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Protected Areas: Buffering nature against climate change

Proceedings of a WWF and IUCN World Commission on Protected Areas symposium, 18-19 June 2007, Canberra

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Foreword

Climate change is not new for life on earth. Indeed there was substantial climate change during the glacial-interglacial swings of the Pleistocene, and biodiversity came through without major extinctions. In contrast, the present day anthropogenic warming of the planet threatens extinctions of large numbers of species through negative synergies between climate change and the loss and fragmentation of habitats from extensive human modification and use of lands and waters.

This is the global conservation challenge confronting countries today and is especially critical to those countries that are "hotspots" of life on earth. Australia – with its glorious flora and fauna – is one of only two developed countries considered to be global biodiversity "hotspots".

Australia has an historic opportunity to become a global leader in providing nature the best chance of adapting successfully through a climate change rescue package for biodiversity. Australia has the resources and the skills. It is a world leader in conservation science and still has vast areas of lands and waters in close to natural condition.

The key message from this meeting of experts is that climate change is already well underway. Indeed it is coming faster and harder than we realise. There is no time to dither. More than enough is known already to implement a concrete rescue package quickly.

The first and most important step the experts recommend is rapid expansion of Australia's reserve system to protect core habitats. Fortunately Australia already has a detailed plan and targets set to do this. Now all that's needed is the investment to create new reserves and other protected areas.

Reserves and protected areas are the safe havens that native species need to retain their natural resilience to climate change. Existing reserves are not in the wrong places. The animals and plants in them may shift around and new biogeographical patterns may emerge, but the overall value of reserves for protecting biodiversity will not change. The only shortcoming is that many more reserves are needed to protect the core habitats like refugia and to provide migration corridors. Protected areas are the best way to protect core habitats by eliminating threats like land clearing, development and deforestation. Pervasive threats like weeds, pests and fire do not, however, stop at reserve boundaries, and will require a lot more effort from reserve managers as climate change unfolds.

The second major step needed is to change land and water use practices in a coordinated way outside the formal reserve system, to reduce all the major threats and to ensure natural processes and linkages are retained. A first class reserve system can be undermined by what the neighbours are doing. It's best to engage all the neighbours and offer ways and means to move their uses of the land onto a more sustainable footing.

Payback for prompt and effective action will be enormous. Not only will this save one of the richest and most unique biotas on our planet, but it will also return billions in ecotourism revenues and ecosystem services, like clean air, rainfall and clean water, climate and flood control. Delay only drives up the risk of losing species and the cost of repairing the landscapes and restoring degraded ecological services for future generations.

The opportunity is Australia's for the taking.

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President of The H. John Heinz III Center For Science, Economics and the Environment, Washington DC
Former Chief Biodiversity Adviser to The World Bank
Canberra, August 2007

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Lastly we thank all the following symposium chairs, speakers and observers. Papers are presented here in the order of presentation on the day covering overviews (1, 2), management issues (3, 4), regional issues (5-9) and reserve system planning issues (10-15) respectively. Some excellent presentations and important discussion could not be reported more fully in this volume, but we hope are captured sufficiently in our overview article.

Martin Taylor and Penelope Figgis August 2007

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1. Protected Areas: buffering nature against climate change ~ overview and recommendations

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Introduction

On 18-19 June 2007, scientists, non government and government experts were brought together by WWF and the IUCN World Commission on Protected Areas (WCPA) to find ways to enhance the key role of Australia's National Reserve System in enabling biodiversity, our native plants and wildlife, to adapt to and survive climate change.

Symposium participants agreed that in the national climate change arena there is a critical need for recognition that we can, and must, take early and practical steps to enhance and recover the natural resilience to climate change of our ecosystems, plants and animals.

The key policy actions needed are to expand the National Reserve System to meet already agreed targets; to take rapid action on freshwater protected areas; to reduce threatening processes and enhance natural processes across the landscape by integrating off-reserve and on-reserve management through bioregional plans.

In this overview we outline the key issues and draw together the key findings of the symposium into a series of recommendations.

The focus of the symposium was on the terrestrial and inland aquatic environments. However many of the same principles apply equally well to marine environments.

Climate change undermines natural resilience

Human forced, rapid climate change is real and is already happening.

There is an urgent, over-riding need for reduction of greenhouse gas emissions worldwide.

Even if greenhouse emissions were controlled today however, our planet is already committed to significant warming.

Australia's native biodiversity has come through major changes in climate and sea level during repeated glacial cycles. This "natural resilience" represents the capacity for species to maintain viable populations and avoid significant extinction risk despite climate change.

However, climate change now is a much more significant problem than in the past due to the pervasive threats to native species from modification of land and waters by human settlements, pastoralism, agriculture, logging, invasive pests and weeds, inappropriate fire regimes, land clearing and resulting fragmentation of natural vegetation (Mackey this volume).

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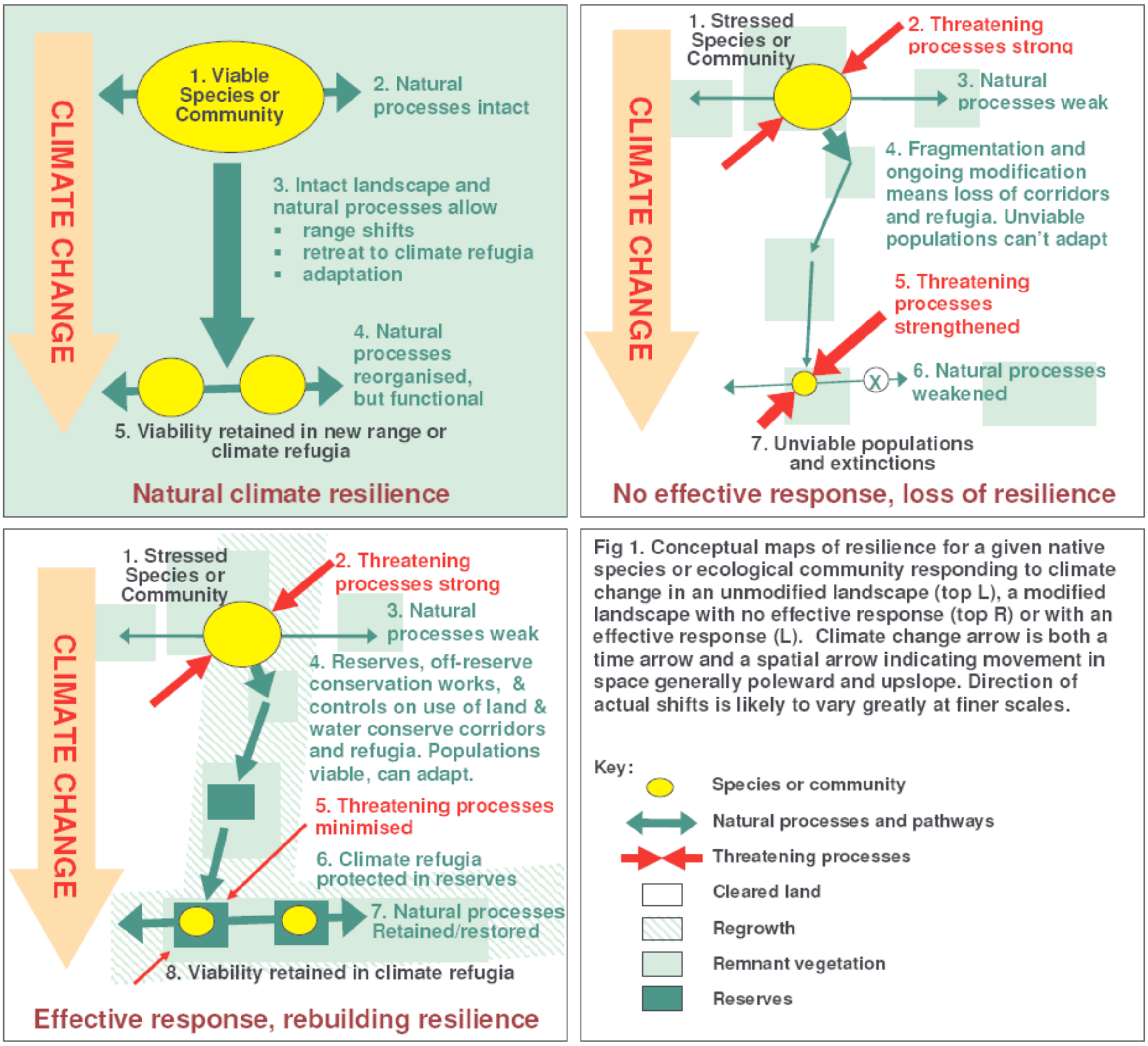

Fig 1. Conceptual maps of resilience for a given native species or ecological community responding to climate change in an unmodified landscape (top L), a modified landscape with no effective response (top R) or with an effective response (L). Climate change arrow is both a time arrow and a spatial arrow indicating movement in space generally poleward and upslope. Direction of actual shifts is likely to vary greatly at finer scales.

These threats erode the natural resilience to climate change of native species by disrupting species movements and natural ecological processes they depend on, and driving populations down to unviable levels (Fig. 1). It has been argued that as a result, we are now living in the sixth great extinction wave in the history of life on earth.

Fig. 1 illustrates how an effective response can recover and enhance resilience and conversely, how inaction will result in continuing extinctions of native species.

While some estimates of future warming are improving, there remains great uncertainty at the regional scale of the direction and magnitude of change in rainfall patterns. Consequently, precise predictions of future ecosystem and species responses await improvements in data collection and modelling. However, we know enough already about the direction and magnitude of temperature changes to offer recommendations for planning.

Key directions for buffering nature against climate change

Now is a critical time to ensure that national and state climate change adaptation strategies give top priority to securing core lands and waters and enhancing resilience across the landscape.

Although governments are developing climate change adaptation strategies, these tend to focus on socio-economic adjustments, rather than biodiversity. The *National Biodiversity and Climate Change Action Plan 2004-2007* should be revised and incorporated into the larger adaptation agenda.

Species show resilience to climate change because they are able to move or retreat to refugia of favourable habitat or alternatively, are able to remain and thrive where they are by adapting (Cowell, Mackey, Mansergh this volume).

Enhancing natural resilience has the following key elements (Fig. 1):

- Identify and protect climate refugia;
- Conserve large-scale migration corridors;
- Maintain viable populations to enable adaptation;
- Reduce threatening processes at the landscape scale;
- Conserve natural processes and connectivity at the landscape scale; and
- Special interventions to avert extinctions.

Identify and protect climate refugia

"Refugia" is the scientific term for places where favourable habitat will persist or develop as the climate changes. Refugia may exist through natural processes or as a result of human actions (Sattler this volume).

Refugia may already exist within the current range of a species. Locations that have served as refugia during past climate changes may serve as refugia for the present period of climate change. As conditions outside refugia become hostile with changing climate, a species will be lost from the wider range and persist only in the refugia. For example, fire sensitive plants and trees of moist forests may be eliminated by drought and bushfire through much of their range, persisting only in deep valleys where wetter closed forests survive. Fire suppression may help retain wet forest refugia that otherwise might disappear (McDougall & Broome this volume).

