effects (for example, by establishing and maintaining forest areas to sequester carbon), or
- *adaptation*, which involves actions in response to climate change-induced impacts that have occurred, are inevitable or are at least likely. Adaptation seeks to take advantage of new opportunities resulting from climate change, and to reduce vulnerability to detrimental climate change impacts.

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

A key role of NCCARF is to coordinate the development of National Climate Change Adaptation Research Plans (NARPs). NARPs identify critical gaps in the information needed by policy and decision makers, set national research priorities, and are developed in partnership with governments, stakeholders and researchers. The focus of this NARP is adaptation in relation to climate change impacts on Australia's freshwater biodiversity.

1.2 National climate change policy context for this National Climate Change Adaptation Research 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 the following 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, of which up to $27 million is being invested in priority research for key sectors as identified in National Climate Change Adaptation Research Plans (NARPs). This gives effect to Action 1.1 of the Framework, which aims to improve national coordination of climate change adaptation research.

In November 2008, the Council of Australian Governments endorsed the development of a *National Water Knowledge and Research Strategy* (KRS), which will establish priority national research themes for water resources, including climate change adaptation. The KRS will also ensure coordinated research efforts and ensure the best returns from investment. The KRS is an important component of the *National Water Policy Agenda*, which has the objective of achieving national economic, social and environmental benefits through a shared vision across jurisdictions of principles and practices for improving the Australian water industry.

This NARP specifically addresses aspects of Australia's water research program that are concerned with climate change adaptation for freshwater biodiversity. The remainder of Australia's water research program is addressed by the KRS. NCCARF will support the development of the KRS to promote collaborative programs and synergistic outcomes.

Image: Tatiana Geris.

1.3 Development of this National Climate Change Adaptation Research Plan

NARPs are developed by NCCARF in partnership with governments, other stakeholders and researchers.The NARP for Freshwater 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* (2003–07) (NRMMC 2004);
- *Biodiversity conservation research in a changing climate* (Hilbert et al. 2006), and
- *Implications of climate change for Australia's National Reserve System* (Dunlop and Brown 2008).

In November 2006, the Natural Resource Management Ministerial Council (NRMMC) 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 (Steffen et al. 2009 (Appendix 1)).

The BVA had the following terms of reference:

- to cover terrestrial, freshwater and marine environments;
- to be strategic in nature and provide policy directions for future adaptation planning (i.e. not to be a systematic, region-by-region, community-by-community assessment);
- to include an assessment of the scientific observations and predictions around impacts/ responses to climate change, and
- to provide comments on ways in which 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. This NARP draws heavily on the principles and recommendations of the BVA, based on ecological principles that characterise:

- how individual species interact with their environment;
- how species interact with each other in ecological communities and ecosystems;
- how ecosystems and landscapes are structured and function, and
- how environmental change affects species and the structure and functioning of ecosystems.

These principles underpin the analyses in this NARP of current and projected biodiversity changes, and of the policies and management strategies required to deal with these challenges.

This NARP is accordingly developed within this overall government water and biodiversity research and policy context. It is a contribution to both the development of the KRS and to the development of a comprehensive approach to managing Australia's biodiversity. The specific focus of this NARP, and the contribution it will make to the KRS and other elements of the Commonwealth policy agenda and to other Australian policy, planning and management initiatives, is to identify and prioritise a research agenda relevant to climate change adaptation for the freshwater biodiversity sector.

Funding of up to $10 million has been provided by the Australian Government over five years to support the establishment and operation of Adaptation Research Networks (ARNs), which form an integral part of NCCARF. An inclusive, multidisciplinary ARN for Water Resources and Freshwater Biodiversity has been established and is convened by Professor Stuart Bunn at the Australian Rivers Institute at Griffith University. This ARN currently includes over 700 members, of whom about 320 are researchers from more than 30 institutions, and is continually expanding. The aim is to include members who represent all Commonwealth, state and territory government freshwater biodiversity and climate change units, and major non-governmental organisations (NGOs) and stakeholder groups. Members of the network collectively incorporate knowledge and experience in all major freshwater ecosystems and taxonomic groups relevant to designing and implementing adaptation strategies.

The Adaptation Research Network collaborates with other NCCARF activities to advance regional and sectoral knowledge about climate change impacts, vulnerability and adaptation options for the management of freshwater 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 NCCARF in synthesising existing and emerging research and in developing and implementing the NARP, and
- 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 this NARP has been led by the following writing team:

- Dr Bryson Bates, CSIRO Climate Adaptation Flagship (co-chair)
- Professor Stuart Bunn, Australian Rivers Institute, Griffith University (co-chair)
- Dr Peter Baker, Department of Sustainability, Environment, Water, Population and Communities
- Associate Professor Malcolm Cox, Queensland University of Technology
- Mr Angas Hopkins, Department of Climate Change and Energy Efficiency
- Dr Bill Humphreys, WA Museum
- Professor Sam Lake, Monash University
- Professor Garry Willgoose, University of Newcastle
- Dr Bill Young, CSIRO Land & Water.

Dr Mark Kennard and Mr Brendan Edgar were contributing authors.

Executive support was provided by Ms Marie Waschka and Dr Ida Fellegara, National Climate Change Adaptation Research Facility.

A number of climate change adaptation workshops held during the past 24 months have contributed further to the development of the research priorities that underpin this NARP.

1.4 The scope of the National Climate Change Adaptation Research Plan

The Freshwater Biodiversity NARP focuses on research to inform adaptation to climate change impacts on freshwater biodiversity.[1] This NARP identifies:

- important gaps in the information, knowledge and tools needed to support effective climate change adaptation for freshwater biodiversity
- adaptation research priorities based on these gaps, and
- capacity that can be harnessed, or needs to be developed, to carry out priority adaptation research.

Research on the nature of climate change impacts and vulnerability *per se* is not emphasised unless such research is considered essential to fill a void in understanding or implementing adaptation options. Research on the physical science of climate change is the responsibility of the Australian Climate Change Science Program and is not the focus of this NARP.

Those responsible for protecting or managing freshwater biodiversity, or whose actions could affect freshwater biodiversity, need to understand interactions between climate change risks and adaptation responses, and other, non-climatic, factors that affect the conservation of Australia's freshwater biodiversity. These non-climatic factors, which include land degradation and trends in social factors such as public support for conservation investment, are expected to have larger impacts on freshwater biodiversity in the near term (i.e. to 2030) than climate change

1 For the purposes of this NARP, the term 'freshwater' is meant to cover all those water bodies in landscapes in which fresh water as precipitation (i.e. meteoric water) either accumulates in or flows through, and may be later modified. Thus the term embraces fresh and saline lakes, creeks, streams, wetlands, groundwater aquifers and discharges, marshes, bogs, swamps, ponds, rivers and estuaries.

will have directly through changes to rainfall, temperature and other parameters.

Future climate impacts on freshwater biodiversity and the required adaptation responses will depend on the future rate of climate change and its interactions with other stressors. While the temporal scale relevant to this NARP is therefore necessarily relatively unconstrained, its focus is a research program for a five to seven year timeframe. However, the research program in this NARP also provides a framework for longer-term climate change adaptation research and response, potentially extending the focus from issues apparent now to those expected to become important in several decades' time. 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 more distant future.

Research will gain greatest acceptance and provide the greatest benefit where the people and organisations who will use the research (that is, the end users of the research products) are involved in the research process. End user involvement is also likely to enhance the relevance of research projects and the capacity of research end users to understand how research outputs can best be applied to their concerns, thus increasing the success of adaptation initiatives. This NARP therefore sets out several principles around end user engagement to guide the research approach and process (see Section 6.1).

The NARP touches on some adaptation issues or options for freshwater biodiversity important to Indigenous communities around Australia. We recognise that these issues are critical. They will be considered further as part of a National Climate Change Adaptation Research Plan for Indigenous Communities.

To enhance the accessibility of this NARP, referencing has been kept to a minimum. The reference list included at the end of the NARP will enable readers to pursue particular interests and the BVA (Steffen et al. 2009) provides a good introduction to key issues.

This NARP, like the others, will be periodically reviewed to ensure research prioritisation takes account of research findings and reflects current information needs.

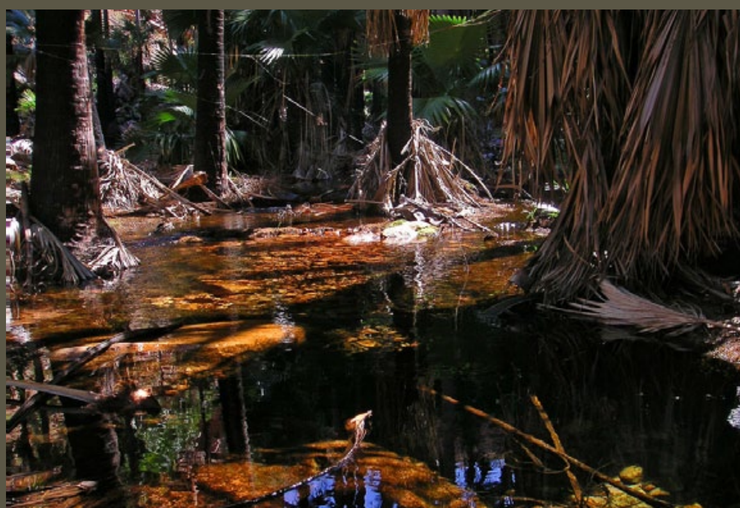


Image: Neils Photography.

This NARP is structured as follows:

- **Section 2** describes the context within which adaptation research is set, including the characteristics of Australian's freshwater biota that will affect its response to climate change, and the interaction of climate change with other environmental stresses.
- **Section 3** describes the primary stakeholders at whom this NARP is aimed, and their information needs.
- **Section 4** sets out the priority research questions, under five climate change adaptation goals, for freshwater biodiversity.
- **Section 5** outlines the criteria used to prioritise the research questions.
- **Section 6** outlines some implementation issues arising from the NARP.

Once this NARP has been completed, a separate implementation plan will be prepared, setting out the research budget, research capacity and further research funding opportunities available to implement the NARP.

1.5 Links to and synergies with the other NARPs

There are clear overlaps between this NARP and research priorities in other NARP thematic areas. Of particular importance is existing and future conflict over water availability and allocation, with emerging water requirements of favoured climate change mitigation technologies potentially exacerbating such conflicts. Conversely, there is a growing body of evidence that adaptation strategies designed to enhance resilience of natural ecosystems have co-benefits for many other sectors. This is particularly the case for climate change impacts on freshwater biodiversity, terrestrial biodiversity, water resources and primary industry, and their management, but it is also true for other thematic areas, as set out below.

Potential synergies exist between this NARP and the Water Knowledge and Research Strategy, currently being developed by the Department of Sustainability, Environment, Water, Population and Communities. These could significantly enhance understanding of climate change adaptation for both water resources and the ecological systems with which they are associated. Integrating research activities and findings is a role of NCCARF

There is a growing body of evidence that adaptation strategies designed to enhance resilience of natural ecosystems have co-benefits for many other sectors.

through its networks, communication program and synthesis activities.

Terrestrial Biodiversity

The Terrestrial Biodiversity NARP has clear links to the Freshwater Biodiversity NARP, including the following:

- Many terrestrial ecosystems share species, nutrients or space with freshwater ecosystems, with riparian habitats being a particular example.
- Management of terrestrial ecosystems can affect the quality and quantity of water resources and affect aquatic ecosystems and vice versa.
- Climate refugia for many terrestrial taxa and ecosystems may coincide with aquatic areas currently important for freshwater taxa and ecosystems.
- Water availability and allocation will be a key conflict and decision issue in climate change policy and actions.
- Management of water bodies needs to be integrated with catchment management, including the management of terrestrial biodiversity.

Water is one of the major factors shaping Australia's freshwater and terrestrial ecosystems, and is therefore particularly relevant to both NARPs. For example, adaptive measures to maintain freshwater ecosystems during dry periods could significantly affect terrestrial biodiversity and vice versa. Well-informed, collaborative and adaptive environmental management at the interface of freshwater and terrestrial ecosystems is therefore critical for both sectors. Adaptation actions that reduce degradation of watersheds, such as reduced deforestation, controlled or excluded grazing, afforestation and soil conservation, can reduce the vulnerability of terrestrial and freshwater ecosystems to drought.

Marine Biodiversity and Resources

The Marine Biodiversity and Resources NARP also links to the Freshwater Biodiversity NARP as follows:

- The Marine NARP is concerned with coastal ecosystems including estuaries.
- Salt water intrusion resulting from high sea levels or increased groundwater abstraction could affect freshwater biodiversity.
- Changes to freshwater ecosystems that result in changes to the seasonality, periodicity, quality or quantity of freshwater outflows could affect coastal and marine ecosystems.