Also, refugia may not currently exist, but may develop outside of the current range of the species as climate zones shift and ecosystems shift with them. In this case it will be crucial to also identify and protect these new refugia and migration corridors to them. Identifying new refugia presents significant methodological hurdles but is an essential job to ensure reserve system decisions are optimal for enhancing natural resilience (Hilbert this volume).

Conserve large-scale migration corridors

Habitat fragmentation and degradation present significant barriers to species that may need to move to new habitats and refugia.

Successful migration requires viable source populations and habitats, destination refugia, and large-scale connectivity in the form of migration corridors or stepping stones between sources and destinations (Cowell, Mansergh, Mackey this volume).

For example, highland rainforest frog species need sufficiently large source populations to produce enough colonists to reach distant refugia. They also need stepping stones of streams or wetlands spaced so that colonists can move safely between them. Alternatively, frog eggs may be carried by water birds to new habitats. Destination refugia must also be protected with appropriate resources and natural processes to allow successful growth and reproduction.

Since every species has other species and resources it depends on with similar requirements, whole communities may need to move together for any given species to survive.

This kind of biological *permeability* is needed at large scales with corridors of the order of tens to hundreds of kilometers across all tenures, to facilitate the migration of animals and plants tracking shifting climatic zones and generally requires protection of extensive areas with intact native vegetation cover.

However it important to remember that enhanced connectivity may also favour some native species perhaps to the detriment of other high conservation value species as well as favouring exotic invasive species, thus requiring more effort to control weeds and pests. The scale and pattern of connectivity must be tailored to the needs of priority species, considered on a bioregional basis (Cowell, Dunlop, Mackey, Sattler this volume).

Maintain viable populations to enable adaptation

Replication of habitats in the reserve system is a vital form of insurance against the risk of extinction by protecting multiple source populations, climate refugia and migration corridors.

Even without climate change, small isolated reserves lose species over time as the result of chance events. For example a disease or fire might wipe out a reptile population in a small rainforest patch. If that is the only remaining habitat, the species is lost forever.

Multiple source populations and destination refugia, and multiple migration routes within large-scale corridors across the entire geographic range of a species are needed for an acceptably low risk of extinction in a dynamic landscape. Replication is a central element in determining the *Adequacy* of the reserve system (Young this volume). The *Representativeness* goal of the National Reserve System is also a means of ensuring replication.

With sufficient replication a species can also remain viable with diverse populations and so retain capacity to adapt to the new climate to remain where they are. High genetic diversity in source populations may also permit evolutionary adaptation to changed climate (Mansergh, Mackey this volume)

For example, multiple refugia for many plants in the Australian Alps are already entirely within the national park system, highlighting the importance of having large reserves with a great diversity of habitats (McDougall & Broome this volume). One way to ensure reserve systems capture a great diversity of habitats, refugia and migration corridors is to ensure reserves encompass significant environmental gradients of temperature, altitude and rainfall across landscapes (Pressey this volume).

Reduce threatening processes at the landscape scale

Recovering resilience for natural systems requires significant reduction of threatening processes. The weaker natural systems are from multiple threats, the greater the likely impact of the additional stresses of climate change.

The major threats impairing natural resilience to climate change are:

- Land clearing and resulting loss and fragmentation of core habitats and migration corridors;
- Unsustainable extractive land use activities, primarily livestock grazing and logging;
- Changed hydrology and extraction of water;
- Invasive weeds and animal pests;
- Inappropriate fire regimes (intensities, frequencies and timings).

Climate change may make many existing threats worse:

- Bushfire risk becomes more extreme with climate change-induced drought and high temperatures;
- Exotic species invasions may be enhanced as native ecosystems come under stress;

- Escalating economic demands and shifts in human populations due to climate change may result in more water extraction and conversion of natural areas to agriculture and settlements (Dunlop, Pickering, Pressey this volume).

In particular the largely intact northern savannas and rivers face renewed efforts to intensity agriculture as prolonged drought and unsustainable practices reduce production in the southeast of the country (Blanch this volume).

A precautionary approach requires prevention of land clearing, water diversion and intensification of uses in remaining natural areas in order to preserve options for a comprehensive climate adaptation response.

Some of these threats are eliminated by creating protected areas. However protected area boundaries rarely contain all necessary elements of high conservation value native ecosystems and must be managed in conjunction with adjoining lands. Some threats like feral pests and weeds can only be managed both on and off reserves. Continuance of threats through poor management practices on adjacent off-reserve lands can detract from the protection provided by the reserve system.

To best deal with threats comprehensively, threat management has to be coordinated across land management agencies at appropriate scales. Bioregional approaches by definition incorporate the full physical variation of natural environments into landscape planning and so are the most appropriate tools. For transboundary and whole-of-nation climate change threats to protected areas, a new, co-operative and integrated management plan is needed, in addition to individual state, territory and Commonwealth initiatives (Worboys this volume). Given adequate financial resources, this will ensure that critical climate change threats that affect multiple bioregions and jurisdictions are dealt with systematically and effectively.

Fire

There is significant pressure to control fires on reserves primarily to protect built assets on neighbouring lands. Fire management agencies must recognise that the prime purpose of protected areas is natural asset protection and must adopt an ecological approach driven by scientific evidence, goal setting, monitoring and evaluation.

Conversely, protected area managers will also have to accept that a new climate may bring a permanent change to fire regimes and ecosystems (Dunlop, McDougall & Broome this volume). They must:

- Find ways to manage species "turnover" as a result of changing fire regime, while minimising losses of key biodiversity assets; and
- Identify and protect fire refugia where natural fire regimes can feasibly be retained.

Invasive species

Invasive weed and pest species are a major threat to Australia's biodiversity and are expected to be climate change "winners" in general. They generally demand the greatest management effort of protected area managers (eg Pickering this volume).

Controlling or eliminating invasive species at a landscape scale by closely coordinating on-reserve and off-reserve control actions is essential to allow recovery of natural resilience.

At the same time efforts to stop new and emerging invasive species before they become problems need to be redoubled.

Conserve natural processes and connectivity at the landscape scale

WCPA has developed the concept of strategic, large-scale "connectivity conservation" in response to the extinction crisis (Worboys 2007). For example, WCPA supports the recent NSW Government initiative to create an "Alps to Atherton" climate change corridor in cooperation with neighbouring states.

Connectivity conservation focuses on maintenance and restoration of ecosystem integrity across entire landscapes. Connectivity is built around core habitats or refugia protected in reserves which are linked and buffered across different tenures and land uses in ways that maintain natural ecosystem processes. Such non-fragmented landscapes will better allow species and ecosystems to survive and move, thus ensuring that populations are viable, and that both ecosystems and people are able to adapt to land transformation and climate change. Connectivity conservation is a proactive, holistic, and long term approach which is achieved by agreements, incentive schemes, land-use planning, philanthropic actions, business transactions or other appropriate actions.

One element of connectivity is migration corridors allowing species to adapt to shifting climate zones to climate refugia (see above).

A second element is the maintenance of the natural processes and access to resources that the species needs to survive when they arrive and establish in those refugia such as:

- Food and water sources;
- Pollinators, dispersal agents and other beneficial species;
- Cover and shelter from enemies and weather;
- Nest, breeding and germination sites.

The challenges for connectivity conservation are to:

- Identify and enhance desired flows particularly for keystone, endangered and vulnerable species;
- Monitor and hinder threatening processes such as feral pests and weeds; and
- Coordinate these actions across tenures and land management regimes both on and off the reserve system.

Special interventions to avert extinctions

In some cases, climate refugia or core habitats cannot be maintained or are unlikely to persist naturally. Moreover, migration may not be possible. In such cases, intensive management may be needed to ensure valued species or ecosystems are not lost. This is of greatest concern for species whose high mountain habitats may disappear with climate change, with little chance of successful natural migration to refugia (Hilbert, Nevill, Pickering, McDougall & Broome this volume). However, such interventions may be less cost effective and more risky in the long term than protecting intact natural areas (Mansergh this volume).

Building effective climate response into protected area policy

The key directions identified above require immediate policy action at all levels. They certainly require the recognition that action is urgent and requires significant investment if Australia is to retain the natural wealth of its species and ecosystems and all the benefits they provide.

Many vital climate refugia, core habitats and migration corridors may presently occur outside reserves. Protected areas provide the most secure option for saving such important habitats. It is imperative therefore, that such critical habitat resources be identified and brought into the National Reserve System.

Where this is neither feasible nor cost effective, conservation actions outside the reserve system, that are well integrated with biodiversity protection and reserve system goals, have a valuable contribution to make.

Policy actions across five areas form the basis of our recommendations:

- Meet National Reserve System targets;
- Identify climate refugia and refine reserve system goals;
- Develop the inland aquatic reserve system;
- Integrate management across the landscape; and
- Sustain a high standard of reserve management.

Meet National Reserve System targets

Australia's national system of protected areas, the National Reserve System, is already making a vital contribution to a national climate adaptation strategy by: protecting source populations, refugia and migration corridors; reducing threats; and enhancing natural processes.

Meeting National Reserve System targets within agreed time frames plays the central role in enhancing natural resilience. These targets have already been agreed by Commonwealth, State and Territory governments. Securing Australia's biodiversity assets - native species, ecosystems and ecological processes- is a major national strategic issue, yet funding remains inadequate to service the commitments already made.

Major funding increases are vital as recommended by the 2007 Senate Inquiry into National Parks:

> "that in the upcoming NHT3 funding round the Commonwealth significantly increase the funding allocation directed to the NRS Programme" (ECITA 2007 p. vii).

The principal target is to protect representative samples of 80% of regional ecosystems within each bioregion by 2010-2015, with priority to endangered species and ecosystems.

A minimum cost estimate to meet this key reserve system target (presentation of Game *et al.* this volume) is now greater than the $400 million estimate based on land values in 2000 of Possingham et al (2002). Such figures signal the need for a detailed reevaluation of investment levels required to meet commitments.

Recommendations

1. Implement the targets for developing a Comprehensive, Adequate and Representative National Reserve System within timeframes agreed to in the 2005 Directions for the National Reserve System: A partnership approach, *as one of Australia's priority adaptation responses to climate change.*

2. For 2007-2012, all partners to invest at least $400 million in creating new reserves to meet the Comprehensiveness and endangered species targets for the National Reserve System, with the Australian Government contributing two thirds of acquisition costs or at least $250 million or $50 million a year.

Identify climate refugia and refine reserve system goals

Targets for Comprehensiveness and Representativeness of the reserve system, meaning the sampling of regional ecosystems at bioregional and sub-bioregional scales, are thought to be robust to climate change (Dunlop this volume).

However, selection of reserves needs to be more precisely targeted within this sampling scheme to protect:

- Climate refugia;
- Key ecological processes; and
- Key migration corridors or stepping stones.

Our understanding of what is an "Adequate" reserve system needs to be more clearly defined in the light of climate change (Young, Dunlop this volume). In particular:

- The nature of the protected biodiversity assets and their ecological needs may change;
- Replication of protected populations and ecosystems will need to increase;
- Larger reserves will be needed to ensure populations remain viable and to absorb higher levels of disturbance; and
- Complementary conservation efforts in off-reserve areas will become more important.

Recommendations

3. By 2009 re-evaluate and revise the NRS directions in the light of climate change, using more detailed modelling and decision analysis to better define:

- *Key source populations and habitat, climate refugia, migration corridors and stepping stones;*
- *The resilience to climate change element of reserve system adequacy;*
- *Priority bioregions and ecosystems for reservation effort;*
- *Priority inland aquatic systems for reservation effort; and*
- *Costs and responsibilities for meeting targets.*

4. By 2008 the Australian Government to establish a National Climate Refugia Program to identify past and likely future climate refugia and critical habitats for endangered species and other matters of national significance, as part of bioregional planning.

Develop the inland aquatic reserve system

Particular attention will be needed for inland aquatic ecosystems. Despite the importance of water in this driest of inhabited continents, aquatic ecosystems are the most poorly protected in the existing reserve system (Nevill this volume). Advancing the inland aquatic reserve system is an already agreed *Direction* for the National Reserve System.

Recommendation

5. As a matter of urgency, the Australian Government in cooperation with the states and territories to develop a comprehensive national inventory and conservation status assessment of inland aquatic ecosystems and initiate a systematic and far-reaching expansion of Australia's inland aquatic reserve system.

Integrate management across the landscape

Numerous studies and reports over the last decade have endorsed the integration of off-reserve conservation initiatives with reserve system directions and management.

A bioregional approach to biodiversity conservation planning and management is needed to coordinate effective climate responses both on and off the reserve system, tailored to the needs of the plants and animals of the bioregion (Sattler this volume).

Off-reserve conservation efforts provide an important complement to the reserve system in responding effectively to climate change. Even if the size of the reserve system doubled overnight, it would still leave about 80% of the landscape open to development and extractive uses (Hilbert this volume). Conservation oriented management is urgently needed on public production lands like state forests, as well as private and leasehold production lands, through:

- Improved mitigation of production impacts;
- Stewardship and other conservation incentives; and
- Fire and invasive species control programs coordinated with programs on reserves.

Such efforts must entail significant land use reform, not the continuation of degrading land/water uses. They should be guided strategically by the value added to the leading role of the reserve system in enhancing resilience to climate change.

The degree to which surrounding lands and waters are sympathetically managed for conservation is recognised as a key contribution to the Adequacy of the reserve system. A comprehensive spatial database of off reserve conservation effort should be developed as a mechanism to document and account for this contribution and to facilitate integrated bioregional responses to climate change.

Regional Natural Resource Management (NRM) arrangements set up and funded through Natural Heritage Trust are a major vehicle for off-reserve conservation effort and land restoration efforts. There is an urgent need to bring regional NRM into a complementary relationship with the core activities of reserve system growth and management.

Bioregional planning is widespread but could be greatly expanded with already available tools and better integrated into NRM planning processes. The same high scientific rigour should drive both reserve system planning, and off-reserve conservation efforts.

Continental scale connectivity visions are invaluable in mobilising and integrating action beyond the bioregional scale to help address established biodiversity priorities including reserve system goals.

Examples include:

- The “Alps to Atherton” connectivity conservation initiative;
- WWF’s “North of Capricorn” tropical savannas and rivers initiative (Blanch this volume);
- The Gondwana link project, linking southwestern forests and woodlands;
- National free flowing rivers legislation (Nevill this volume).

Protected areas are far from “money sinks”. They generate return on investment even in conventional economic terms, not only from tourism but from ecosystems services. These strengths need to be reflected better in reserve system planning.

Spending by domestic and overseas visitors to protected areas can be considerable: of the order of $13.7 billion a year (TTF 2007 p. 20). The 10% of this amount representing Goods and Services Tax provides base revenue to State and Territory governments.

Protected areas provide ecosystem services such climate control, erosion, water pollution and flood control, pest control and pollination services which have immense value but generally go unrecognised by markets and national accounts.

However, tourism and ecosystem services are not the only yardsticks for measuring the value of protected areas. By far the greater value lies in protection of our nation's irreplaceable biodiversity assets. Although currently uncosted by markets, the high value placed on biodiversity protection by society is expressed through strong public support for government biodiversity investments and legislation.

Bioregional planning bodies should fully explore "conservation economy" incentives to help realise an effective climate adaptation response such as payments for biodiversity protection or stewardship services and ecotourism dependent on protected areas.

Recommendations

6. Evaluate progress on the National Biodiversity and Climate Change Action Plan 2004-2007 *and develop a new practical and concrete action plan based on bioregional planning. The revised plan should set targets and timelines for implementation, which agency/agencies are responsible, and how actions will be funded.*

7. By 2010, complete bioregional plans in key bioregions for development of the NRS that:

- *Anticipate changes in ecosystem dynamics (functions and processes) and species shifts due to climate change;*
- *Coordinate reserve system planning and management and off-reserve conservation efforts;*
- *Incorporate conservation economy opportunities to help realise outcomes;*
- *Significantly reduce threats to biodiversity assets across all tenures; and*
- *Coordinate effectively with climate change responses in other sectors - finance, agriculture, water use, coastal and marine management, urban and regional planning.*

8. By 2020 all jurisdictions coordinate priority bioregional plans including continental connectivity visions such as the Alps-to-Atherton and North of Capricorn initiatives, to meet established biodiversity priorities including reserve system goals.

Sustain a high standard of reserve management

The National Reserve System is a cross-tenure system encompassing government reserves, private land trust reserves, covenanted private lands and Indigenous Protected Areas. Taken together, they provide the best opportunity for whole-of-landscape conservation.

All these categories have different strengths and weaknesses but all have a role in building the reserve system as long as all are subject to standardised monitoring and evaluation protocols to ensure sustained effectiveness of management. National investments are needed to ensure high standards can be sustained across the reserve system.

Indigenous Protected Areas were recognised in a recent review as a successful formula for meeting both indigenous aspirations and biodiversity protection goals (Gilligan 2006). However the review also highlighted the need for a minimum base level of funding for ongoing management of IPAs. This need will become more acute with climate change.

The leading role of the National Reserve System in enhancing natural resilience of species and ecosystems to climate change needs to be strongly communicated to the community. The community also needs to be assured that the reserve system is being effectively managed to achieve climate change adaptation goals through, among other things, State of the Parks reporting at state and national levels (Worboys this volume). Nationally agreed evaluation areas and indicators would assist.

More frequent and severe flood, storm, and fire incidents will also affect protected areas and biodiversity assets. Current incident response efforts are generally not driven by biodiversity asset protection and are generally confined within single agencies. Management of major incidents and major threats has to be reoriented to biodiversity asset protection and coordinated on and off-reserve and across jurisdictional boundaries. This is best achieved by cross-agency and cross-jurisdictional task groups established through bioregional and national scale planning (Worboys this volume).

Recommendations

9. By 2008 Australian Government in collaboration with states and territories supports ongoing Indigenous Protected Area management through employment and capacity building for IPA rangers.

10. By 2009, all National Reserve System owners and managers adopt management standards, and a common monitoring, evaluation and reporting process for management of all protected area tenures in the National Reserve System.

11. By 2008 all National Reserve System partners adopt a State of the Parks reporting system as a basis for an national State of the Parks report following a common framework of standards and indicators including the extent to which the Comprehensiveness, Adequacy and Representativeness goals of the reserve system are being achieved.

12. By 2009, cross-agency threat management taskgroups are established as part of bioregional plans for key bioregions, and a national, integrated and cooperative plan for the management of national and transboundary climate change threats has been prepared, funded and is being implemented.

Summary of recommendations

1. Implement the targets for developing a Comprehensive, Adequate and Representative National Reserve System within timeframes agreed to in the 2005 Directions for the National Reserve System: A partnership approach, *as one of Australia's priority adaptation responses to climate change.*

2. For 2007-2012, all partners to invest at least $400 million in creating new reserves to meet the Comprehensiveness and endangered species targets for the National Reserve System, with the Australian Government contributing two thirds of acquisition costs or at least $250 million or $50 million a year.

3. By 2009 re-evaluate and revise the NRS directions in the light of climate change, using more detailed modelling and decision analysis to better define:

- *Key source populations and habitat, climate refugia, migration corridors and stepping stones;*
- *The resilience to climate change element of reserve system adequacy;*
- *Priority bioregions and ecosystems for reservation effort;*
- *Priority inland aquatic systems for reservation effort; and*
- *Costs and responsibilities for meeting targets.*

4. By 2008 the Australian Government to establish a National Climate Refugia Program to identify past and likely future climate refugia and critical habitats for endangered species and other matters of national significance, as part of bioregional planning.

5. As a matter of urgency, the Australian Government in cooperation with the states and territories to develop a comprehensive national inventory and conservation status assessment of inland aquatic *ecosystems and initiate a systematic and far-reaching expansion of Australia's inland aquatic reserve system.*

6. Evaluate progress on the National Biodiversity and Climate Change Action Plan 2004-2007 *and develop a new practical and concrete action plan based on bioregional planning. The revised plan should set targets and timelines for implementation, which agency/agencies are responsible, and how actions will be funded.*

7. By 2010, complete bioregional plans in key bioregions for development of the NRS that:

- *Anticipate changes in ecosystem dynamics (functions and processes) and species shifts due to climate change;*
- *Coordinate reserve system planning and management and off-reserve conservation efforts;*
- *Incorporate conservation economy opportunities to help realise outcomes;*
- *Significantly reduce threats to biodiversity assets across all tenures; and*
- *Coordinate effectively with climate change responses in other sectors - finance, agriculture, water use, coastal and marine management, urban and regional planning.*

8. By 2020 all jurisdictions coordinate priority bioregional plans including continental connectivity visions such as the Alps-to-Atherton and North of Capricorn initiatives, to meet established biodiversity priorities including reserve system goals.

9. By 2008 Australian Government in collaboration with states and territories supports ongoing Indigenous Protected Area management through employment and capacity building for IPA rangers.

10. By 2009, all National Reserve System owners and managers adopt management standards, and a common monitoring, evaluation and reporting process for management of all protected area tenures in the National Reserve System.

11. By 2008 all National Reserve System partners adopt a State of the Parks reporting system as a basis for an national State of the Parks report following a common framework of standards and indicators including the extent to which the Comprehensiveness, Adequacy and Representativeness goals of the reserve system are being achieved.

12. By 2009, cross-agency threat management taskgroups are established as part of bioregional plans for key bioregions, and a national, integrated and cooperative plan for the management of national and transboundary climate change threats has been prepared, funded and is being implemented.