Image: Amy Barker.

Both sea level rises and increased storm activity will have significant impacts on the marine–freshwater interface and coastal ecosystems, including the condition and distribution of salt marshes, mangroves and coastal wetlands, including subterranean estuaries.

Primary Industries

Primary industries and freshwater ecosystems often compete for land and water. Without careful management, climate change will intensify this conflict, such as in situations where agriculture might seek to capture more water for irrigation or other production purposes, to relocate to regions of reliable water availability or to use wetter parts of the landscape under drier climate conditions. Relocation of agriculture could lead to increased nutrients or sediment in freshwater systems, the introduction of pests and weeds, or degraded riparian zones.

Forest establishment on currently unforested areas is likely to increase transpiration, and thus exacerbate water scarcity where this has resulted from reduced rainfall or higher temperatures. However, re-establishing forests on previously forested lands could help move the landscape and hydrologic system closer to its natural state. If well managed, this could lead to enhanced biodiversity, soil health and water quality. Optimum design of riparian buffer zones within reforested areas and plantations is required.

Other potential synergies between primary industries and freshwater biodiversity include a common interest in maintaining genetic diversity to protect future adaptation options and increased use of integrated landscape management options.

Emergency Management

Natural systems, including freshwater ecosystems, are especially vulnerable to the introduction and spread of invasive species following damaging natural events such as floods or cyclones. A key recommendation of the Biological Diversity Advisory Committee's 2008 *Climate Change and Invasive Species report* (Low 2008) was that policy frameworks be developed to 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 therefore should

Image: Liebniz.

include protocols for preventing the spread of weed seeds and other invasive organisms during rescue and cleanup operations.

Settlements and Infrastructure

Current patterns of population growth and urbanisation will increase demands for development of areas currently used for stormwater management or freshwater 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 freshwater 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 affects freshwater habitats directly, and may impede the continuity and connectivity of freshwater habitats, as well as reduce the capacity of aquatic species to disperse in response to changed climate conditions. Conversely, climate change adaptation projects for the built environment could be designed to facilitate the movement of species through establishing or improving dispersal corridors and habitat continuity. There are potential co-benefits or synergies where stormwater harvesting helps to restore or create wetlands and freshwater conservation areas, but care will be required to avoid introducing pollutants or degrading important habitats.

Climate change adaptation research for freshwater biodiversity can contribute to and benefit from land use planning through influencing priority-setting and decision-making criteria, helping to reconcile competing needs and informing direct interventions.

Social, Economic and Institutional Dimensions

Developing and implementing adaptation responses to the potential impacts of climate change on freshwater biodiversity will require changes to freshwater biodiversity management practices, potentially including an expanded role for conservation on private land and other considerations that require a sophisticated understanding of social attitudes and similar factors. Migration of human population and changes to regional socioeconomic trends will affect regional conservation challenges and management. The institutional and regulatory arrangements needed and the best mix of economic incentives will be addressed broadly in the Social, Economic and Institutional Dimensions NARP.

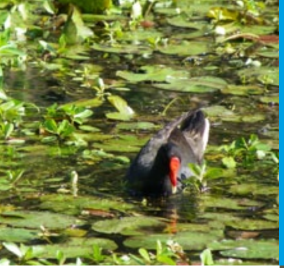
Human Health

Healthy water and waterways are key to human health and well-being. As freshwater ecosystems change in response to the changing climate, so will the complex interactions between disease-causing organisms, vectors and human hosts. The NARP for Human Health recognises links with freshwater biodiversity, especially with regard to vector-borne diseases such as Ross River virus, Barmah Forest virus and environmental pathogens such as *Leptospira* (Weil's Disease).

Loss of freshwater biodiversity may also negatively affect the mental and physical health of all Australian residents, including Indigenous people in remote settlements and those maintaining a close spiritual connection to the land. The loss of important aquatic food sources could detrimentally affect communities that do not have alternatives.

Indigenous Communities

Indigenous communities, groups and individuals are significant landholders and managers, have considerable knowledge about freshwater ecosystems and biodiversity, and are closely connected culturally to Australian landscapes, regions and species. The Indigenous Communities NARP will identify key cross-cutting issues relevant to climate change adaptation by Indigenous communities.



2. Context of this NARP

2.1 Introduction

Effective management of climate change impacts on freshwater biodiversity requires knowledge about future climate conditions, how changed climate conditions will affect water resources and systems (amount, quality and periodicity), how changed climate conditions and changed water resources and systems will affect freshwater biodiversity, and how adaptation responses may reduce the detrimental impacts of climate change and increase beneficial outcomes. This information is subject to uncertainty at all stages of the evaluation process, and includes:

a. the socio-economic, political, demographic and technological assumptions that underpin the number and range of greenhouse gas emissions scenarios
b. the general circulation models (GCMs) used to produce climate change scenarios (different models may be equally good at simulating past climate, but respond differently when simulating future climates under increasing atmospheric concentrations of greenhouse gases)
c. the capacity for GCM climate projections to be downscaled to a level that enables key parameters such as rainfall to be included with confidence in analyses for local or even regional management purposes
d. the conceptual or mathematical models used to predict the responses of hydrological systems and ecosystems to climate change
e. the information and assumptions used in environmental water requirement modelling
f. management options for water resources and freshwater biodiversity
g. the joint impacts of other sources of anthropogenic stress (e.g. changing land use, pollution, invasion by exotic species), and
h. the effectiveness of and feedbacks from adaptation and mitigation activities.

Future freshwater biodiversity research planning, management and policy-making will need to operate in the context of these uncertainties. The Australian Climate Change Science Program is concerned with improving knowledge in relation to points (a), (b), (c) and part of (d). This NARP addresses part of points (d) and (h), and points (e), (f) and (g).

2.2 Australia's water resources

Australia is the driest inhabited continent on Earth, and has a more variable climate than most – if not all – of the world's major agricultural nations (Croke & Jakeman 2001). In many parts of Australia, runoff and hence stream flow variability are high compared with the rest of the world (e.g. Puckridge et al. 1998). This has been a key factor in shaping its unique freshwater ecosystems, and also in guiding water resources policy and management. These factors are demonstrated, for example, by variations in stream flow and water chemistry in drainage systems throughout Queensland by McNeil et al. (2005).

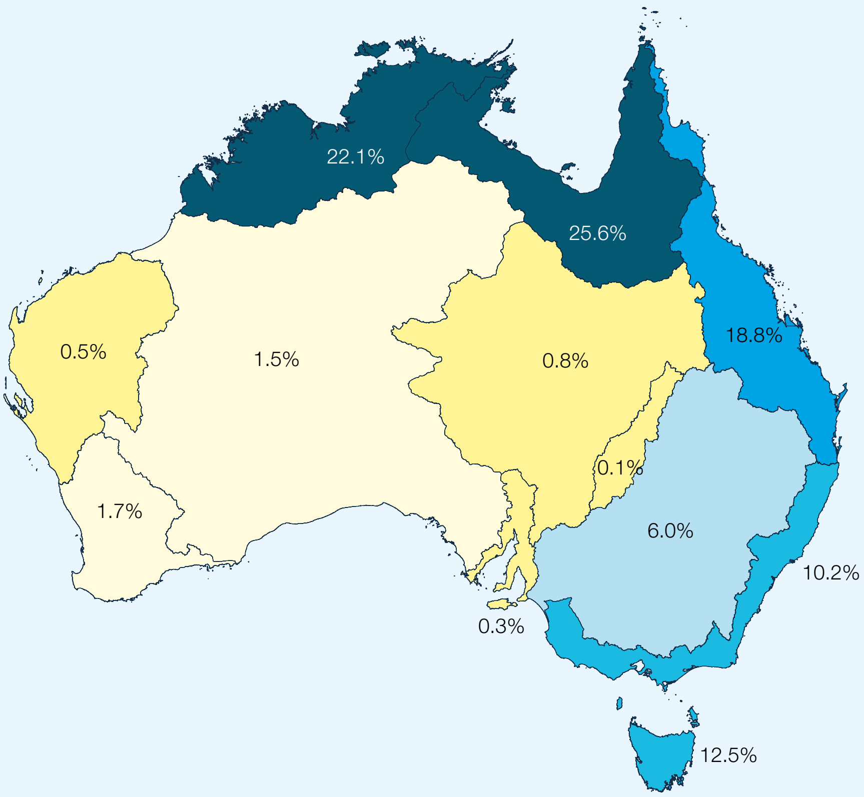
The geographic distribution of Australian surface water resources is highly variable, reflecting the latitudinal variation of climatic zones from the tropics to southern temperate Australia. Many of Australia's freshwater systems occur in the northern parts of the country. In contrast, nearly 75 per cent of irrigated agriculture occurs in southern Australia, in the Murray-Darling Basin, which generates only about 6 per cent of the total runoff in Australia (AWR 2005) (see Figure 1).

There is abundant evidence from the instrumental record and existing impact assessments that the water resources of southern Australia are at least vulnerable to, and have the potential to be strongly impacted by, projected climate change (PMSEIC 2007).

Surface water systems and groundwater systems can have substantial interaction, influenced by season and/or climate (e.g. McNeil & Cox 2007). Water may move directly between the subsurface and the surface, such as through a spring, but interactions are usually through more diffuse flows, such as seepage into or out of drainage channels, or from wetlands into surrounding groundwater systems. These flows are controlled primarily by the hydraulic gradient, or the height of the water table, and by ground permeability. The hydraulic gradient of a groundwater system is significantly influenced by recharge, which depends on factors such as climate, topography, geology and vegetation, and therefore has significant temporal and spatial factors. For example, the aquifers in semi-arid Australia are in a state of net discharge (Hatton 2001), and are

Image: Liese Coulter.

Figure 1: Distribution of mean annual surface water runoff (AWR 2006)



still responding to widespread oscillating climatic and fluctuating hydrologic conditions after the last interglacial period (English et al. 2001; review in Hesse et al. 2004). The long time periods over which groundwater systems operate may mask the onset of contemporary climate change effects. In many cases, changes in land use and groundwater abstraction for irrigation can substantially alter the natural balance of groundwater systems.

Hydrogeologically diverse groundwater systems occur across Australia, in broadly sedimentary settings such as the Great Artesian Basin that underlies one-fifth of the continent, or in hard rock settings with fracture porosity. Groundwater is a critical component of the total water cycle at catchment or regional scales, and contributes to surface water ecosystems as well as supporting diverse subterranean aquatic ecosystems comprising locally endemic species (Humphreys 2008; Tomlinson & Boulton 2010). Groundwater is the major source of water for agricultural irrigation, stock watering, mining operations and community use in many locations in Australia's arid interior. Groundwater is also an important additional source of potable water supply to most coastal cities, and notably the major source of water for the Perth Metropolitan Region.

2.2.1 The impact of climate change on Australia's water resources

The impact of climate change on freshwater bodies will vary, and hydro-morphological changes will influence freshwater habitats. Changes consistent with climate change projections have already occurred in intensity, distribution and seasonality of rainfall, snow cover and precipitation runoff, increasing acidity and changes in extreme events such as floods, droughts and fire (Kundzewicz et al. 2007).

Higher air temperatures have been associated with increased river and stream temperatures (e.g. Kaushal et al. 2010), which is a key factor in the health of a stream ecosystem (Ward 1963). Higher water temperatures and variations in runoff are likely to produce adverse changes in water quality affecting human health, ecosystems and water use (Webb et al. 2008). Eutrophication is a major water quality problem associated with higher temperatures (Davis 1997; SOE 2001). Increased nutrient load and higher surface water temperatures will promote algal blooms and increase bacteria levels and fungi content. Lower water levels in rivers and lakes will lead to bottom sediments becoming resuspended and toxic compounds liberated, with negative effects on water supplies and quality. More intense rainfall will lead to an increase in turbidity, erosion and deposition in river channels, and the introduction of pollutants and nutrients from adjacent agricultural areas. Acidification in rivers and lakes is also expected to increase because of acidic atmospheric deposition. Salinity may increase in estuaries and inland reaches with decreasing streamflow.

Changes to rainfall will affect water availability. Climate change already affects water resources in southwest Western Australia, where lower mean annual rainfall has been reflected in reduced river flows and dam inflows (CSIRO 2009). Climate models suggest that drought could become as much as 20 per cent more common by 2030 over much of Australia and up to 80 per cent more common in south-western Australia by 2070. However regions such as Northern Australia are not expected to become more drought affected. Increases in extreme rainfall events are projected for many regions across Australia, resulting in more flash flooding, strains on drainage systems and impacts on groundwater recharge (Hennessy et al. 2007).