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2. Implications of climate change for the National Reserve System

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Abstract

Climate change is already having, and will continue to have, many impacts on species and ecosystems. While the details of future changes are uncertain there are some clear implications for biodiversity conservation and the National Reserve System (NRS) in Australia. The fundamental goal of biodiversity conservation needs to be reassessed and changed from, essentially "preserving biodiversity as is" to "managing changes in biodiversity to minimise losses". Many of the changes that will occur to biodiversity would most effectively be managed at the bioregional scales through coordinated efforts of different conservation programs and activities including protected areas and off-reserve conservation. Although many species may be threatened by climate change, the framework used to develop the NRS ensures that it will continue to provide effective and critical protection of a wide diversity of ecosystems and species. The added pressures on biodiversity suggest greater conservation effort may be required. Managers of individual reserves will be among the first to be confronted with many of the impacts. Many threats to biodiversity will change. Four particularly difficult changing threats will be: altered fire regimes, the arrival of new species, changing land use and altered hydrology. Managers, researchers and policy developers will all need new types of information to help them anticipate and respond to climate change.

Introduction

Increases in the atmospheric concentration of CO_2 and other greenhouse gases will lead to changes in temperature and rainfall, and the occurrence and intensity of storms, wind, run-off, floods, droughts, fires, heat waves and other aspects of climate (IPCC 2007).

These changes affect primary productivity and many biological processes; hence there is every reason to believe many, if not virtually all, species on Earth will be affected. Many different types of impact have been hypothesised. Extensive modelling and monitoring studies over the last ten years provide considerable evidence that global climate change is affecting, and will continue to affect many species and ecosystems, including leading to declines and extinctions of many species (Hughes 2000, 2003; Walther 2002; Parmesan & Yohe 2003; Root *et al*. 2003; Lovejoy & Hannah 2005; Parmesan 2006). However, because of the interacting nature of biological and ecological systems, with their positive and negative feedbacks, and the multifaceted nature of the environmental changes in response to climate change and other pressures, it is not immediately obvious what the net impacts on biodiversity are likely to be.

In short, climate change will affect many aspects of Australia's biodiversity that are valued by society including the "look, sound and smell" of ecosystems, tourism and recreational opportunities. Significant reductions of diversity would be likely to also result in interruption to ecosystem function and loss of ecosystem services (Chapin *et al*. 2000). These changes will also have a wide range of

Dunlop M. & Brown P. (2007) Implications of climate change for the National Reserve System. In: *Protected Areas: buffering nature against climate change. Proceedings of a WWF and IUCN World Commission on Protected Areas symposium, 18-19 June 2007, Canberra.* (eds M. Taylor & P. Figgis) pp. 13-17. WWF-Australia, Sydney.

impacts on biodiversity conservation and the National Reserve System. These include a need to reassess some of the fundamental goals of biodiversity conservation, managing ever changing biodiversity, dealing with new and changing threats, and responding to different information needs.

Impacts of climate change on biodiversity

We present a scheme for considering the many different types of impacts on biodiversity in terms of a “cascade of impacts” from climate change through individual organisms, species and ecosystems to human wellbeing (Fig. 1).

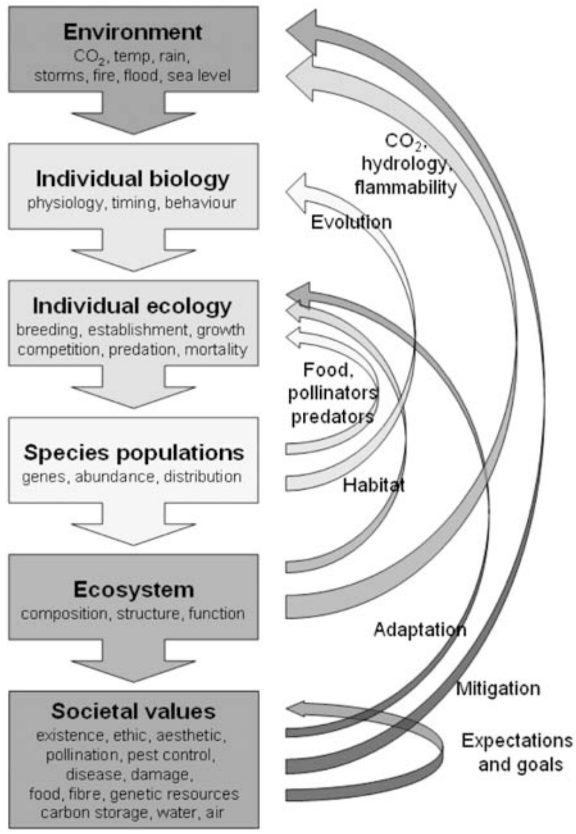

Fig. 1. Schematic representation of cascading impacts resulting from environmental changes caused by climate change. A series of flow-on effects occur down the figure, but there are important feedbacks indicated back to earlier stages of the cascade.

Environmental impacts include the changes arising from increased greenhouse gas (GHG) concentrations that drive impacts on biodiversity; they include changes in CO_2, temperature and rainfall regimes climate, fire regimes, and sea temperature, chemistry and level. These impacts clearly combine with other non-climate-related environmental stresses on biodiversity, and are affected by feedbacks from population and ecosystem impacts (e.g. affecting hydrology and flammability - below).

Biological impacts include the direct changes to organisms arising from environmental changes; they take in physiological and behavioural changes and include changes in the timing of life cycle events (phenology).

Ecological impacts result from changed interactions between organisms and the environment; they include changes in breeding, establishment, growth, competition, and mortality. These impacts result directly from climate change related impacts (above), and indirectly via interactions with other species that are affected by climate change leading to changed competition, food, habitat and predation. These indirect impacts can be represented as a feedback from population impacts and possibly ecosystem impacts (below) to ecological impacts. For some species these indirect impacts may be stronger than direct impacts. Ecological impacts are also affected by how climate change impacts interact with other stresses.

Population impacts: the ultimate impact on species in terms of changes in abundance and distribution.

Ecosystem impacts: changes in the identity, composition, structure and function of assemblages and ecosystems.

Value impacts: representing the reason society cares about climate change and biodiversity. These can be thought of as impacts on human wellbeing and they include:

- Economic and other material benefits derived from consumptive and non consumptive uses of biodiversity; e.g. production of food and fibre; pollination and pest control, as well as damage and diseases; regulation of water and air quality; and carbon storage and cycling, and
- Less tangible values such as: concern for the existence of species and ecosystems; a land ethic, “caring for country,” stewardship of the planet for future generations; and aesthetics and recreational values.

The downward arrows in Fig. 1 show the direct flow of impacts arising from climate change, some impacts may be very rapid and others may take decades of centuries to materialise. There are also many feedbacks that will lead to indirect impacts. Some of these are indicated by the upward arrows on the right of the diagram.

The dominant impacts on some species will not be direct climate impacts but because species with which they interact strongly (right-hand arrows) are affected in some way. Feedbacks can also lead to evolution of the response of species to climate and other environmental parameters, altered habitat and changed environmental parameters.

Human responses can also be represented as feedbacks, including reductions in greenhouse gas emissions, ecological management to facilitate adaptation, and altered expectations about the state and dynamics of biodiversity.

These cascading impacts on biodiversity will interact with other human pressures on biodiversity, including habitat degradation and loss, extraction of water, alteration of flow regimes and introduction of exotic species. Not only will climate change impacts add to these other pressures, they will interact, altering the way species and ecosystems would otherwise respond and adapt.

Implications for biodiversity conservation and the National Reserve System

In February 2007, a workshop was held at CSIRO Sustainable Ecosystems in Canberra drawing together a diverse group of conservation planners, reserve system managers and stakeholders to examine the implications of climate change for Australia’s terrestrial reserve system. Following the workshop a series of key challenges were identified for the National Reserve System (NRS) that are likely to arise as a result of the many and cumulative impacts of climate change on biodiversity. While focusing on the implications for the development and management of the NRS, many of the issues have broader implications for all conservation programs.

The changing nature of biodiversity conservation

Climate change will have a significant impact on biodiversity leading to changes in species and ecosystems. Some of these changes will result in loss of biodiversity values which will present many new challenges to Australia’s conservation programs including the NRS. Conserving communities may no longer be necessary or sufficient for conserving species. Understanding these challenges is a complex task for planners, managers and conservation stakeholders. Climate change could require a fundamental change to the very nature of Australia’s conservation goal from “preserving biodiversity as is” to “managing changes in biodiversity to minimise losses”.

In this context it may be useful to explicitly recognise two complementary goals:

- To facilitate natural adaptation and change in biodiversity; and
- To preserve elements of biodiversity that are threatened by climate change and particularly valuable to society.

In some situations these goals might require quite different management responses. For example increasing connectivity might facilitate the evolution of ecosystems and shifting of species distributions, but increasing connectivity may also accelerate the demise of vulnerable species by making it easier for competitors or predators to establish.

Bioregional conservation planning

There would be significant benefit to a coordinated approach, across scales and the diversity of conservation programs, to address these challenges. The bioregional framework used in the NRS would provide a solid basis for coordination of goals, assessments of biodiversity condition and threats, planning, investment prioritisation, and monitoring and evaluation. Then appropriate and complementary implementation targets could be developed at the scales relevant to each of the different delivery programs (e.g. NRS, threatened species, Natural Heritage Trust, Landcare, non-government organisations).

Implications for development of the NRS

There are implications for both development and management of the NRS. The process for achieving comprehensiveness and representativeness of the NRS provides an excellent basis for developing a protected area system that practically conserves as many species as possible through providing a system of areas that will always support a wide diversity of landforms and habitats even as ecosystems change.

The question of adequacy is much more challenging; in general, larger areas and more populations of species will be required to provide the same level of viability for species as could be expected without climate change; however it is probable that some species will become extinct regardless of how much area is reserved.

In addition, the adequacy of the national conservation program will be enhanced by coordinated efforts across programs to strategically address landscape scale objectives such as managing connectivity and threats.

Implications for management of reserves

In the near-term there will probably be greater impacts on reserve management than development of the reserve system. Managers will be directly confronted with changing species and ecosystems, and the challenge of managing the changes to minimise losses in the face of considerable uncertainty. They will also need to manage changing and new threats, and will require new types of information much of which will not be available, especially in the short term. It will also be managers who face the impact of institutional lags in responses to the new realities of climate change while society considers the implications, policies and guidelines are revised and information emerges.

Changing threats to biodiversity

Many threats to biodiversity will change as a result of climate change. Four key changing threats will be: altered fire regimes; the arrival of new species; changing land use; and altered ground and surface water systems. Each of these threats has strong biophysical and social dimensions, greatly complicating management of their impact on biodiversity.

Strategic approaches to managing biodiversity

The changing nature of biodiversity and biodiversity conservation will affect the balance between single species and strategic conservation programs, with logical arguments for the need to increase efforts in both.

There will also be a need to clearly define the role of species, community and ecosystem level information and aspirations along the conservation "value chain" from: ecological knowledge, conservation aspirations, planning processes, data, and management goals right through to national conservation outcomes.

For example, while the close conceptual links between species and communities dissolve over time, information about the contemporary spatial patterns of communities may still be very useful in planning for conservation of species as climate changes.

Information needs

Due to the changing nature of biodiversity, new threats and evolving conservation goals, new types of information will be needed by managers, planners, researchers and the general community to fulfil their respective roles. Acquiring much of this information will require carefully designed and concerted monitoring programs. Increasingly, planning will need to consider future changes the details of which will be quite uncertain.

Conclusion

While there is considerable uncertainty about exactly how species and ecosystems in any specific region will be affected by climate change, many actions can be undertaken now to begin to address some of the implications for biodiversity conservation and the National Reserve System.

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3. Managing Australia's protected areas for a climate shifted spectrum of threats

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Abstract

Climate change directly and indirectly threatens many of the values of Australia's more than 7720 protected areas. Management organisations need to respond to such threats to minimise impacts, to slow change effects and to help build resilience for natural ecosystems. Strategic, tactical and operational planning responses are needed by individual protected area organisations to achieve effective threat responses. In addition, because of Australia's constitutional land management accountabilities, a supplementary strategic plan is recommended to respond to whole of Australia and transboundary protected area climate change threats. Such a plan is based on an integrated and cooperative management approach involving multiple protected area organisations and is modelled on the cooperative governance method used by the Australian Alps protected area agencies.

This plan needs to consider seven strategies for implementation by the eleven government and other protected area organisations which include: responding to key threats; an informed Australia; unified national climate change policies; Australian "State of the Parks" reporting; enhanced research; targeted greenhouse gas reductions; and, a national incident response capacity. These national responses would contribute benefits to communities including improved protected areas; better (and more local) climate change information; improved water catchments; improved fire management; and the conservation of many of Australia's iconic species. Given Australia's comparatively lower average per hectare investment in protected area management for a developed country, new finances will be needed to achieve the implementation of such a plan.

Introduction

Protected areas are Australia's single greatest land-use after agriculture and in 2005 they occupied 10.25% of the continent and included 7720 marine and terrestrial reserves (UNEP-WCMC 2005). All of these areas required active management to maintain the purposes for which they were established, and this purpose has been recognised by the International Union for the Conservation of Nature (IUCN) in their definition of protected areas which states:

> "protected areas are an area of land/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means" (IUCN 1994).

They are important for society since they help maintain healthy environments and contribute directly to healthy people. There are multiple threats to such areas, and climate change has exacerbated many of these as well as introducing new threats. This paper identifies some Australian protected area management responses to these climate change threats.

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Background

Managing protected areas

Australia's Constitution and federal system of government (essentially) delegates land management to the eight states and territories. This requirement, as well as the Commonwealth's responsibilities for external territories and territorial waters has helped establish eleven government protected area management organisations (Worboys 2007a). These include eight organisations managed by the States and Territories as well as Parks Australia, The Great Barrier Reef Marine Park Authority and the Queensland Wet Tropics Management Authority. The areas managed are dominated by IUCN Protected Area Categories I-IV (UNEP-WCMC 2005) which means that there is an emphasis on natural and cultural heritage conservation (IUCN 1994). There are other Australian protected area governance types and these include Indigenous Protected Areas and Private Protected Areas (Worboys *et al.* 2005; Lockwood *et al.* 2006). A range of use and non-use values are conserved by Australia's protected areas.

Values of protected areas

The values of protected areas include use values from direct use and ecosystem services, and non-use, ecocentric or intrinsic values. Intrinsic values include biodiversity, geo-heritage, soil, water, air, scenic, amenity (such as areas free of artificial light and noise), natural phenomena (such as fire and weather), recreation, wilderness, cultural-site, cultural place and spiritual values (Worboys *et al.* 2005). Many of these values are threatened by climate change and active management can help maintain their conservation status.

Forecasts of climate change threats to protected area values

The Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC 2007) forecasts a range of climate changes that will directly and indirectly threaten protected area values. There are forecast mean temperature increases of 1.3-1.7 ^{0}C to 2055, (and 1.7-4.0 ^{0}C to 2095), and sea level rises of 0.19-0.58 metres by 2100 (IPCC 2007; Pearman 2007). Some of the resulting threats to values include marine inundation of coastal lowlands; coral bleaching of the Great Barrier Reef; the poleward shift of plant and animal ranges; the altitudinal shift of animal and plant species such as in the Australian Alps national parks; impacts by introduced species and more frequent and severe bushfires (NRMMC 2004; Pittock 2005; Lowe 2005; Lockwood *et al*. 2006; Steffen 2006; IPCC 2007; Pearman 2007). Substantial changes and impacts to Australian environments and communities may also place social and political pressure on politicians to change aspects of protected areas and their management.

Context for threat management

Climate change will require astute and responsive management by our protected area leaders and managers over the next forty years and beyond. Managing the social and political roller-coaster that parallels climate change impacts to communities will be critical. When climate change impacts are combined with other global change factors (such as population growth, competition for resources and post "peak oil" effects) (Lockwood *et al.* 2006), there will be potential for social instability and reactive political responses (Mason 2003; Heinberg 2006). A key challenge will be to help achieve a community view that is supportive, that values protected areas and considers them to be critical for the long term health and well being of society.

Rationale for responding to climate change threats

A rationale for responding to climate change threats relates to the purpose for which protected areas are reserved (IUCN 1994; Welch 2005; Worboys 2005; Dunlop 2007a,b). It includes:

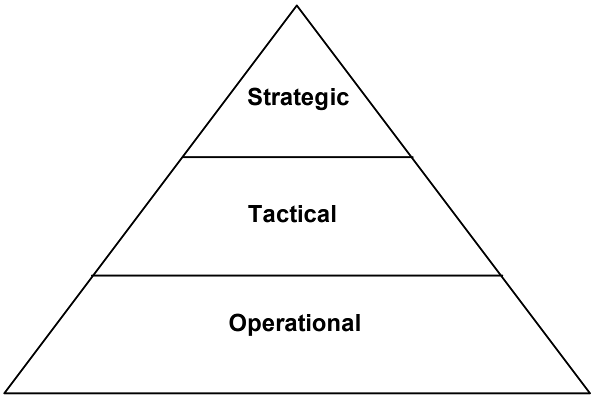
- Protected areas help conserve natural and cultural heritage values and healthy environments, including the diversity of life on earth and essential ecosystem services needed for humans such as clean air and clean water;
- Human-caused climate change or global warming is a world wide phenomenon and introduces non-natural changes to the values of protected areas;
- Management intervention to minimise threats and maximise resilience to the values of protected areas will help slow the rate of change, will help conserve species, and will help maintain healthy environments; and
- Healthy environments maximise opportunities for the provision of ecosystem services and for the retention of the diversity of life on earth.

Principles of management: responding to climate change threats

Eleven key management principles guide how protected area management organisations can respond effectively to climate change threats. They are:

- People and governments worldwide have a responsibility to respond to climate change causes, and to minimise such effects to help retain a healthy, life-sustaining planet;
- Organisational planning for climate change adaptation and responses at strategic, tactical and operational levels of protected area management are fundamental management responses to climate change threats;
- Researching, modelling, and forecasting the effects of climate change are essential adjuncts to such adaptation planning and will assist in minimising surprises;
- Unexpected climate change threats are inevitable, and identifying and monitoring such threats requires research, the monitoring of key values of protected areas and assessing their change in their condition over the long term;
- Climate change threats to Australia's protected areas can be minimised by an effective and climate change responsive national reserve system design, an expanded reserve system, and by effective and strategic continental scale connectivity conservation;
- Greenhouse gas emissions can be minimised by protected area organisations by implementing quantified emission reductions, evaluating performance and instigating adaptive management improvement responses;
- Climate change induced biome shifts will alter the composition of biodiversity of protected areas, but the same protected areas will remain critical for conservation of different mixes of natural habitats and species and will be essential as a continued and integral part of the national reserve system;
- Climate change biodiversity refugia exist and will require identification and special management responses;
- Climate change will introduce changes and uncertainty, such that risk management and anticipatory approaches to management will be important;
- Other special values of protected areas including social, spiritual, cultural and recreational values may be threatened by climate change and may require particular management responses; and
- Cooperative and integrated management responses to climate change threats will be important at a range of different levels in Australian society (Welch 2005; Worboys 2005; Worboys *et al*. 2005; Dunlop 2007a,b; Pearman 2007;).

Protected area organisational levels



Strategic responses:
(For a national, cooperative and integrated response by eleven government and other protected area organisations)
1. Responding to key threats
2. An informed Australia
3. Speaking with one voice: climate change response policies
4. Telling it as it is: a national "State of the Parks" report
5. National research: protected areas - the coal miner's canary
6. Leading by example: reducing greenhouse gas emissions
7. Mobilisation: a national incident response capacity

Tactical responses:
(For an individual protected area organisation)
1. Landscape level, bioregional threat response planning
2. Protecting water catchments
3. Preparing for wild fire events
4. An integrated approach to pest animal and weed control
5. Responding to incidents
6. Preparing for new tourism
   - No snow
   - Bleached reef
   - Eroded beaches
   - Salty wetlands
   - Hot summers

Operational responses:
(For an individual protected area organisation)
1. Baseline and change of condition research, and regular state of park assessment
2. Research, task planning and adaptive management that achieves:
   - Ecosystem and catchment health
   - Responsible fire management
   - Endangered species survival
   - Pest animal reduction
   - Weed reduction
   - Sustainable visitor use.
3. Informing and working with local communities (especially for incident management)
4. Investing in staff training and competencies to deal with climate change threats
5. Minimising the generation of greenhouse gases

Fig. 1. Strategic, tactical and operational organisational planning responses to protected area climate change threats.

Goals: climate change threat management

Based on the purpose of protected areas and principles of climate change threat management, the key goals for managing threats include:

- A healthy, resilient, and adaptive National Reserve System that comprehensively, and adequately represents Australia's full range of natural environments and other values including ecosystem services;
- The strategic conservation of large, unfragmented, and interconnected natural landscapes; climate change refugia; and key protected area values of long term significance to the community;

- A national, integrated and principled response to climate change threats by protected area management organisations and governments; and
- An informed and supportive Australian community.

Climate change threat management

Managing for climate change threats includes the functions of planning, organising, leading and monitoring (Worboys *et al.* 2005). This paper focuses on planning at strategic, tactical and operational levels (Bartol *et al.* 1998) with action at all three organisational levels required for an effective threat response by protected area agencies.

Strategic responses

Strategic plans articulate the major long term (greater than three years) actions that are necessary to deal with climate change threats. For Australia, this includes three types of protected area management strategic responses:

- Individual organisation responses;
- An integrated, cooperative, whole-of-nation response by many protected area organisations and governments to transboundary and national climate change threats; and
- International responses such as for international migratory animal species.

For the whole of nation response, seven integrated cooperative strategic responses are recognised as being critical (Fig. 1) and these are presented in more detail below.

Tactical responses

Tactical planning provides more detailed articulation of climate change threat goals and strategic actions for an individual organisation and is typically undertaken by middle level managers. Tactical plans develop integrated responses to threats at a landscape or bioregional scale and often involve a range of private and government organisations, especially local government. Six key tactical planning responses for climate change threat management are identified as being needed by individual Australian protected area management organisations (Fig. 1).

Operational responses

Operational planning is typically undertaken at an individual protected area level and implemented as individual actions. Cumulatively, the results of these actions help to achieve the planned tactical and strategic threat outcomes sought by organisations. Five key operational responses to climate change threats have been identified (Fig. 1).