The Murray-Darling Basin is Australia's largest river basin, accounting for about 75 per cent of irrigated crops and pastures (MDBC 2006). By 2030, average annual runoff across the Basin could decrease by as much as 33 per cent, but could also increase by up to 16 per cent; the median estimate is for a 9 per cent reduction (CSIRO 2008). The median estimate (under a medium global warming scenario) for 2050 is a 15 per cent reduction, and for 2070 a 23 per cent reduction is predicted; under a high global warming scenario, much greater reductions are possible (CSIRO 2008). In Australia by 2020, the average salinity of the lower Murray River is likely to exceed the 800 EC threshold set for desirable drinking and irrigation water (MDBMC 1999).

While it is well known that climate change will affect groundwater recharge, levels, resources and ecosystems through changed rainfall, flooding and evapotranspiration patterns, better predictions about these effects are required (Jones et al. 2007). Where climate change results in reduced rainfall, as in south-western Australia, reduced groundwater recharge may be exacerbated by increased reliance on groundwater abstraction to meet human demand.

Any decrease in groundwater recharge will exacerbate the effect of sea level rises on coastal aquifers and freshwater ecosystems. In inland aquifers, a decrease in groundwater recharge can lead to saltwater intrusion from neighbouring saline aquifers; increased evapotranspiration in semi-arid and arid regions may lead to the salinisation of shallow aquifers. A warmer climate, combined with increased climate variability, will increase the risk of both floods and droughts. Excessive water withdrawals can exacerbate the impact of drought. Conversely, increased evapotranspiration, especially resulting from reforestation, may lower saline water tables that have caused widespread salinisation of the landscape and loss of agricultural land (Malcolm 1983).

The demand for groundwater is likely to increase in the future, mainly due to increased water use but also due to the need to offset declining surface water availability due to increasing precipitation variability in general and reduced summer low flows in southern Australia. However, the water being extracted from many aquifers – particularly confined aquifers – is 'ancient', and will not be recharged in current human timeframes.

Changes to hydrological regimes will affect the formation and location of estuaries associated with marine shores and salt lakes, the rich subterranean fauna they host, the distribution and abundance of potable groundwater, submarine groundwater discharge, the location of saltwater interfaces, and discharge and location of springs. Higher sea levels will increase saline intrusion into coastal aquifers and influence patterns of submarine groundwater discharge (Werner 2010).

2.3 Australia's freshwater biodiversity

2.3.1 Features of Australia's biota and ecosystems

Climate change adaptation in Australia is, and will continue to be, informed by global experience and research. However, management of Australia's freshwater biodiversity needs to accommodate several unique features of the Australian biota, of the organisation and structure of Australian ecological communities, and of the environment within which they have evolved. Research to inform climate change adaptation initiatives for freshwater biodiversity should therefore focus on these features, since information relevant to them is unlikely to be available from overseas research.

Key features of the Australian continent and its freshwater species and ecosystems are outlined below.

- *Biogeographic history and degree of endemism:* The Australian continent has been isolated from other land masses for over 45 million years. Today, Australia is home to 7 to 10 per cent of all species on Earth, and a significant portion of these species occur nowhere else. For example, more than 90 per cent of Australia's reptiles, frogs and vascular plants are endemic. Many endemic species are already considered threatened and/or have small geographic and climatic ranges – factors that indicate high vulnerability to rapid climate change. Many of Australia's freshwater biota are more diverse and endemic than elsewhere in the world (e.g. galaxiid fish, parastacid crayfish, phreatoicid isopods and candonine seed shrimps and diving beetles in groundwater), and include relicts of ancient life forms of Pangaean and Gondwanan origin (e.g. syncarid shrimps, petalurid dragonflies, lungfish, salamander fish and Spelaeogriphacea) and Tethyan origin (e.g. in groundwater, Thermosbaenacea, Remipedia). Although fish diversity is relatively low (~200 spp) by world standards, the fauna has a high degree of endemicity. While Australia's freshwater biodiversity has not been fully described, recent studies have highlighted high levels of local endemicity and cryptic species complexes in some regions (e.g. Baker et al. 2003, 2004; Cook et al. 2008; Page et al. 2008; Bradford et al. 2010) and whole new ecosystems (Humphreys 2008).
- *Aridity and rainfall variability*: Australia's climate spans a very wide gradient and is highly variable, with extremes in temperature and precipitation (droughts, floods and storms). These episodic climate events are important in terms of driving the structure and function of Australian freshwater ecosystems. If Australia's climate becomes drier, the pre-adaptation of some species to climate variability could bestow a degree of resilience not found in many other parts of the world suffering similar drying conditions. However, many species may already be operating close to their physiological limits, and even small changes could therefore have large impacts.
- *Flat topography*: Australia has limited topographic relief with less than 5 per cent of the land more than 600 metres above sea level. Lack of topographic variability can increase the spatial impact of climate extremes, such as heavy rainfall, flooding and droughts and sea level rise. It also reduces altitudinal options for species migration in response to changed climate conditions.
- *Tectonic stability*: Over several geological periods, much of Australia has been free of major mountain-building processes and

glaciation, and has been emergent, resulting in deep regolith and a mosaic of different types of soils and vegetation, with landscape dominated by palaeovalleys. Where ecological community mosaics are significantly influenced by soil characteristics, there may be special challenges to adaptation.

- *Role of fire*: The combination of aridity, high temperatures and an abundance of sclerophyllous vegetation means that fire plays an important role in determining ecological community composition, distribution and function. Fire directly affects the boundaries and health of ecosystems sensitive to fire, including wetlands and bogs. Climate-associated change in fire regimes may be one of the most significant drivers of ecosystem change in many regions.
- *Nature of human impacts*: Intensive farming, widespread grazing and trampling by ungulates, and extensive mining are relatively recent phenomena in Australia compared with most other continents. Australia's biodiversity is still responding and possibly adapting to these relatively recent land use changes.
- *Invasibility of Australian ecosystems*: Nutrient enrichment of Australia's water systems from agricultural and urban development has had negative consequences for many freshwater ecosystems, including the establishment of many alien plant species. Introduction of vertebrates and invertebrates has also had devastating consequences for native biodiversity.
- *Limited data and mapping*: For large parts of Australia (e.g. about 75 per cent of Western Australia) there is no mapping of freshwater ecosystems or information about freshwater system values, typology, hydrology or variability. Even less knowledge exists about groundwater-dependent ecosystems in Australia.

2.3.2 Water resources and freshwater biodiversity

Water quality changes, often related to salinity, sediment, water temperature and nutrients, may demonstrate strong links to aquatic biodiversity because of changes to individual species' habitat requirements and the direct impact on the ability of species to survive.

With increased temperatures, summer stratification may set in earlier and last longer (Hering et al. 2010). Such a situation may result in 'a shift towards dominance of cyanobacteria (blue-green algae) in warmer water and may lead to progressive loss of phytoplankton diversity. Models suggest that cyanobacterial dominance will be greater if high water temperatures are combined with high nutrient loads.' (Jeppesen et al. 2010). Furthermore, in cases of extreme drawdown in lakes and reservoirs during drought (predicted with climate change), conditions may result whereby nutrients – especially nitrogen and phosphorus – become mobilised and stimulate cyanobacteria blooms (Baldwin et al. 2010). This happened in the recent drought in Lake Hume, producing a 150 kilometre-long blue-green algal bloom down the Murray River. Saltwater intrusion as a result of sea level rise, decreases in river flows and increased drought frequency are very likely to alter species composition of freshwater habitats, with consequent impacts on estuarine and coastal fisheries (Bunn & Arthington 2002; Hall & Burns 2002; Herron et al. 2002; Schallenberg et al. 2003). Saltwater intrusion into freshwater swamps, which has occurred since the 1950s in the Northern Territory, has been accelerating since the 1980s, possibly associated with sea level and precipitation changes (Winn et al. 2006).

Many coastal and estuarine settings host complex hydrological systems with interaction of fresh and saline groundwaters and surface waters, tidal influences, common mixing of waters and often specific localised environments related to a delicate balance of physico-chemical conditions (e.g. Hodgkinson et al. 2007, 2008). This complexity results in highly variable habitats. Modifications of groundwater regimes and changes in the balance of water resources in such areas can result in ecological changes, such as mangrove colonies invading salt marshes and *Casuarina* stands. Rising sea levels in these settings will also impact on coastal groundwater systems and associated freshwater *Melaleuca* wetlands, with effects being propagated along tidal estuaries.

Rivers and wetlands are the most threatened ecosystems on the planet, and face growing pressures from an expanding human population (Malmqvist & Rundle 2002; Postel & Richter 2003). Many of the world's larger river systems are fragmented by dams and flow regulation, with significant consequences for migratory species, coastal and inland fisheries (Nilsson et al. 2005; Pringle 2001). River corridors in Australia have been transformed for urban and agricultural land use to the extent that many floodplain ecosystems are functionally extinct (Tockner et al. 2008), and increases in nitrogen loading from cities and agriculture have resulted in order-of-magnitude increases in riverine nutrient fluxes to the coastal zone (Green et al. 2004). Dams and river regulation greatly reduce the capacity of biota to adapt to drought and to recover from both floods and drought. As a consequence of these and other cumulative impacts, freshwater systems have the highest rates of extinction of any ecosystem.

2.3.3 Freshwater biodiversity and climate change

Climate, and particularly its influence on surface and groundwater availability, plays a fundamental role in determining the distribution and abundance of freshwater species, the distribution and structure of vegetation, and the rates of most ecosystem processes (Kernan et al. 2010). Phenology (the timing of life cycle events), physiology, respiration, growth and reproduction are all affected by climate.

The extent to which a species or ecosystem will be vulnerable to or benefit from climate change impacts is a function of sensitivity and exposure to climate change as mediated by the resilience, evolutionary potential or ecological plasticity of the species, habitat or process (Williams et al. 2008).

It is clear that small recent rises in temperature have had detectable effects on freshwater ecosystems in the Northern Hemisphere (Nickus et al. 2010). These changes include increases in thermal regimes in lakes, decreases in ice cover of lakes, increased dissolved organic carbon (DOC) levels in lakes and streams, and increased solutes in glacial lakes (due to increased melting of glaciers).

Responses of species and ecosystems to rapid climate change will vary, with both winners and losers emerging. Adaptation management requires objective prioritisation based on relative vulnerability or benefits to allow the efficient allocation of management resources and to avoid wasting resources on species or ecosystems that can adapt on their own.

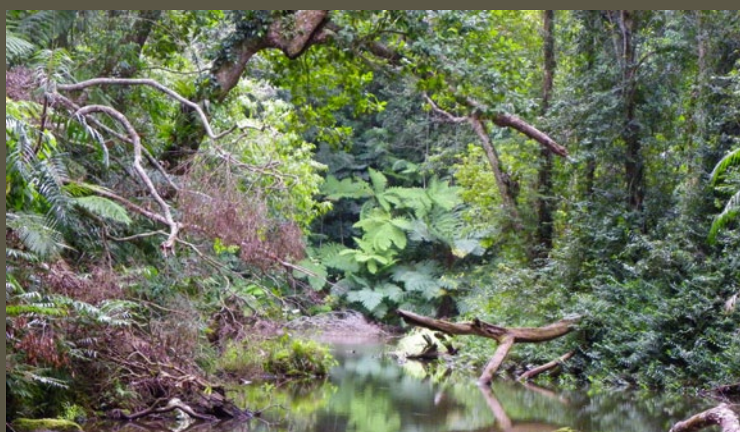


Image: Liese Coulter.

Assessing the relative vulnerability of species and ecosystems requires consideration of three factors:

a. *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. Life history traits have an important influence on both resilience and evolutionary potential to adapt.
b. *Degree of exposure*: The degree and rate of climate change will vary from region to region. Habitats and regions vary greatly in their degree of climatic buffering. For example, temperatures in coastal areas are less variable than inland areas, and maximum daily temperatures are lower where there is cloud cover during part of the day. Regions with high topographic relief, such as dissected plateaus with cool, moist gorges, may continue to provide refugia within a landscape as the regional climate warms. The relative influence of variable exposure is an important aspect of adaptation and conservation planning, and will need consideration at several spatial scales. Identifying and protecting climatic refugia will be an important component of future adaptation actions. Refugia are areas that provide significant buffering to extreme events or maxima. They can either give rise to a relictual situation or can provide temporary refugia that, with connectivity, can allow species to move and survive the disturbance coming from climate.
c. *Adaptive capacity*: Some species have sufficient phenotypic plasticity to tolerate new conditions in *situ*, while others may adapt genetically in the longer term. Others may be able to cope, at least in the short to medium term, by altering their use of microhabitats, colonising subterranean waters (Humphreys 2008), or by shifting their geographic range. The capacity of mobile species to travel some distance to more suitable areas will depend on the permeability of the landscape matrix between suitable habitats. Some species capable of shifting their range will be prevented from doing so by physical barriers such as dams or unsuitable habitats such as cleared farmland that impede connectivity. Changes of these types may occur incrementally or rapidly, as a result of biophysical or ecological thresholds for species and ecosystems being reached.