A national response to protected area climate change threats

Given that strategic planning for a protected area organisation is important, one type of such planning is described in greater detail here. There is a need for an Australian response to climate change that integrates the efforts of all eleven protected area organisations. It is a cooperative response to climate change threats in addition to individual organisational strategic responses.

One of the great strengths of the Australian Constitution is that it has facilitated a protected area system managed by eleven separate protected area organisations. For Australia's huge 7.68 million km^2 land area, this ensures local, State and Territory management relevance, and inspires constructive competitiveness and innovation in protected area management for our nation.

Because of this and our developed status, Australia's protected area management organisations have been recognised as world leaders in their field. However, one of Australia's great national weaknesses is its current inability to achieve effective national responses to protected area climate change threats (ECITA 2007).

Models for integrated and cooperative management consistent with Australia's Constitution, involving many protected area organisations already exist, such as the Australian Alps Liaison Committee (Crabb 2003) and could provide guidance for how an integrated approach is achieved. It would need to involve all eleven state, territory and Commonwealth protected area organisations and would be guided by a single cooperative strategic plan.

An integrated national plan is recommended as an important response to Australian protected area climate change threats and seven strategies have been identified for such a plan (Fig. 1). With the conservation of protected areas as a catalyst and focus for threat responses, the trans-boundary and national action would be undertaken as a team effort by appropriate protected area organisations. The actions would operate at a landscape or bioregional scale and potentially would involve many other organisations, communities and individuals. The seven strategies identified account for some of the *National Biodiversity and Climate Change Action Plan* actions (NRMMC 2004) and recognise the recommendations of the Biological Diversity Advisory Committee's 2003 climate change report (CSIRO 2003). They are discussed in more detail below.

Strategy 1: Responding to key threats

Strategic preventative and response actions to climate change threats will help to conserve protected area values and these are described.

Meet the National Reserve System targets

Building a comprehensive, adequate and representative National Reserve System (NRS), as already accepted as a target by all Australian jurisdictions, will help Australia minimise climate change threats to protected areas (Gilligan 2006a,b; Sattler & Glanznig 2006).

Implement continental-scale connectivity conservation

Achieving continental scale connectivity conservation for some of Australia's very important and very large remaining natural and interconnected areas (such as the Alps-to-Atherton corridor proposal "A2A"), in addition to the NRS, will help to minimise climate change threats to protected areas and help maintain healthy environments (Pulsford *et al.* 2004; Soule *et al.* 2006; Worboys 2007b).

Respond to altered fire regimes

More frequent and extreme fire events are forecast (Lucas 2007) and they highly probably will transgress state and territory boundaries from time to time, as evidenced by the 2003 Australian Alps fires (Worboys 2003). A national and integrated fire management response for protected areas is advised to help minimise the impacts to both natural and built assets from the fire event and form operational responses to the fire.

Manage for healthy catchments and water yield

Managing protected area catchments to help maintain maximum water yield over the long term is a critical investment. Climate change enhanced threats including fire, pest animals, weed invasions will need to be managed carefully. Strategic catchments such as the Australian Alps for the Murray Darling Basin (Williams & McDougall 2007), and A2A for the eastern forests of Australia and its four capital city and eastern Australian town water storages (Pulsford *et al.* 2004), are two examples of important national needs. Managing for the use and recharge of ground water is also important.

Reduce introduced animal and plant impacts

Introduced animals impact most protected areas in Australia and require active management. Many nationally significant introduced pest animals transcend state and territory borders and have the potential to expand their impacts with climate change. They need to be targeted and controlled over the long term using a national response. Actions to deal with new pest animals will also be needed (ECITA 2004).

Climate change will assist many introduced plants to spread and impact protected areas (Pickering *et al.* 2004). They will need to be dealt with at a landscape scale.

Strategy 2: An informed Australia

Changes to protected areas such as vegetation, stream flow and the presence or absence of animals will happen. This needs to be forecast by scientific modelling and formally identified as changes happen. Community awareness and understanding is needed to help deal with these changes. Protected area managers should not be put in the position of being blamed for the consequences of climate change effects. Communicating climate impacts will be a very long term program and will need effective two-way communication.

Strategy 3: Speaking with one voice- climate change response policies

Climate change threats will introduce a range of social and ethical issues that will need to be addressed. Some of these will have national application, and a common approach by protected area organisations ("speaking with one voice") will have benefits. Developing such national policies would include community consultation and debate. Some policy responses to climate change threats needed include:

- Establishing conservation priorities amongst alternatives such as the conservation of genetic diversity, the targeting of specific ecosystems or even specific species (Dunlop 2007ab);
- Identifying if and how carbon trading and water catchment conservation incentives may be used to resource responses to climate change threats;
- Recognising that protected areas will remain a valuable part of the National Reserve System even if native ecosystems and species protected might change in type and composition;
- Establishing legal and managerial responses for administering long term tourism leases and licenses for destinations impacted by climate change (such as snow loss, bleached reef, salinisation of freshwater wetlands, wildlife decline); and
- Identifying common, baseline standards for greenhouse gas reduction targets.

Such policy statements could be part of a suite of climate change information made available to the community.

Strategy 4: Telling it as it is: An Australian "State of the Parks" report

Integrating strategic evaluation information from eleven protected area management organisations could provide an Australian "State of the Parks" assessment. As exemplified by Parks Victoria's 2007 State of the Parks report (PV 2007), it could provide a five yearly conservation status assessment for protected areas and the benefits they are providing for Australians. It could include catchment protection and water yield, fire management, species management, and responses to climate change threats reporting. Trends in threats and the conservation status of many key species and climate change refugia could also be reported. This would require national agreement on evaluation subjects and selected evaluation indicators, but would provide a single source of information needed for Australia's five yearly State of the Environment report.

Strategy 5: Research: protected areas, "the coal miner's canary"

A great deal of Australia's pre-European biodiversity stabilised over the past 6000 years under a relatively uniform climate regime and stable indigenous Australian presence and use of the landscape. Protected areas represent vestiges of such lands. Some high diversity rainforest refugia, such as the Queensland Wet Tropics (White 1994; McDonald & Lane 2000), the Central Eastern Rainforest Reserves (Adam 1987) and some valleys of the NSW Wollemi National Park (Jones *et al.* 1995) conserve even more ancient habitats and species.

Protected areas therefore provide a perfect baseline to measure changes to the environment, and as such, can provide a service to the community by providing advice of change in condition from this measure (Welch 2005). A nationally coordinated and funded approach to such long term monitoring in protected areas would provide a clear indication of climate change effects for Australians.

Some of this monitoring work is already happening in protected areas. Any serious environmental shifts would become evident and the overall monitoring information in effect becomes "a coal miner's canary" warning system for Australia. Such research information means that managers and local communities can be better informed about: 1) immediate forecast climate change effects; 2) what management responses are possible; 3) what benefits existing management responses are providing and how they can be improved; and 4) the implications of climate change for the longer term (DEH 2002; IPCC 2007).

Strategy 6: Leading by example: greenhouse gas reductions

Australia's protected area organisations need to lead by example in reducing their greenhouse gas emissions. They need to assess their emission impacts, establish reduction targets and publish their reduction results. Targeted reductions for protected area management would need to include big energy use areas such as for aviation, motor vehicle fleets, heavy plant operations, office air-conditioning and other (non-green) electricity consumption. However, all aspects of direct and indirect energy consumption such as waste management and purchasing practices and offsets need to be considered.

Public scrutiny of greenhouse gas emissions will be heightened with time, and the community will demand full accountability, especially for environmental management organisations. However, greenhouse gas reductions will be more difficult when managing for incidents such as fire operations, given they rely on helicopters and other high energy users. Such consumption may require the use of responsible offset schemes to achieve targeted reductions, and could include the rehabilitation of disturbed protected area lands.

Strategy 7: Mobilisation: A national incident response capacity

More frequent and severe flood, storm, and fire incidents are forecast (Dunlop 2007a,b; IPCC 2007; Pearman 2007). They will impact protected areas, and many incidents will be large, complex and prolonged and will require substantial staff and equipment resources. If a capacity to mobilise and share national protected area management resources existed across Australia, it could assist individual organisations. Major and prolonged incidents can quickly "burn-out" the professional staff available and relief support would be helpful. Mobilisation of staff and equipment resources already occurs intrastate and the concept of mobilising interstate protected area management resources could be developed quickly.

There is potential to achieve such mobilisation. In 2005, the eleven Australian protected area management organisations employed 5818 people, with most states and territories employing between

200 and 1400 staff (Worboys 2007). This would also introduce a new level of professional training and co-operation between the protected area management organisations of Australia.

Financing an integrated national response plan

In 2005, Australia spent about one third less per hectare on average on protected area management than other comparable developed countries. The national average level of investment by Australian governments was estimated from Commonwealth, State and Territory data to be $7.69 per hectare of protected area (Worboys 2007), and this was lower than world standards where estimates of approximately $12.50 per hectare were identified as being needed for most developed countries (James *et al.* 1999), despite considerable variation in investments by countries (Balmford *et al*. 2003). If a national response is to be achieved, it would need to be resourced by new climate change threat response funds. It is critical that such new resourcing is achieved.

Conclusion

Protected areas will be impacted by climate change threats, and management responses are needed to mitigate impacts, increase the resilience of healthy environments, help protect water catchments, conserve key species, provide protection and support to communities and slow the rate of the inevitable changes that will occur. Management planning responses to these threats are required at strategic, tactical and operational levels for each of Australia's eleven government and other protected area organisations, with an additional national, integrated strategic plan also recommended for a whole of continent climate change threat response. Seven key national strategies are identified for such a national cooperative plan. With Australia's lower than average per hectare protected area funding investments for a developed country, additional and long term funding investments are needed to achieve strategic responses to climate change threats.

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4. Climate change and other threats in the Australian Alps

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Abstract

The importance of protected areas will increase with the impact of climate change, with climate change adversely affecting natural ecosystems in Australia and globally. Unfortunately, climate change is also likely to show negative synergies with many existing threats to protected areas.

For the Australian Alps National Parks, which conserve most of mainland Australia's snow country, predicted increases in temperatures and changes in precipitation will result in a dramatic loss of snow cover. These changes will increase existing threats associated with loss of biodiversity, intensive fires, diversity and abundance of feral animals and plants, human demands on ecosystem services and tourism uses.

By recognising the range of possible negative synergies, managers in these and other protected areas will be able to prioritise control and amelioration measures. They will also need to reduce their own contribution to greenhouse gas production, and assist in increasing public awareness of just how great the threats are from climatic change.

Threats to protected areas in Australia

Globally and in Australia the priority for protected areas is conservation of the natural values (Lockwood *et al.* 2006). Threats to these natural values such as those from fire, weeds, pest animals, urban encroachment and climate change are all core issues for the effective management of protected areas (Worboys 2007).

Global temperatures have risen by approximately 0.74°C in the past 100 years with the Fourth Intergovernmental Panel on Climate Change (IPCC) reports predicting that without intervention this trend will continue (IPCC 2007a). By the end of this century global temperatures are predicted to increase by 1.8°C to 4°C with higher latitudes having the greatest warming (IPCC 2007a). It is predicted that climate change will cause major environmental and economic impacts particularly from increases in the frequency of extreme weather events such as bushfire, droughts, floods and heatwaves in Australia (Hughes 2003; Pittock 2003; IPCC 2007a,b).

In addition to global increases in surface temperatures, climate change is already affecting the alpine environments including: increase in the size of glacial lakes, reduction in the size and number of glaciers, increase erosion events in mountains and areas that had permafrost and changes in snow fall patterns (IPCC 2007a,b). Biological response include changes in the timing of event such as arrival of birds, butterflies, flowering of plants, changes in the distribution of species and resulting changes in biodiversity (Hughes 2003; Parmesan & Yohe 2003; Root *et al.* 2003; IPCC 2007b).

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Synergies between climate change and current threats to protected areas

Climate change will interact with many existing threats to protected areas, unfortunately usually resulting in even greater negative impacts on the environment. This includes increasing the threat from:

- Loss of biodiversity from increasing fragmentation of habitat, disturbances to ecosystem processes and/or alteration to the timing of events critical for species survival (migration patterns etc, Hughes 2003; Pittock 2003; Parmesan & Yohe 2003; Root *et al.* 2003; IPCC 2007b).
- Increase in risk of intense fires: Extreme fire events are predicted to increase in Australia as a result of climate change (Williams *et al.* 2001; Hughes 2003; Pittock 2003). In Australia the management of fires is a critical issue for protected areas. Fire directly affects ecosystems, with some impacts needing management responses. Fire control also diverts resources away from other management activities. This includes resources used for fighting fires, and also for replacing burnt park infrastructure and rehabilitating fire trials. There will also be an increased potential for fire to spread from protected areas into urban areas in high risk periods, with resulting political and economic repercussions for protected area managers.
- Increase in pests and weeds: Climate change will benefit species best adapted to disturbance (Hughes 2003). Weeds and feral animals already benefit from disturbance, with their spread in protected areas directly related to past and current human disturbance (Williams & West 2000). Climate change will directly alter the areas suitable for exotic species by altering climatic patterns. It will also result in increase in disturbances that benefit weeds and feral animals (fires and extreme weather events). Ecosystems will experience increased stress from climate change increasing their suitability to invasions by exotics.
- Increase in human demands on protected area ecosystem services: Protected areas worldwide and in Australia provide a wide range of ecosystem services for local and wider communities (Worboys *et al.* 2001; Lockwood *et al.* 2007). In Australia this includes acting as water catchments with the water then used for generating hydroelectricity as well as for drinking and irrigation (ISC 2004). They are important sources of soil conservation, preserving existing soils, and reducing erosion and risks of landslides (ISC 2004). They also act as CO_2 sinks. All these services will be put under additional stress by climate change.
- Change in demand for tourism activities: Current visitation to tourism destinations including protected areas is weather/climate dependent (Maddison 2001). Changes in climate including increased risk of extreme weather related events will alter the patterns of visitation (Maddison 2001). In some places this may result in reduced usage, or changes in the types of activities that occur, while in others it may result in increased usage — a "see the Great Barrier Reef while its still there" reaction (Maddison 2001).

Direct and indirect impacts of climate change on the Australian Alps National Parks illustrate many of these issues that apply broadly to protected areas in Australia and around the world.

Mountains and Climate Change

Mountains are recognized worldwide for their important economic, cultural and ecological values (Harmon & Worboys 2004; ISC 2004). For example, they are important water catchments receiving precipitation and channelling it to lowland areas where it can be used in agriculture, for domestic services and for industries (UNEP-WCMC 2002). Mountains are also popular tourist destinations valued for their pristine wilderness, dramatic landscapes and natural beauty. The flora and fauna of mountains are often rich in endemic species and act as important biodiversity reserves (Harmon & Worboys 2004).

Predicted climatic changes may threaten the values of mountain environments (UNEP-WCMC 2002; IPCC 2007a). Increased temperatures and changes in precipitation have already been documented in many mountain areas around the world. These are already changing the distributions of animal and plant species in some protected areas (Nagy *et al.* 2003; Pauli *et al.* 2006; IPCC 2007b).

Significance of the Australian Alps

Snow country in mainland Australia occurs in the southern section of the Great Dividing Range in the southeast of the continent. Known as the Australian Alps, this area is almost entirely conserved in a series of linked national parks and nature reserves that are cooperatively managed by authorities in Victoria, New South Wales and the Australian Capital Territory. The region is considered to be of world heritage standard (Kirkpatrick 1994), although a proposal for nomination has not yet been made. The largest of the national parks, Kosciusko National Park (KNP, 690 411 ha), has been classified as a UNESCO Biosphere Reserve based on the international significance of its natural values (ISC 2004).

As with many mountain regions around the world, there are economic values associated with the natural assets of the Australian Alps (Good 1992; ISC 2004; Mules *et al.* 2005). The region is a highly valued tourist destination, worth the order of $40 billion, with varying estimates of visitor numbers including over a million visitors to just one park, Kosciuszko National Park. Visitors generate considerable spill over revenue, supporting local businesses and communities (ISC 2004; Mules *et al.* 2005). Catchments also provide much of southeastern Australia with clean water, some of which is channelled into the Murray-Darling Basin (Good 1992b; ISC 2004). The hydroelectricity generated by water from the region is also a critical resource (ISC 2004).

Predictions of climate change in the Australian Alps

The Australian Greenhouse Office has identified the Australia Alps as particularly vulnerable to climate change impacts (Green 1998; Hughes 2003; Pittock 2003; Pickering *et al.* 2004). Snow is spatially and temporally limited in Australia, compared to Europe, north and south America (Costin *et al.* 2000). Approximately 0.15% of the continent receives regular winter snow falls (Costin *et al.* 2000). The most extensive snow covered areas are in the southeast of the continent in the Snowy Mountains in NSW, (around 2500 km^2). Of this only 1200 km^2 receives 60 or more days of snow cover and only 250 km^2 (or 0.0001% of Australia) is truly alpine (Green & Osborne 1994; Costin *et al.* 2000).

The latest climate change scenarios for the Australian Alps are based on the CSIRO temperature and prediction models for 2001 (Table 1). Based on these values, changes in temperature of +0.6^{o}C under a low impact scenario and +2.9^{o}C under a high impact scenario by 2050 are predicted (Hennessey *et al.* 2002). Consequent reductions in snow cover resulting from changes in temperature and precipitation in both scenarios will be dramatic. In the worst case scenario there will be a 96% reduction in the area that experiences more than two months snow cover a year.

These predictions have important implications for ski resorts with reductions of 30-40 days in the average season length by 2020 in the worst case scenarios. By 2050 under worst case scenarios, there are even more dramatic reductions in season duration by around 100 days, with only the highest ski resorts having season durations of more than ten days.

For the highest peak in Australia, the predicted changes in climate include a change in the duration of snow cover from around 183 days to 96-169 days by 2050. But even more dramatic is the change in the peak snow depth from over 2 m to under 50 cm under the worst case scenario by 2050 (Hennessy *et al.* 2002). Another way of viewing the change is to consider that +2.9^{o}C is approximately the equivalent of a 377 m upward shift in the snowline (using a 0.77^{o}C lapse rate: Brown & Millner 1989). Therefore under the worst case scenario in 43 years, conditions equivalent to the current tree line at around 1850 m altitude in the Snowy Mountains would be found a meter above the top of continental Australia's highest mountain, Mt Kosciuszko (2228 m).

Table 1. Best and worst case climate change scenarios for the Australian Alps as predicted change from conditions in 1990 (Hennessy *et al.* 2002)

	Best Case		Worst Case	
Change in	2020	2050	2020	2050
Temperature	+0.2°C	+0.6 °C	+1.0 °C	+2.9°C
Precipitation	+0.9%	+2.3%	-8.3%	-24%
Reduction in area with snow cover				
At least 30 days	14%	30%	54%	93%
At least 60 days	18%	38%	60%	96%

These predicted changes in climate are clearly likely to have dramatic affects on the natural values of the Australian Alps.

Synergies between climate change and threats in the Australian Alps

It has been predicted that a temperature increase of just 3°C could alter the climate of the area that is currently alpine, to that of the subalpine (Green *et al.* 1992). This would result in the loss of the rare endemic communities such as the groundwater communities (fens, bogs and peatlands: Good 1992) and the endemic snowbank, feldmark and short alpine herbfield communities (Pickering *et al.* 2004). These latter two communities are the only known locations for four plant species endemic to the Kosciuszko alpine area (Costin *et al.* 2000). Conversely, higher temperatures are expected to increase the distribution of the dominant alpine and subalpine plant communities (tall alpine herbfield, heath and sod-tussock grassland) (Pickering & Armstrong 2003; Pickering *et al.* 2004).

Climate change in the subalpine or montane areas of the Australian Alps is expected to benefit exotic species and weeds which may be currently excluded from the alpine zone due to the severe environmental conditions at higher altitudes (Johnston & Pickering 2001; Pickering *et al.* 2004; Bear *et al.* 2006). With warmer and drier conditions associated with climate change the altitudinal ranges of some weed species are likely to increase. This invasion process may be facilitated by the predicted increase in frequency of natural disturbances (bushfire and drought) which reduce the cover of native vegetation.

The alpine region around Mount Kosciuszko is expected to be particularly vulnerable as it is small (100 km^2) with a limited altitudinal range (400 m from the treeline to the summit of Mount Kosciuszko at 2228 m) (Pickering *et al.* 2004). The lack of a permanent nival zone in the Australian Alps, a region perpetually covered in snow, to act as a refuge for altitudinal succession may limit the ability of many endemic alpine species to survive (Green *et al.* 1992; Pickering & Armstrong 2003; Pickering *et al.* 2004).

Three examples are used to illustrate the potential synergies between existing threats to the Australian Alps and climate change.

Direct affects on flora and fauna

Increasing temperatures and decreasing snow cover is likely to result in changes in species richness in the Australian Alps. Species richness of plants and animals is related to altitude in mountain regions world wide (Körner 2002; Nagy *et al.* 2003). In mountains there is a general trend of a decline in native and exotic plant diversity, and an increase in the proportion of the biota that is endemic with increasing altitude (Körner 2002; Nagy *et al.* 2003; Pauli *et al.* 2006). For example in the Australian Alps, the distribution of many mammal and bird species is strongly effected by snow cover (Green & Osborne 1994; Green & Pickering 2002). There is already some evidence that there have been changes in the altitudinal extent and timing of migration into the mountains from the lowlands with reduced duration of snow cover in the Australian Alps (Green & Pickering 2002; Pickering *et al.* 2004). For many species there will be gradual changes in distribution. For others, however, there is a real risk, particularly for some mammal populations, that this process might be rapid and dramatic. This is particularly likely where climate change results in a disassociation in the timing between key events for species.