Freshwater biodiversity will be affected by *primary*[2] impacts directly, through the effects of increasing CO_2 concentrations and the resulting climate changes (changes in temperature and rainfall, etc.), and indirectly, through impacts on ecosystem processes such as fire, or on interactions between species and consequent effects on ecological communities and ecosystems. Freshwater biodiversity will also be affected by *secondary*[3] impacts on existing stressors on, or adaptations taken in, other sectors.

With the current rapid rate of climate change, novel combinations of species will appear in the future, creating ecological communities that have no present day analogue. These changes will affect ecosystem services on which humans depend. Such ecosystem services include provision of food, pest control, purification of water and biogeochemical (nutrient) cycling. The impact of climate change on the provision of ecosystem services is largely unknown.

Primary impacts

Changes to hydrology, such as riverine flow regimes and groundwater connectivity sustaining base flow, are widely regarded as key drivers of riverine ecosystem structure and function (Poff et al. 1997; Bunn & Arthington 2002; Boulton 2003)[2]. Other freshwater habitats are similarly influenced by hydrologic regimes. On the basis

2 In this NARP, primary impacts are those that result from changing CO_2 concentrations and climate change affecting freshwater species and ecosystems through changes to rainfall, temperature and associated factors.

3 In this NARP, secondary impacts on freshwater biodiversity are those that result from climate change affecting other sectors.

of ecological principles, climate change impacts would thus be expected to affect the diversity and function of aquatic habitats.

Dryer conditions in some parts of Australia have already impacted on flow regimes, and similar impacts will occur as climate change progresses (e.g. CSIRO 2009). Changes in the physical environment affect the physiological processes of 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 their phenology, such as flowering, dispersal, migration and reproduction (Murphy & Timbal 2008; Dai 2010).

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. Both physiological tolerances and how close these tolerances are to existing limits – that is, how much safety margin is available – are important. For example, recent research suggests that tropical species that have narrower tolerance ranges than temperate species are also, on average, closer to their upper limits with a smaller safety margin (e.g. Deutsch et al. 2008, Colwell et al. 2008). Understanding physiological and other thresholds, extreme events and tipping points is important, as many biological patterns and processes are more determined by upper or lower climate thresholds rather than by average climate conditions.

Freshwater biota and ecosystems will be affected by climate change in several ways:

- by the thermally-induced changes of global warming
- by changes in hydrologic regime (i.e. changes in the timing, magnitude and frequency of low and high stream flows, groundwater recharge and discharge, and the magnitude and distribution of hyporheic exchanges)
- by changes in aquatic chemistry both directly and through groundwater and hyporheic exchange (e.g. dissolved oxygen, pH, nutrients, salinity and turbidity), and
- by sea level rises.

Increased air and water temperatures have many implications for plant and animal physiology, and subsequent changes to ecosystem structure and processes. For example, differential changes in growth rates can change competitive balances between organisms – impacts that have the potential to change ecosystem processes and structure in ways that are inherently hard to predict.

Freshwater taxa in some regions of Australia are already close to their thermal tolerance levels, and unable to migrate to cooler environments (Davies 2010). Some taxa have restricted distributions (e.g. mountaintop species of stream frogs and crayfish in north-eastern Australia), and may have little ability to move in response to rising temperatures or changed hydrology.

The response of freshwater plants to rising CO_2 concentrations in the atmosphere and water will also be important, especially coupled with warming and/or altered water availability patterns. Increased CO_2 is also likely to result in differential responses between plant species that could have large impacts on plant community structure, net primary productivity, animals that use plants as habitat or food, and even nutrient cycles in ecosystems.

These effects could be compounded in the short term if more surface and ground water is diverted to meet agricultural, industrial and mining needs without sound consideration of ecological water requirements.

The impacts of climate change on freshwater ecosystems systems are yet to be examined carefully in a quantitative framework that captures the linkages between climate, hydrologic regime, water quality, physical habitat and aquatic ecosystem health.

Secondary impacts

Many non-climatic drivers already affect freshwater resources[3]. Adaptation must therefore take account of the many factors that already impact on freshwater biodiversity, how they may be affected by climate change, and what new factors may result from climate change impacts and from society's responses to climate change. Current factors include water diversion and clearing; future factors may include water use by increased forest development associated with carbon sequestration initiatives and other activities.

The quantity and quality of water resources, and their associated species and ecosystems, are influenced by changes in land use, construction and management of reservoirs, pollutant emissions, and water and wastewater treatment. Anthropogenic water use is driven by changes in population, food consumption, economic policy (including water pricing), technology, lifestyle and society's views of the value of freshwater ecosystems. Climate change impacts on any of these factors will have secondary impacts on freshwater biodiversity.

Climate change is thus a new stressor that adds to and interacts with a range of existing stressors that have already significantly changed and diminished Australia's freshwater biodiversity. These stressors include degradation, fragmentation and loss of habitat, introduction and spread of invasive species, stormwater or stream diversion and over-harvesting of water resources.

These stressors arise from other human activities, such as urban development and community activities, infrastructure development and use, farming, forestry, industry, tourism, recreation and water resource management. Most of these activities are discussed, and climate change adaptation research priorities are defined, in other NARPs.[4] In addition, this NARP must identify research to inform climate change adaptation decisions for freshwater biodiversity that includes an integrated understanding of how these stressors may affect biodiversity in the future.

Climate policy changes advocated in Australia that may exacerbate these impacts include those promoting expanded deployment of afforestation, biochar, biofuels, solar thermal, pumped storage hydropower, carbon capture and storage, coal seam gas, interbasin water transfers and greater water storage.

Dispersal

Future changes in climate and resulting changes to water resources will redistribute many of the factors that define the optimal locations for freshwater systems. Individual species' responses to climate change will result in changes to both the structure and composition of many ecological communities and ecosystems.

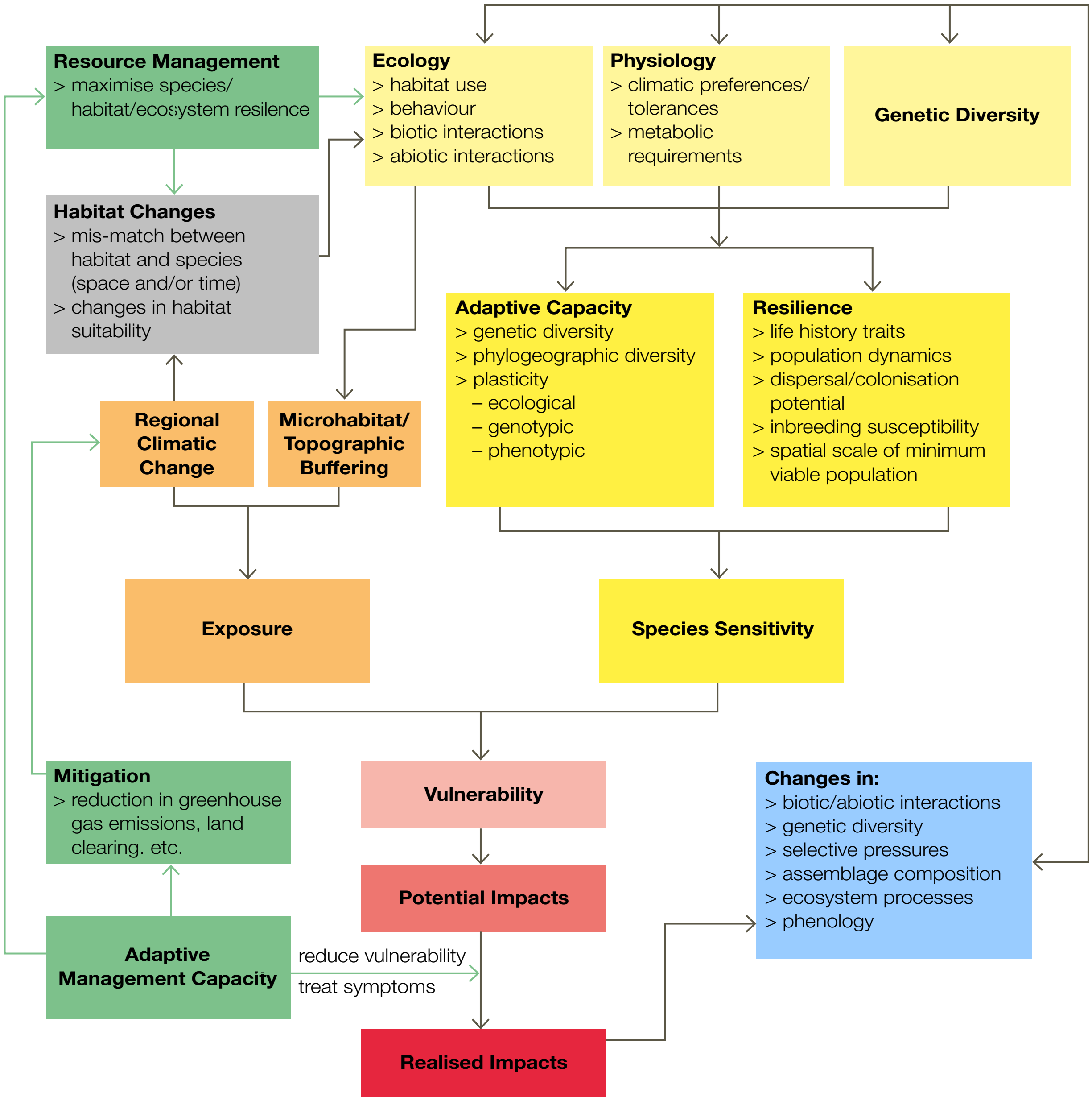
However, dispersal capacity, as well as geographical and human barriers, will limit colonisation of new locations by many freshwater biota. Many species or habitats may not be able to move at all due to habitat fragmentation and lack of connectivity, natural barriers or specialisation for specific environmental conditions. For instance, fish – which are highly vulnerable to increased habitat fragmentation and alterations to both temperatures and river flows – could be considered highly mobile species, but their movement may be blocked by a lack of connectivity between their current locations and future suitable habitats. Changes in fish species composition can lead to cascading impacts on other freshwater biota through aquatic food webs – for example, through changes in the intensity of biotic interactions such as predation and competition.

Understanding species and ecosystem responses to climate change

Current research on predicting impacts and vulnerability is mostly focused on changes to species or vegetation structure that would result from specified levels of climate change impacts. The framework presented in Figure 2 outlines the factors involved in assessing climate change impacts and the vulnerability of a species. It also indicates how the vulnerability of ecosystem composition, structure and processes might be investigated. However, more research effort is required to develop and evaluate methods and appropriate measures to determine the vulnerability to climate change impacts of ecosystem processes and function, and effective adaptation responses. See Williams et al. (2008) and Steffen et al. (2009) for full discussion.

4 The management of water resources, including climate change adaptation research planning for water resources, is the focus of the National Water Knowledge and Research Strategy.

Figure 2: Prioritising species based on relative vulnerability and adaptive potential: a general framework to assess the vulnerability of species to global climate change.



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

On other continents, particularly in the Northern Hemisphere, the availability of long-term biological datasets has enabled comparisons of recent climate and biological trends. The clearest evidence for such changes comes from observations of phenology (life cycle events occurring earlier in the season) 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 climate change.

To the extent that similar organisms respond to climate change in similar ways in Australia, some changes in species' life cycles and distributions recently observed in Australia are also likely to be correlated with climate change, at least in part. For instance, past phases of aridity led to colonisation of caves and groundwater by lineages that, by their adaptations, became trapped *in situ* and so have endured climate change through geological periods and may serve as exemplar models of adaptation.

Because many ecological changes are likely to have significant non-climate causes, the precise role of different factors may be difficult to identify. 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. Relatively faster processes such as dispersal, migration and population growth in small organisms will be more obvious in many species. For further information about observed trends, see Chapter 5 of Steffen et al. (2009).

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.

Knowledge of how climatic changes in the past have affected freshwater biodiversity is very limited. Such knowledge, once developed, would provide useful insights into how freshwater species and ecosystems might respond to future climate conditions. Many species and ecosystem responses to climate change are expected to be non-linear, and there may be thresholds where rates of change to species distribution and ecosystem composition, structure, processes and services increase rapidly. This behaviour inherently increases uncertainty in predictions.

As a class, groundwater ecosystems have great pragmatic value for climate adaptation research because they contain assemblages of aquatic species that have entered the subterranean realm in response to past climate change and survived there *in situ*. The fauna are confined to groundwater as a result of its evolutionary adaptations and consequently exhibit local-scale endemicity. Colonisation of the groundwater was widespread during the onset of aridity in the late Tertiary (Leys et al. 2003; Finston et al. 2007; Humphreys 2008), and the numerous endemic communities (Humphreys 2008) have persisted through all subsequent climatic vicissitudes.

2.3.5 Summary

Predicting and managing the impacts of climate change on Australia's freshwater biodiversity are challenging for a number of reasons:

- There is a considerable uncertainty inherent in most aspects of climate change and biodiversity impacts and responses.
- Climate change will interact with other drivers that are currently affecting freshwater biodiversity.
- Responses to physical and chemical changes will occur at the level of the individual organism, 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 is generally lacking about limiting factors, genetics, movement patterns and interactions among species and ecosystem processes that make up Australian ecological communities and ecosystems.
- Management actions taken to adapt to and/or mitigate the impacts of climate change on human systems could have further adverse impacts on biodiversity. Clearing, infrastructure (e.g. dams) and other human activities may impede dispersal.

Current understanding of future climate conditions, species' climate dependencies and thresholds, and climate-ecosystem interactions will support general guidance about potential vulnerability and management options. Adaptation decisions made in such circumstances need to incorporate 'no regrets' approaches and risk management, and could include research elements that improve knowledge and understanding over time. Sound experimental approaches are required, including observation, monitoring and model testing, together with effective stakeholder engagement.

Image: Matthew Stewart.

2.4 Adaptation responses

Adaptation responses reduce regional exposure, treat impacts or increase system resilience – for example, by reducing other threats or stressors. There are five main classes of adaptation responses for freshwater biodiversity currently available to decision makers. These adaptation responses form the framework for Section 4 (Research priorities).

2.4.1 Incorporate climate change adaptation into freshwater biodiversity management

Freshwater biodiversity is already the focus of many Australian conservation and other programs and initiatives. Climate change needs to become a fundamental element of these programs. While some species may be able to adapt to the new environmental conditions and even thrive, other species may already be close to the limit of their physiological capacity, be unable to adapt to climate changes or suffer competitive disadvantage. Some species are likely to experience local extinction, and the cost of retaining some others in their current locations will be high. Managers of existing programs need to identify and distinguish those species for which current approaches may need to be altered for conservation goals to be achieved, and to formulate new management responses, such as ensuring appropriate connectivity.

So far, there has been little research focused on potential adaptation responses to projected climate change impacts on freshwater biodiversity. While adaptation options such as assisted colonisation have been suggested for aquatic species of conservation significance with restricted geographic distributions (Hoegh-Guldberg et al. 2008), these options are expensive and hold risks such as introducing potential weed or pest species. Other options also need to be carefully reviewed and configured to meet the needs of freshwater species and ecosystems. Long-term monitoring and effective data set management would help accelerate the validation of projections and the utility of climate change adaptation and other management activities, and the development of new management responses.

2.4.2 Identify and protect current and future refugia

Refugia are places where biota with appropriate life history strategies reside when disturbances such as droughts or floods occur. They are highly diverse with respect to climatic conditions, topography, geology, soil type, vegetations and the form of the surface water source. Refugia

Managers of existing programs need to identify and distinguish those species for which current approaches may need to be altered for conservation goals to be achieved, and to formulate new management responses, such as ensuring appropriate connectivity.

may be temporary, or they may endure over long periods – even, like aquifer ecosystems, through many millions of years. Refugia are important as repositories of species or genotypes that may repopulate areas after the causative factor is no longer affecting the areas (Sheldon et al. 2010).

Refugia range from clearly identifiable pools to an array of smaller sites, such as under stones or in yabby holes in riparian and littoral vegetation. In dry periods, refugia will tend to be those locations that remain wet or moist; in wet periods, they are locations that are well drained, in rain shadows or sunny. In other words, they tend to be locations that offer alternatives to prevailing climate or other environmental conditions.

Refugia may be located in rugged highland terrains, valleys, coastal plains and along shorelines. They may be found where diffuse groundwater discharge occurs at local topographic lows, or on high slopes where perched groundwater conditions exist. Subsurface aquatic ecosystems (including the hyporheic zone) may constitute refugia from periods of no flow in surface streams (Lake 2003).

In southern Australia, refugia in most cases are related to or exist at sites where surface water remains during dry periods. Thus, during droughts, fish may survive in pools and many invertebrate freshwater biota become dormant. When water returns, surviving individuals move to potentially repopulate newly wetted habitats. Movement to and from refugia requires refugia to be connected to other areas that can be repopulated, or from which escape is required.

In riverine systems, water holes may be refugia, enabling species to survive dry periods and from which they can repopulate the remainder of the system once flow returns. In wetlands, refugia will tend to be the lowest-lying area, where groundwater expression is most likely to endure through dry periods. Many river systems in Australia are characterised by episodic flows, and for much of the time are reduced to a series of disconnected pools and waterholes, which provide important refugia for fish and other aquatic species (Hamilton et al. 2005). Increasing the duration of no-flow events (e.g. because of water extraction or more frequent or longer droughts) reduces the physical persistence of these important habitats, and often leads to local extinctions (Bunn et al. 2006).

Refugia are attractive for many human activities and needs, including summer paddocks, stormwater management and sports. They can be damaged or destroyed by rural or urban land use and development. Grazing, poor channel

Image: David Cook Wildlife Photography.

management, water diversion or harvesting, fertiliser and other pollution, clearing or ploughing can damage rural refugia. Urban refugia can be damaged by poorly planned development, flood control measures or other water-management measures. Changes to vegetation can have a major impact on refugia where they alter evapotranspiration and thus groundwater levels. Degraded refugia may need to be restored; a powerful way to engender resilience in many aquatic ecosystems is to undertake effective restoration (Johnson et al. 2010).

Establishing forests or plantations is likely to increase evapotranspiration, thus reducing groundwater levels and the extent of damp refugia. Removing deep-rooted vegetation can reduce evapotranspiration, resulting in higher groundwater levels and possibly altering water chemistry. Temporal changes in evapotranspiration are usually slow with vegetation growth, but can also be significant in the short term, such as after fires or forestry plantations are harvested, with an associated water table rise. Impacts on a groundwater system that contributes to the support of refugia may be spatially distant and involve a temporal lag.

Refugia need to be managed in a broader landscape context, in conjunction with other high conservation value aquatic ecosystems. Connectivity is important for refugia management, but is vulnerable to infrastructure development and other actions such as changes to water use and catchment water budgets resulting from altered rainfall patterns. Weirs, farm dams and other barriers may prevent aquatic organisms dispersing to otherwise connected aquatic habitats and limit recolonisation when flows return. Climate change will exacerbate these impacts on existing refugia, either through changes to water regimes, or through changes to water management or abstraction. A sophisticated approach is required to spread risk, to identify and manage different types of refugia, and to maintain and increase connectivity.

Future changes in climate and the hydrologic cycle will redistribute freshwater systems. Colonisation of new locations by freshwater biota may be limited by dispersal difficulties and inabilities due to the species' physiological tolerance, lack of connectivity with existing systems, human barriers and geographical regions. This will constrain the dispersal of species to areas suitable for them, and also affect the composition of new ecosystems and the services they are able to provide.

2.4.3 Reduce threats and impacts arising from climate adaptation initiatives in other sectors

Developing and assessing the potential effectiveness of climate change adaptation responses for freshwater biodiversity is complicated by the need to consider activities and processes in other sectors. These activities and processes may operate across catchments and in upstream drainage networks, the surrounding land, between surface and groundwater, in the riparian zone and, in the case of migratory species, in downstream reaches of rivers and wetlands (Dudgeon et al. 2006). This highlights two issues for climate change adaptation:

1 Actions taken in most other sectors have the potential to affect freshwater biodiversity (see Section 1.5).

2 In particular, climate change adaptation responses taken in other sectors could affect freshwater biodiversity.

Freshwater biodiversity can thus be detrimentally or beneficially affected by actions in virtually all other sectors, including terrestrial biodiversity, primary industry, water resource management, and urban and infrastructure development. Climate change policy responses that could affect freshwater biodiversity include afforestation, biochar and biofuel production, solar thermal operations, pumped storage hydropower, carbon capture and storage, coal seam gas, interbasin water transfers, new agricultural production areas and greater water storage.

2.4.4 Ensure policies, plans and programs enhance the resilience of freshwater biodiversity to climate change

National environmental goals and policies have key roles to play in protecting Australia's biodiversity at all scales from national to local, landscapes to species or even individual organisms.

The overall goals of conservation in Australia include: (1) maintaining well functioning ecosystems; (2) protecting a representative array of ecosystems; (3) removing or reducing existing stressors; (4) building and restoring habitat connectivity; (5) identifying and protecting current refugia; and (6) minimising the loss of species. Climate change could pose challenges for a 'preservationist' approach to conservation policy, with a move towards approaches that seek to manage change in ways that will minimise loss of biodiversity and maintain evolutionary processes, ecosystem functions and the delivery of ecosystem services. This would mean, for instance, anticipating or identifying refugia that develop as climate change impacts occur, and protecting them through reservation, management agreements or other options.

Climate change is also likely to test the utility of the criteria of comprehensiveness, adequacy and representativeness (CAR) that currently underpin the protected area estate and inform national approaches to conservation. Resolving the meaning and utility of CAR and other criteria for conservation planning and reserve programs will become more pressing under climate change, to ensure Australia's protected area system can meet the challenges of climate change. For freshwater biodiversity, this will include a focus on maintaining the utility of functionally critical freshwater habitats.

The role of Australia's protected area network for freshwater biodiversity is further complicated by the relatively limited protection currently afforded freshwater species and ecosystems. While protected areas comprised around 89. million hectares (11.5 per cent) of Australia's landmass in 1998, the proportion of certain types of ecosystems in protected areas can vary considerably, as shown in *Australia's Strategy for the National Reserve System 2009–2030* (National Research System Task Group 2009). This situation is common globally, as 13 per cent of land areas, 6 per cent of coastal areas but less than 1 per cent of the planet's ocean areas are currently protected (Nellemann & Corcoran 2010).

Protection of Australia's freshwater biodiversity will be improved through activities currently under development under the National Water Initiative, including a *'national imperative to ensure the health of river and groundwater systems'* (Clause 5) and an initiative that tasks all states and territories to *'identify and acknowledge surface and groundwater systems of high conservation value'* (Clause 25x). Several riverine and wetland freshwater ecosystems are currently being assessed under the *Environment Protection and Biodiversity Conservation Act 1999* as threatened ecological communities (e.g. the River Murray from the Darling to the sea, the wetlands of the Darling, and the Mary River of South-east Queensland). Such initiatives would provide alternative and complementary conservation benefits to the national reserve system.

The Aquatic Ecosystems Task Group (AETG), a multi-jurisdictional group under the Natural Resource Management Ministerial Council, was formed to develop a framework to identify and classify High Conservation Value Aquatic Ecosystems (HCVAEs) (Sinclair Knight Merz 2007). The framework is designed for systematic application at several scales (national, state/territory and regional). Regular reviews of data and HCVAE assessments will enable impacts (due to both climate change and other causes), to be identified.[5] The AETG is also developing an Australian National Aquatic Ecosystem (ANAE) Classification Scheme (Kennard 2010) to provide a nationally consistent set of aquatic ecosystem classes across Australia.

The AETG is scoping the development of an Integrated Ecological Condition Assessment Framework for aquatic ecosystems. The Framework is intended to provide the capacity to assess and report at the individual aquatic ecosystem scale or on a number of connected aquatic ecosystem types at a range of scales. It will provide a rapid assessment technique that identifies risk and incorporates a diagnostic capacity to inform adaptive management. It is envisaged that the Framework will establish condition based on the functional processes and ecological characteristics that underpin the

5 A website for HCVAE is being developed and will be found at the Department of Sustainability, Environment, Water, Population and Communities, http://www.environment.gov.au/water/policy-programs/environment/index.html.

aquatic ecosystem's key values. Condition will be evaluated in relation to critical thresholds/tipping points and management triggers (i.e. thresholds of potential concern) identified as essential to maintain critical functions and processes.

2.4.5 Cross-cutting issues: Ensuring that adaptation initiatives for freshwater biodiversity and other sectors are mutually supportive and integrated where appropriate

As noted above, freshwater biodiversity is significantly affected by actions taken in primary industries, water management and use, infrastructure, and settlement development and use, as well as many other aspects of society and the economy. Achieving successful adaptation initiatives and programs for freshwater biodiversity will require effective collaboration between all of these sectors. Integrated approaches to adaptation responses that take account of economic and social factors will also be required to ensure investments are well directed and to avoid maladaptation or perverse outcomes.

Image: Tim Keegan.

3. Key stakeholders and their information needs

NARPs are an important tool for coordinating climate change research across Australia. NARPs identify critical gaps in the information available to decision-makers in key vulnerable sectors and regions, set national research priorities, and identify science capacity that could be harnessed to conduct priority research. The process by which NARPs are developed enables stakeholder groups to contribute to the identification of priority research topics that will help meet key end users' information needs.

NARPs have four main stakeholder groups: researchers; research investors; research end users; and the beneficiaries of effective research uptake and application.

It is important that research priorities identified in the NARP address the management needs of key end users, including government, industry and the community (Table 2). Different stakeholder groups may have views about the relative importance of issues and topics, and this diversity of opinion helps frame the research agenda of the NARP. Moreover, engagement with all stakeholders and the wider community about the intent of the NARP will help build support for implementing the NARP and applying the resulting research outputs over the medium and longer terms. Involving stakeholders from the beginning of a research planning process will help ensure that the communication of results will be in user appropriate forms and methods.

A collaborative research approach, of which this NARP is the first element, will encourage national, state and territory, regional, and local partnerships between researchers, policy analysts, managers, interested citizens and others (this is set out in further detail in Sections 6.1.1 and 6.1.2). While all stakeholders need to be involved in coordinated responses to climate change adaptation, these stakeholder groups also have distinct roles to play:

- The Australian research community seeks to provide information, tools and insights required to address critical issues faced by Australia, including climate change adaptation. This community includes:
  - professional scientists based in universities, government agencies, the CSIRO and other research organisations, who can apply creative and structured approaches to programs that research complex questions and uncertainties,
  - Commonwealth, state and territory biological collections, such as museums, herbaria and zoological gardens and their researchers, which provide an essential resource to verify past and current species distributions and molecular diversity,
  - citizens, individually and in groups, such as NGOs, private entities, regional bodies, peak organisations, landholders and land managers, who are able to provide cross-sectoral insights about national or regional issues or specific issues in particular places. Local knowledge from these stakeholders can help verify model outputs from other research activities, and
  - Indigenous groups, which can provide important knowledge about aquatic ecosystems, particularly in remote areas where limited information may be available.
- Commonwealth, state and territory governments, research and development corporations and research investment organisations seek to ensure that Australia has the information it requires for effective decision-making, delivered effectively and efficiently.
- A diverse array of research end users have well-defined needs for research outputs:
  - Commonwealth agencies have a key role to play in ensuring that Australia has a comprehensive and effective national response to unavoidable climate change.
  - State and territory biodiversity and water management agencies have a significant role to play in leading regional collaborations because they have both an extensive on-ground presence and considerable management capacity. The roles of these agencies include managing protected area systems and water resources, and administration of a wide range of natural resource management (NRM), biodiversity and water legislation, programs and policies.
  - Local government plays a key role in forming and supporting local responses

Image: Ann Penny.

and collaborations and implementing local adaptation initiatives.
  - Citizens and groups such as NGOs, regional bodies and peak industry and other organisations need information to support advocacy about issues of concern, and to mobilise effort to respond to issues.
  - Landholders and land managers, including Indigenous groups, local environmental groups and activists, school groups and others, need information to support management decisions that result in sustainable use of ecosystems and the protection of biodiversity.
  - Researchers and research investors require access to research outputs to formulate new research priorities.
- Virtually every Australian resident has a personal stake in the sustainable use of ecosystems and the protection of biodiversity, and benefits in some way from effective adaptation to climate change.

This NARP aims to ensure research investors and research providers deliver research outputs required by three broad groups of end users: government agencies; local government, individuals and community organisations; and research scientists and research providers.

Government agencies

Commonwealth agencies are responsible for ensuring Australia meets the responsibilities it has adopted under international treaties, and play a critical role in coordinating efforts across levels of government, sharing knowledge, administering Commonwealth legislation and managing Commonwealth resources. State and territory government agencies are responsible for managing climate change impacts, protecting biodiversity values and guiding implementation at the sub-national scale. Governments need information that will support sound policies, programs, plans and on-ground initiatives. An overriding policy question is whether current policies will guide effective responses to climate change impacts and vulnerabilities and, if they will not, how they need to be revised in terms of both adaptation and mitigation benefits. Resolving this question will require insight into species adaptation and ecosystem resilience thresholds, future reserve system representativeness, adequacy and viability, and instances where enabling dispersal or undertaking translocation would be effective. Information about potential secondary impacts from climate change and effective management responses will help avoid or reduce changes to ecosystem composition, structure, processes and services.

Image: Oliver Teike.

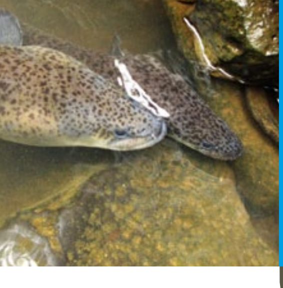
Government agencies	Private organisations, industries and community	Research scientists and research providers
▪ Department of Sustainability, Environment, Water, Population and Communities ▪ Department of Climate Change and Energy Efficiency ▪ Bureau of Meteorology ▪ Department of Agriculture, Fisheries & Forestry ▪ Murray-Darling Basin Authority ▪ National Water Commission ▪ R&D Corporations ▪ ABARES ▪ Australian Research Council ▪ State and territory government agencies with responsibility for aspects of the environment, climate change, water resource management and agriculture ▪ Catchment management authorities ▪ Local government	▪ Australian Water Association ▪ Water Boards/Authorities ▪ Water utilities ▪ Power utilities ▪ Mining companies, Mineral Council of Australia ▪ Petroleum and coal seam gas industry ▪ Community groups ▪ Catchment associations ▪ Irrigator associations, Cotton Australia, Dairy Australia, Rice Growers' Association ▪ Building and industry development ▪ Australian Conservation Foundation, World Wildlife Fund and regional environmental organisations ▪ Indigenous land councils, communities and water policy groups ▪ National Farmers' Federation and state/territory equivalents (of which PGA is one) ▪ Tourism industry ▪ National/state recreational fishing groups/angling groups ▪ Banks, insurance companies, consultants and other professional groups and advisers	▪ State and territory biodiversity, land management and water agencies ▪ CSIRO ▪ Australian universities ▪ eWater CRC ▪ GeoScience Australia ▪ Environmental Research Institute of Supervising Scientists ▪ Other research agencies

Local government, individuals and community organisations

These stakeholders will have diverse information needs. National conservation, industry and community groups will require information that enables them to develop and evaluate policy proposals related to climate change adaptation. Agencies that manage natural resources, such as local government, catchment management authorities, regional or local community groups, businesses, landholders and some Indigenous groups, 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, although it will normally be more heavily focused on supporting the inclusion of climate change risks in regional, local or site planning and on-ground projects.

Research scientists and research providers

Research providers need to understand the broader context in which their research activities occur, and particularly research being undertaken by other researchers and the potential applications of their research by end users. This is also a critical requirement for research investors seeking to make informed decisions about allocation of research funding.



4. Priority research topics

Five research goals that focus on immediate priorities for climate change adaptation initiatives have been developed in this NARP. As these goals are related, the outputs of each will in many cases also inform work towards the others. In addition, the research resulting from this NARP will inform and be informed by research resulting from the KRS (see Section 1.2). The goals are:

1 Incorporate climate change adaptation into management of freshwater species and ecosystems.

2 Identify climate change adaptation options for Australia's freshwater biodiversity refugia.

3 Understand climate change adaptation interactions between freshwater biodiversity and other sectors.

4 Understand the role of environmental policies in protecting freshwater biodiversity under changed climate conditions.

5 Cross-cutting theme: Ensure adaptation initiatives for freshwater biodiversity and other sectors are mutually supportive and integrated where appropriate.

The priority research questions identified in this section focus on informing initiatives to manage climate change impacts on freshwater biodiversity. Research into the questions can therefore benefit from early, ongoing and direct involvement by people and groups responsible for or interested in freshwater biodiversity, as discussed in Sections 6.1.1 and 6.1.2.

Goal 1: Incorporate climate change adaptation into management of freshwater species and ecosystems

Overview

Climate change will affect species survival, competitive pressures and species interactions, leading to changes in ecosystem services. Managers of freshwater biodiversity will need to understand the potential implications of these changes for their conservation programs.

Our capacity to project these impacts on freshwater species and ecosystems is limited by several factors, including the following:

- There are critical methodological, technical and data challenges (Heikkinen et al. 2006; Dormann 2007), including significant gaps in existing datasets about freshwater species and ecosystems and their locations (Humphreys 2008).

Image: Ann Penny.

Image (top): Rob and Stephanie Levy.

- There is limited scientific understanding of the complex interactions among environmental and hydrological processes and the responses of aquatic biota to scale-dependent environmental conditions (Ward et al. 2002; Allan 2004).

Information about these matters is required to enable climate change to be incorporated into current freshwater biodiversity management programs.

Priority research questions

1. What management options will conserve freshwater species and ecosystems that are currently at or near their climate limits?
2. What attributes will enable freshwater species to adapt and ecosystems to change successfully and autonomously in response to climate change?
3. How will climate change alter current freshwater biodiversity management effectiveness, and what management changes will be required, including for poorly understood species and ecosystems?
4. How can freshwater ecosystem services be maintained or improved under climate change?
5. What monitoring systems are needed to evaluate the effectiveness of climate change adaptation initiatives for freshwater biodiversity?

Goal 2: Identify climate change adaptation options for Australia's freshwater biodiversity refugia

Overview

A refugium is a location that has remained relatively unaffected by a climatic (or other) change in comparison to surrounding regions, and that, therefore, forms a haven for biota. Refugia thus contain concentrations of plants and animals and sometimes unique ecosystems. These may be relicts of formerly widespread biota that have remained there for thousands of years, or biota that have retracted to the refugium in the face of intermittent or shorter term adverse environmental conditions such as widespread drought.

Refugia provide biota with an opportunity to survive within a limited area while hostile environmental conditions occur over a broader area at a variety of time scales. Identifying and protecting such areas is therefore a key management response to predicted climate change impacts on freshwater biodiversity.

Faced with rapidly changing environmental conditions due to climate change and human population growth, systematic selection of areas for conservation action must be undertaken, with future climate change and other environmental changes integral selection factors (Hannah et al. 2002).

Priority research questions

6. How can the climate resilience of freshwater biodiversity refugia be increased?
7. What changes are required to Australia's conservation reserve system to improve protection of current and projected climate refugia and to support connectivity for freshwater biodiversity?
8. What adaptation options will facilitate the type and level of connectivity and dispersal required under climate change impacts?

Goal 3: Understand climate change adaptation interactions between freshwater biodiversity and other sectors

Overview

Freshwater biodiversity is affected by agriculture, grazing, forestry and other types of rural development and activities, mining, water abstraction and most types of urban development. These activities are expected to have larger impacts on freshwater biodiversity in the near term (i.e. to 2030) than climate change will have directly through changed rainfall, temperature and other parameters. Climate change will affect virtually all of these activities, as well as water demand and use, with flow-on effects on freshwater biodiversity. Climate change adaptation actions taken in other sectors could also have positive or negative impacts on freshwater biodiversity. These interactions need to be understood to avoid detrimental impacts and to promote adaptation responses that benefit all relevant sectors.

Priority research questions

9 How will climate change impacts on other sectors affect existing stressors on freshwater biodiversity?

10 How can current non-climate stressors on freshwater biodiversity be managed or reduced to minimise the synergistic effects of climate and non-climate stressors?

11 What integrated climate change adaptation response plans at the local, landscape, catchment and regional scales will build the resilience of freshwater biodiversity, and also terrestrial biodiversity, primary industries, water resources, and associated communities and industries?

Goal 4: Understand the role of environmental policies in protecting freshwater biodiversity under changing climate conditions

Overview

Conservation goals need to reflect environmental processes, the public good and private attitudes to conservation. While conservation policies will vary in response to specific circumstances, and the precise objectives of conservation initiatives will vary from region to region, they must be informed by an enhanced understanding of what is ecologically, economically and socially desirable and achievable. Conservation managers in both the public and private sectors will need guidance on the most appropriate timing to move to new management goals and interventions while continuing their current initiatives to address existing challenges and opportunities.

Priority research questions

12 How will climate change affect existing conservation goals, policies and programs for freshwater biodiversity, including meeting Australia's international obligations?

13 What principles will provide guidance for climate change adaptation across different regions of Australia?

14 How can climate change adaptation be incorporated in conservation programs and activities undertaken by non-governmental organisations such as community groups, industry and environmental organisations?

Goal 5: Cross-cutting theme – ensure that adaptation initiatives for freshwater biodiversity and other sectors are mutually supportive and integrated where appropriate

Overview

Many of the critical factors that will determine successful adaptation for freshwater biodiversity involve actions in, or collaboration with, other sectors. Links and synergies between freshwater biodiversity and other NARP sectors are outlined in Section 1.5 (above). Some of these are further considered in Section 2.4.3 and Goal 3 (above). However, some aspects of freshwater biodiversity adaptation to climate change require further specific collaborative research with other disciplines. This research is required to ensure that adaptation initiatives for freshwater biodiversity and other sectors are mutually supporting and integrated where appropriate, and to ensure that investment is well directed.

Priority research questions

15 What policy initiatives are required to address the social and economic consequences of climate change impacts on freshwater biodiversity?

16 What climate change adaptation and mitigation actions taken in other sectors will benefit freshwater biodiversity?

17 What are the costs and benefits of different climate change adaptation measures for vulnerable freshwater species and ecosystems?

5. Research prioritisation

5.1 Criteria and considerations for prioritising research questions

The National Climate Change Adaptation Research Facility has developed a set of six criteria for prioritising research topics (see Appendix 3 for details). These criteria are used in all the NARPs developed by NCCARF.

The criteria are:

- severity of potential impact or degree of potential benefit (essential)
- immediacy of required intervention or response (essential)
- need to change current intervention and practicality of alternative intervention (essential)
- potential for co-benefit (desirable)
- potential to address multiple, including cross-sectoral, issues (desirable), and
- equity considerations (desirable).

5.2 Freshwater biodiversity climate change adaptation research priorities

Ranking research questions into high, medium and low priority is difficult, given that many aspects of research are not directly comparable and timeframes for research vary. Nonetheless, the six prioritisation criteria have been applied to the research questions identified under each of the four sub-themes in Section 4.

Applying the criteria outlined above, the 17 priority research questions were ranked from low to high. The full assessment matrix is shown in Table 4 in Appendix 3. As a result of these criteria being applied, six priority research questions were identified as very high priority and four research questions were identified as high priority. These questions are listed in Table 3.

Image: Liese Coulter.

Image (top): Tony Rodd.

Table 3: Summary of high and very high priority research questions for freshwater biodiversity

Goal 1: Incorporate climate change adaptation into management of freshwater species and ecosystems	
1	What management options will conserve freshwater species and ecosystems that are currently at or near their climate limits? (Very high)
2	What attributes will enable freshwater species to adapt and ecosystems to successfully change autonomously in response to climate change? (Very high)
3	How will climate change alter current freshwater biodiversity management effectiveness, and what management changes will be required, including for poorly understood species and ecosystems?
Goal 2: Identify climate change adaptation options for Australia's freshwater biodiversity refugia	
6	How can the climate resilience of freshwater biodiversity refugia be increased? (Very high)
7	What changes to Australia's conservation reserve system are required to improve protection of current and projected climate refugia and to support connectivity for freshwater biodiversity? (Very high)
8	What adaptation options will facilitate the type and level of connectivity and dispersal required under climate change impacts?
Goal 3: Understand climate change adaptation interactions between freshwater biodiversity and other sectors	
9	How will climate change impacts on other sectors affect existing stressors on freshwater biodiversity?
10	How can current non-climate stressors on freshwater biodiversity be managed or reduced to minimise the synergistic effects of climate and non-climate stressors? (Very high)
11	What integrated climate change adaptation response plans at the local, landscape, catchment and regional scales will build the resilience of freshwater biodiversity, and also terrestrial biodiversity, primary industries, water resources, and associated communities and industries?
Goal 4: Understand the role of environmental policies in protecting freshwater biodiversity under changing climate conditions	
12	How will climate change affect existing conservation goals, policies and programs for freshwater biodiversity, including meeting Australia's international obligations? (Very high)
Goal 5: Cross-cutting theme – ensure that adaptation initiatives for freshwater biodiversity and other sectors are mutually supportive and integrated where appropriate	
16	What climate change adaptation and mitigation actions taken in other sectors will benefit freshwater biodiversity?

6. Implementation strategy

This section summarises the requirements for effective implementation of this National Climate Change Adaptation Research Plan for Freshwater Biodiversity. These include the principles on which effective adaptation research should be based, research funding and research capacity available to undertake the research identified in the NARP.

The Freshwater Biodiversity NARP provides a strategic framework for priority research for a five to seven year period. Some of this research will be supported directly by Commonwealth funding allocated for this purpose. However, the breadth of research required is so great that significant further resources will be required, not all of which have specifically been allocated at the time this NARP was prepared. It is anticipated that further resources will be available from a wide range of sources, including natural resource management organisations, and state and territory agencies. For these groups, the NARP provides a conceptual framework and prioritised statement of research requirements that can enable a higher level of coherence and effectiveness in the implementation of adaptation research than would have otherwise been possible. Each research funder will have its own priorities, and most research projects will focus on a context-specific issue, ensuring that the broad high priority research questions will be explored at scales that will generate information, knowledge and tools that are meaningful at the local and regional scales as well as being relevant to national and sub-national policy development.

Implementation of this NARP will be supported by the NCCARF Adaptation Research Network for Water Resources and Freshwater Biodiversity. The Network brings together people from diverse sectors and disciplines relevant to freshwater biodiversity adaptation. It also provides a focus for synthesis, communication and distribution of knowledge, experience, data resources and information.

Given that climate adaptation research raises new and challenging areas of work, this NARP focuses on learning-by-doing, with ongoing assessment of success/failure and a redirection of research based on these assessments.

This section also provides a brief overview of the resourcing issues – both financial and human – that are likely to arise in the implementation of this NARP.

6.1 Research principles

6.1.1 Emphasis on end user engagement

Adaptation to climate change is fundamentally different from the underlying physical climate science and from the impact studies derived from that science. Practical adaptation in the field must be driven by the key sector groups, peak industry bodies and other organisations, natural resource-based industries, local government, local communities and regions, and private and not-for-profit organisations. In this NARP, groups able to contribute to adaptation include those that traditionally have been concerned with freshwater biodiversity conservation, but also an increasing number of groups from other sectors, such as water management, agriculture, forestry, mining and tourism, whose activities affect or depend on freshwater biodiversity.

An approach to defining research needs and conducting research in which end user engagement is a specific focus of the research process brings a broad community of both practitioners and scholars to bear on the climate adaptation problem. Some of these stakeholders may not previously have been involved in climate change research or with biodiversity conservation – for instance, water engineers, farmers, natural resource managers, regional planners, political scientists, lawyers, economists, sociologists, geographers, national park managers, foresters, conservation biologists, agricultural scientists, and so on. This approach increases both the research effort and commitment to the research being performed, and commitment to its findings. In addition, it enables research scientists to develop a better understanding of how to communicate research findings to potential users.

Many of the researchers, communities and organisations interested in freshwater biodiversity conservation operate at regional or local levels, and will rely on knowledge focused on the

Image: Jose Alfonso Palad.

species/genetic, ecosystem/community and landscape scales described in the previous sections to implement adaptation actions. Nevertheless, 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 be addressed. Both 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 freshwater 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.

Understanding the context and manner in which research will be used will help determine what modes of dissemination and uptake are most appropriate. Few end users access research through traditional academic publications, instead preferring toolkits, presentations and workshops, interactive web-based material, CDs and DVDs, and so on (although traditional academic publications are still very important).

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 Dealing with uncertainty

The approach to adaptation research described above emphasises biodiversity conservation, freshwater ecology and end user engagement. This is in contrast to climate change impact research, which is often based on climate change scenarios derived from modelled changes in the physical climate system.

Uncertainty is pervasive throughout the approach of adaptation analysis. A risk-management approach to adaptation involves (1) a directed but flexible approach to forming, implementing and evaluating adaptation responses, and (2) a close interaction between researchers and

Image: Tony Rodd.

practitioners to enable new learning to be introduced as it emerges and to avoid ineffective or counterproductive initiatives being continued. This is possible through collaborative research involving end users, ecologists, social scientists, economists and others.

6.1.4 Building on national and international research

The approach to adaptation research described above (Sections 6.1.1 and 6.1.2) carries an emphasis on engagement with non-scientist stakeholders, sometimes at the national level but often at the local or regional level. This is an essential aspect of ensuring that research will meet the needs of end users. However, Australian science and knowledge can build on developments overseas, and can benefit from interaction with and insights from overseas research and scientists. Similarly, Australian researchers can advise on overseas adaptation responses and thus contribute to global responses to climate change as a global challenge.

6.2 Financial resources

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 and Energy Efficiency Adaptation Research Grants Program, in response to research proposals addressing the priorities described in this NARP. However, to fully address these identified priorities, it will be necessary to access additional funding sources. Particularly relevant to the Freshwater Biodiversity NARP are key government organisations such as the Department of Sustainability, Environment, Water, Population and Communities, and state and territory agencies entrusted with conservation and natural resource management. Likewise, collaborative research with local government can attract local government co-funding. Furthermore, the growing private conservation sector and some NGOs 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 NARP. The CSIRO Climate Adaptation Flagship can also be a major contributor to freshwater biodiversity adaptation research.

For university-based researchers, the Australian Research Council (ARC) grants program is an important funding source for many researchers and research institutions. Relevant grants offered by the ARC include Discovery Projects; Future and Laureate Fellowships; Linkage Infrastructure, Equipment and Facilities; and Linkage Projects. The last of these supports collaborative research and development projects between universities and other stakeholder 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 available, 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 National Environment Research Program (NERP) 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 state, territory and Commonwealth governments, the Australian Research Council, and various Research and Development Corporations that are targeting either the impacts of or responses to climate change.

Government agencies are working together to develop targeted outcome-based research programs to address climate change in freshwater 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 of relevance to this NARP. CSIRO has focused existing and new research on climate change impacts and adaptation in the 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 research centres that similarly signal a new focus on these issues.

All these activities demonstrate an increasing focus and capacity in Australia on research to support climate change adaptation, either directly or indirectly. 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 effectiveness in delivering priority information, and efficiency in the allocation of limited research funds.

The Freshwater Biodiversity NARP has identified the most important adaptation research questions to assist the management of freshwater 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 Freshwater Biodiversity plays a significant role in the implementation of the NARP 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 United Kingdom 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.

Further information about research capacity available and needed for this NARP will be available in its Implementation Plan.

6.4 Information, knowledge and tools transfer

Successful adaptation will require both sound research and the communication of research findings to end users who need them. Research uptake by stakeholders will be encouraged by the bottom-up, integrated approach outlined in Section 6.1, and will be supported by the research activities outlined in Section 4.6. This matter remains a significant challenge and will be a major component of future reviews of this NARP (see Section 6.5).

6.5 Review of the National Climate Change Adaptation Research Plan

The Freshwater Biodiversity NARP provides a strategic framework for priority research for a five- to seven-year period. During this period, which will involve a rapidly changing research, knowledge and policy environment, the NARP will be reviewed to assess its effectiveness. Information about the process of the review will be available on the NCCARF website, http://www.nccarf.edu.au.

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NCCARF: <http://nccarf.edu.au>

Abbreviations and acronyms

ARC: Australian Research Council

BVA: Biodiversity Vulnerability Assessment

CERF: Commonwealth Environment Research Facilities Programme

COAG: Council of Australian Governments

CRC: Cooperative Research Centre

CSIRO: Commonwealth Scientific and Industrial Research Organisation

DCCEE: Department of Climate Change and Energy Efficiency.

DEWHA: Commonwealth Department of Environment, Water, Heritage and the Arts

DSEWPaC: Department of Sustainability, Environment, Water, Population and Communities

GCM: General Circulation (or Global Climate) Model

IFD: Intensity-Frequency-Duration

IPCC: Intergovernmental Panel on Climate Change

NARP: National Climate Change Adaptation Research Plan

NCCARF: National Climate Change Adaptation Research Facility

NGO: Non-government Organisation

NLWRA: National Land and Water Resources Audit

NRM: National Resources Management

NWI: National Water Initiative

Appendix 1

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 twenty-first 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 below, 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, while 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 socioeconomic 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 best be 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: (1) strengthening national leadership to underpin the reform agenda required; (2) devolving responsibilities and resources to the most local, competent level, and building capacity at that level; (3) facilitating a mix of interacting regional governance arrangements sensitive to local conditions; and (4) 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

Appendix 1 continued

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.

Image: Matt Hansen.

Appendix 2

Terms used in this NARP

Adaptation
Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory, autonomous and planned adaptation.

Adaptive capacity
The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities or to cope with the consequences.

Connectivity
Landscape connectivity is the degree to which areas in a landscape are connected spatially, biologically and temporally in ways that facilitate or impede the movement of organisms between potential habitats. Landscape connectivity is thus a key factor in determining the capacity of species to move from less suitable conditions to more suitable conditions.

Cryptic species
In biology, a cryptic species complex is a group of species that satisfy the biological definition of species – that is, they are reproductively isolated from each other, but their morphology is very similar (in some cases, virtually identical). The species in a cryptic complex are typically very close relatives.

Edaphically
Relating to or influenced by the soil.

Hyporeic
The saturated zone of stream bed sediments.

Maladaptation
Climate change adaptation initiatives that have negative or detrimental impacts elsewhere are termed maladaptations. This also includes adaptation activities that over time become less beneficial and more of a hindrance.

Orogeny
Process of mountain formation, especially by folding or faulting of the Earth's crust.

Perverse outcomes
Detrimental results of actions intended to yield beneficial outcomes. Perverse outcomes often result from actions applied to systems that are sufficiently complex or unknown that the results of the actions cannot be fully predicted.

Refugium
A refugium (plural refugia) is a region in which certain organisms persist during a period in which most of the original geographic range becomes uninhabitable because of climatic change. However, the term refugium may be used in other ways, particularly to mean a region to which species retract for short periods (i.e. for a number of years at the most) when large parts of their preferred habitats become uninhabitable because of drought or other effects.

Regolith
A layer of loose, heterogeneous material covering solid rock. It includes dust, soil, broken rock and other related materials.

Resilience
The widely accepted definition of resilience, originally derived from the ecological literature, is the capability of a system to experience shocks whilst retaining essentially the same function, structure, feedbacks and therefore identity. This so-called 'ecological' definition of resilience is relevant at various scales, including biodiversity, ecosystems, landscapes and integrated natural resource management systems. It can also be applied to social systems.

Sensitivity
The degree to which a system is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g. a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g. damages caused by an increase in the frequency of coastal flooding due to sea level rise).

Transformation

Where change exceeds the adaptive capacity of a system, it may be appropriate to reduce the resilience of that system to facilitate transformation, for example of species composition and even ecological function. Transformation at one scale (e.g. change of species composition and even ecological function locally) may be necessary to enhance resilience at a broader scale (e.g. persistence of those species somewhere in Australia).

Ungulate

Hoofed mammal (i.e. sheep, cattle, goats).

Vulnerability

The degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate change and variation to which a system is exposed, its sensitivity and its adaptive capacity.

Image: Tseyin.

Appendix 3

Research prioritisation matrix

The criteria listed below have been used to prioritise the research questions identified in Section 4. Table 4 shows the results of this exercise.

Essential
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 current intervention and practicality of the alternative 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? Research that will contribute to practicable interventions or responses will be prioritised. Does research into the potential impact of the intervention being considered contribute to the knowledge base required to support decisions about these interventions?
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?
6 Equity considerations Will research priorities recognise the special needs of particular groups in Australia?

Table 4 Research prioritisation matrix for freshwater biodiversity

	Research question	Essential: Severity or benefit	Essential: Immediacy
	Goal 1: Incorporate climate change adaptation into management of freshwater species and ecosystems		
1	What management options will conserve freshwater species and ecosystems currently at or near their climate limits?	**High** This addresses a critical conservation requirement.	**High** This addresses the issues of most immediate concern.
2	What attributes will enable freshwater species to adapt and ecosystems to successfully change autonomously in response to climate change?	**High** This will enable adaptation planning to identify where investment is not needed in the short term.	**High** This will enable limited resources to be directed where they are most needed.
3	How will climate change alter current freshwater biodiversity management effectiveness, and what management changes will be required, including for poorly understood species and ecosystems?	**High** This will improve current freshwater biodiversity management.	**High** This will generate information that can be immediately translated into current adaptation activities.
4	How can freshwater ecosystem services be maintained or improved under climate change impacts?	**High** The delivery of ecosystem services is a key purpose for managing and conserving biodiversity.	**Medium** This will build on knowledge about freshwater ecosystem services and climate change impacts.
5	What monitoring systems are needed to evaluate the effectiveness of climate change adaptation initiatives for freshwater biodiversity?	**High** Long-term observational systems now being developed need to serve climate change adaptation needs.	**Medium** This will be required to inform decisions.

	Desirable				Overall
	Need to change intervention/ practicality	**Potential co-benefits**	**Cross-sectoral relevance**	**Equity considerations**	**Priority ranking**
	Medium This focuses on key management investments.				**Very high**
	High This will help overcome a key uncertainty.		**Yes** This question would inform other sectors.		**Very high**
	High This will help focus climate-related changes to management activities.		**Yes** Marine and terrestrial ecosystem management will also benefit.		**High**
	Medium Maintaining ecosystem services is vital for sustainability.	**Yes** This is specifically about gaining co-benefits.	**Yes** This is specifically about avoiding impacts on freshwater biodiversity from climate change adaptation.	**Yes**	**Medium**
	Medium This will be useful for guiding the development of climate change adaptation initiatives over time.		**Yes** This information will benefit other sectors.		**Medium**

Table 4 Research prioritisation matrix for freshwater biodiversity

		Essential	
	Research question	**Severity or benefit**	**Immediacy**
	Goal 2: Identify climate change adaptation options for Australia's freshwater biodiversity refugia		
6	How can the climate resilience of freshwater biodiversity refugia be increased?	**High** Refugia resilience to climate change impacts is a fundamental management objective.	**High** Increasing resilience is an ongoing long-term management goal.
7	What changes to Australia's conservation reserve system are required to improve protection of current and projected climate refugia and to support connectivity for freshwater biodiversity?	**High** The reserve system is established to protect places of conservation significance.	**High** Early protection will better ensure protection as climate change impacts occur.
8	What adaptation options will facilitate the type and level of connectivity and dispersal required under climate change impacts?	**High** Refugia benefits only occur if connectivity supports dispersal.	**High** Connectivity needs to be assessed in conjunction with refugia identification.
	Goal 3: Understand climate change adaptation interactions between freshwater biodiversity and other sectors		
9	How will climate change impacts on other sectors affect existing stressors on freshwater biodiversity?	**High** Most current stressors on freshwater biodiversity result from activities in other sectors.	**High** This knowledge needs to be included in climate change adaptation plans for other sectors.

	Desirable			Overall
Need to change intervention/ practicality	**Potential co-benefits**	**Cross-sectoral relevance**	**Equity considerations**	**Priority ranking**
High These initiatives would likely form the basis of future refugia management programs.		**Yes** Increasing resilience would involve managing impacts from other sectors.		**Very high**
High The conservation reserve system's objectives are to protect places having high conservation significance, including refugia.		**Yes** Freshwater refugia also help conserve many species often classified as terrestrial, particularly during droughts.		**Very high**
Medium Loss of connectivity is a function of other sectors' activities.		**Yes** Loss of connectivity is a function of other sectors' activities.		**High**
Medium Managers of other sectors and biodiversity need to understand the flow-impacts of climate change on other sectors to freshwater biodiversity.	**Yes** This knowledge could help avoid maladaptation, perverse outcomes and inefficient investment.	**Yes** This is specifically about understanding inter-sectoral climate change impacts.	**Yes** This will help improve understanding by stakeholders having interests in differing sectors of the likely cross-effects of climate change.	**High**

Table 4 Research prioritisation matrix for freshwater biodiversity

		Essential	
	Research question	**Severity or benefit**	**Immediacy**
10	How can current non-climate stressors on freshwater biodiversity be managed or reduced to minimise the synergistic effects of climate and non-climate stressors?	**High** Most current stressors on freshwater biodiversity result from activities in other sectors.	**High** This knowledge needs to be included in climate change adaptation plans for other sectors.
11	What integrated climate change adaptation response plans at the local, landscape, catchment and regional scales will build the resilience of freshwater biodiversity, and also terrestrial biodiversity, primary industries, water resources and associated communities and industries?	**High** This will help ensure adaptation options contribute to benefits in freshwater biodiversity and other sectors.	**High** Regional and NRM planning needs to integrate climate change as soon as possible.
	Goal 4: Understand the role of environmental policies in protecting freshwater biodiversity under changing climate conditions		
12	How will climate change affect existing conservation goals, policies and programs for freshwater biodiversity, including meeting Australia's international obligations?	**High** Conservation goals form the basis for public investment in biodiversity conservation.	**High** Conservation goals undergo ongoing review.
13	What principles will provide guidance for climate change adaptation across different regions of Australia?	**Medium** A framework will support investment decisions.	**Medium** A framework would be developed as research produces information about differing regions.
14	How can climate change adaptation be incorporated in conservation programs and activities undertaken by non governmental organisations such as community groups, industry and environmental organisations?	**High** These groups provide very important conservation services.	**Medium** These groups are largely self-directed and are attuned to local priorities.

	Desirable			Overall
Need to change intervention/ practicality	**Potential co-benefits**	**Cross-sectoral relevance**	**Equity considerations**	**Priority ranking**
High Managers of other sectors and biodiversity need to understand the flow-impacts of climate change on other sectors to freshwater biodiversity.				**Very High**
Medium Climate change will increase the need to develop integrated regional and catchment plans and to integrate climate change adaptation in existing plans.	**Yes** This knowledge could help avoid maladaptation, perverse outcomes and inefficient investment.	**Yes** The question is specifically about developing synergistic adaptation responses that involve many sectors.	**Yes** This will support development of climate change adaptation initiatives that benefit several sectors and their interest groups.	**High**
High Conservation goals need to relate to community views and be informed by the best possible expert knowledge.		**Yes** Ensuring conservation goals are relevant and effective benefits many sectors.		**Very high**
High Frameworks for conservation investment decisions need to include climate change.		**Yes** Conservation investment decisions need to take account of other decisions.		**Medium**
Medium These groups are largely self-directed and are attuned to local priorities.		**Yes** These groups integrate many different elements.		**Medium**

Table 4 Research prioritisation matrix for freshwater biodiversity

		Essential	
	Research question	**Severity or benefit**	**Immediacy**
	Goal 5: *Cross-cutting theme*: Ensure adaptation initiatives for freshwater biodiversity and other sectors are mutually supportive and integrated where appropriate		
15	What policy initiatives are required to address the social and economic consequences of climate change impacts on freshwater biodiversity?	**High** Decisions about biodiversity management need to take account of social and economic consequences.	**Medium** Research is better undertaken once results of Social, Economic and Institutional Dimensions research program available.
16	What climate change adaptation and mitigation actions taken in other sectors will benefit freshwater biodiversity?	**High** This will improve understanding about the implications of climate change adaptation by other sectors.	**High** This information will become important as other sectors develop and implement climate change impact responses.
17	What are the costs and benefits of different climate change adaptation measures for vulnerable freshwater species and ecosystems?	**High** Cost-benefit analysis is a very useful tool to direct investment.	**Medium** More information is required before this research can commence.

	Desirable			Overall
Need to change intervention/ practicality	**Potential co-benefits**	**Cross-sectoral relevance**	**Equity considerations**	**Priority ranking**
High Freshwater biodiversity management needs to take account of all factors.		**Yes** This is about managing inter-sectoral climate change impacts.	**Yes**	**Medium**
High It will be very important to ensure that climate change adaptation by other sectors does not detrimentally affect freshwater biodiversity.		**Yes** The question is specifically about understanding inter-sectoral climate change impacts.	**Yes** This will help ensure the interests of groups concerned with freshwater biodiversity can be included in climate adaptation programs.	**High**
Medium Adaptation measures are just commencing for freshwater biodiversity.				**Medium**

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Image: Kasia Wallis.

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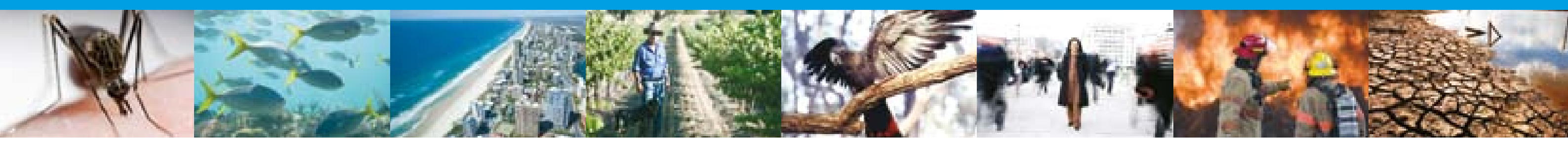

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