For the endangered broad-toothed rat, it appears to be the timing of the thaw, and the increased risk of cold conditions post snow melt. For the endangered Pygmy possums it may be that early thaws result in the possums emerging from torpor before the arrival of their main food supply, Bogong moths in spring (Green pers. comm.).

There are also likely to be changes in the distribution of vegetation communities. This may involve changes in the tree line, both in frost hollows and between the alpine and subalpine zones. There is also likely to be changes in the distribution of specialist communities adapted to long periods of snow cover such as those under late-lying snowbanks, but also other communities dependent on snowmelt such as bogs and fens (Pickering & Armstrong 2003; Pickering *et al.* 2004). For plants some changes in distribution may be apparent in the short term, while for others it might be masked. Many alpine species are long lived perennials. Therefore there may be dramatic reductions in the size of populations and the cessation of recruitment for many populations, but a few long-lived individuals may survive for longer, masking the functional loss of the species.

Fires

Fires are likely to be more frequent, more intense and cover greater areas. Fires in the snow country of the Australian Alps are infrequent with decades or even centuries between fires in some areas prior to European arrival (Williams & Costin 1994; ISC 2004). The alpine zone can act as a large fire break, restricting the spread of large scale fires (ISC 2004). However, the intensity, area burnt and the frequency of fires are all likely to increase with climatic warming of the region (Hughes 2003; ISC 2004; Pickering *et al.* 2004). Although some of the flora will recover showing many of the adaptations seen in lower altitude flora for surviving fire, the capacity to survive fires that are more frequent and more intense is low (Wahren *et al.* 2001; ISC 2004; Bear & Pickering 2006). For example Snowgums can regenerate from lignotubers, and over 95% survived the extensive 2006 fires (Pickering & Barry 2005). However, the regenerating tissue is highly susceptible to damage from fires during the following 20 years. As a result, an increased frequency of fires may result in dramatic increases in tree death.

Weeds and feral animals

The Australian Alps like most of Australia has already been invaded by a diverse range of weeds and feral animals. Many of the species are general pests including foxes, rabbits, pigs, horses and hares (Green & Osborne 1994). Among the plants are some common weeds such as Sheep's sorrel, Catsears, Yarrow, White clover, Sweet vernal grass, Dandelion, Cocksfoot and Brown top bent which are also found in many protected areas including overseas (Bear *et al.* 2006; Pickering & Hill in press). Currently the distribution of many exotic plants and animals is limited by climate factors in the Australian Alps, particularly the duration of snow cover. Therefore, they are likely to directly benefit from reduced snow cover, resulting in an increase in the diversity and abundance of exotics at any given altitude (Bear *et al.* 2006; Green & Pickering 2003, Pickering *et al.* 2004). They are also likely to benefit from disturbances associated with climate change including changes in patterns of human use of the region. This could be changes in visitor use and activities, with an increase in summer tourism use of walking trails. It could also be due to changes in the ecosystem services of the region such as a greater priority on harvesting water in the region.

Recommendations

Clearly there is a need for protected area managers to find ways to deal with the impacts of climate change. This includes recognising how climate change will interact with many current threats to protected areas. Just some of the things that could be done include:

- Even greater emphasis on the control of weeds and feral animals, particularly those likely to benefit from climate change.
- Evaluate risk of increased risk of fires on biota and what can be done, which may not be much for intense fires in extreme fire conditions.
- Manage changes in tourism use and demand. This includes identifying what types of visitor use are, and will be appropriate in a particularly park. In the Australian Alps this will involve managing changes in ski tourism as it becomes economically less viable and more dependent on snow making. However, snow making itself may become less economically, socially and environmentally feasible with increasing demands on limited water and hydroelectricity supplies in the region.
- Reducing the management organisations' own contributions to production of greenhouse gases. We too must be eco-friendly and contribute to international reductions in greenhouse gas production.
- Making the community even more aware of the threats and likely impacts some of which are already occurring from climate change. For the Australian Alps this unique environment is particularly at risk, and this needs to be part of Australia's knowledge of what is and will be happening in a warmer world.
- Research and monitoring of changes in climate, temperature and snow cover and its effects on the natural environment of the Australian Alps. Currently several long-term monitoring projects have been established by researchers, several of which are part of international programs.

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5. Challenges facing protected area planning for Australian wet-tropical and subtropical forests due to climate change

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Abstract

While landscapes and their ecosystems are continuously changing over long time-scales, human beings have and continue to cause very rapid changes at both regional and global scales. The magnitude and rate of these changes have created severe challenges for protected area planning. This brief essay reviews some published research about how climate has affected Australian rainforest over millions of years, what has been predicted as possible impacts of anthropogenic climate change in the future, the value of bioclimatic modelling, and briefly discusses a few of the implications of rapid climate change for management and policy.

Introduction

At short time-scales, landscapes appear to be relatively unchanging but ecological research shows that landscapes are constantly changing at many temporal and spatial scales. This dynamic is driven by geological and evolutionary processes, climate change and human impacts of various kinds.

Because of the high rate and extent of landscape change due to human actions, the phrase "global change" has come into currency. Describing, understanding, and predicting rapid global change has become a major scientific pursuit. Managing protected areas in the face of rapid change has become both more important and more difficult (Hilbert in press). Climate change is likely to become the most significant issue in all of Australia's rainforest reserves and is exacerbated by the highly fragmented nature of rainforests at both regional and continental scales

History of rainforest change

In the long-term and at a continental scale, all the remaining rainforests in Australia can be thought of as refugia, small remnants of once extensive Miocene/Pliocene rainforests. A significant change coincided with the arrival of humans c. 45 000 yr BP when fire-adapted, sclerophyll forests expanded greatly and coniferous *Araucaria* dominated rainforests declined (Kershaw 1986). The result is that Australia's rainforests are "naturally" fragmented into a number of small and widely separated units.

Within each rainforest area, rainforest types are further fragmented by local climates that are mainly caused by topography. For example, cool-temperature adapted forest types occur in the uplands of the Wet Tropics bioregion where the climate is essentially warm-temperate, while the lowlands experience a tropical climate and have different rainforest types. Long-term changes in climate through the Quaternary changed the extent of rainforests as a whole (Fig. 1) and the relative proportions of the various rainforest types (Hilbert *et al.* 2007).

Hilbert D. (2007) Challenges facing protected area planning for Australian wet-tropical and subtropical forests due to climate change. In: *Protected Areas: buffering nature against climate change. Proceedings of a WWF and IUCN World Commission on Protected Areas symposium, 18-19 June 2007, Canberra.* (eds M. Taylor & P. Figgis) pp. 35-40. WWF-Australia, Sydney.

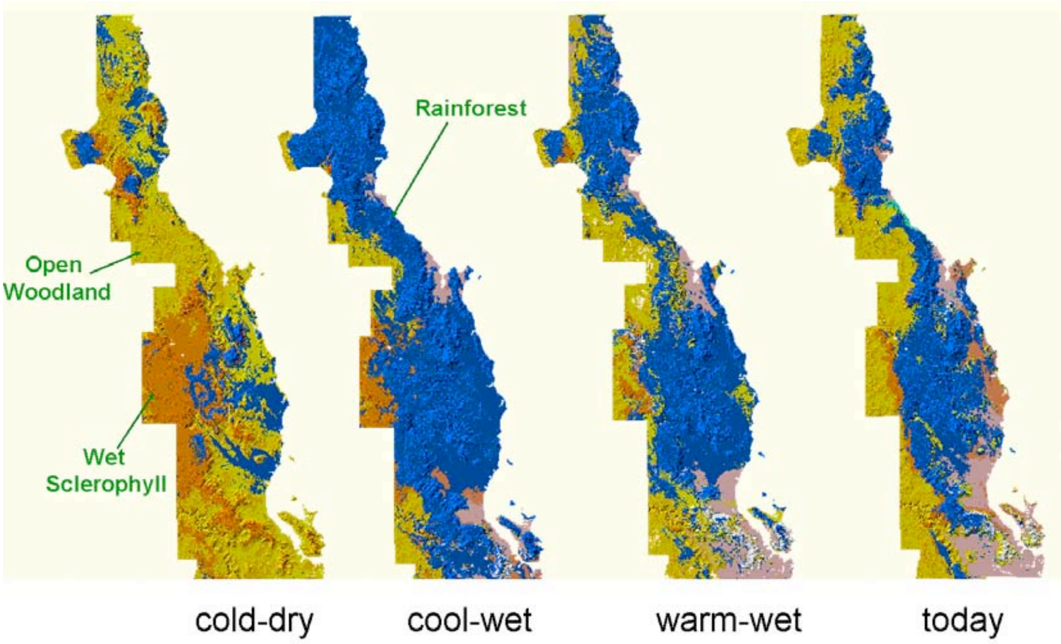

Fig. 1. Changes in the extent of rainforest environments (blue) in the Wet Tropics bioregion in three past climates (see Hilbert *et al.* 2007 for more detail). The maps extend from just south of Cardwell to just south of Cooktown in the north.

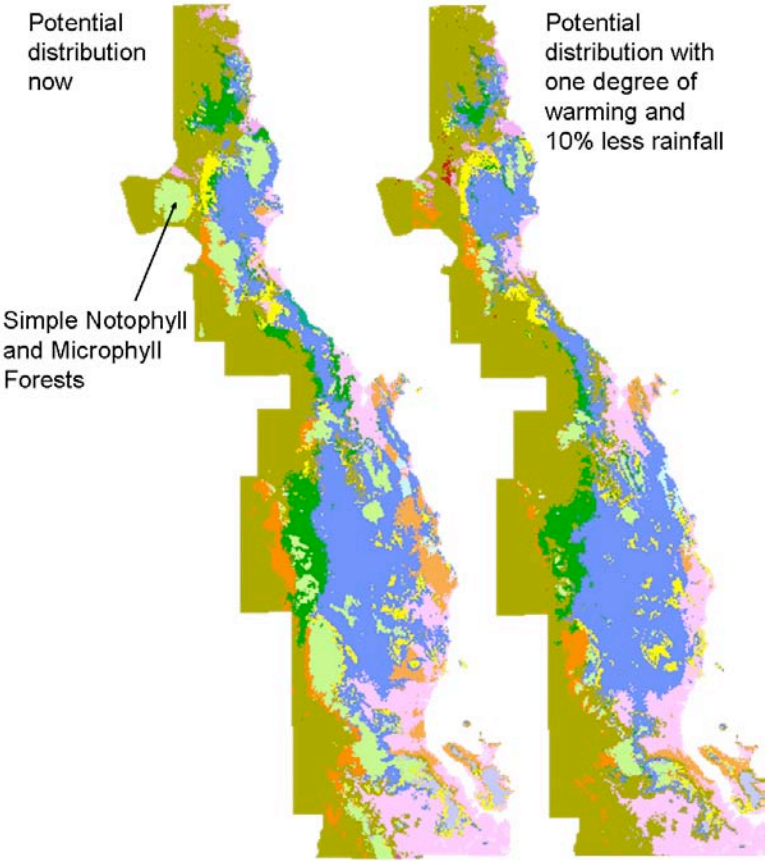

Fig. 2. Maps showing change in forest environments with a small amount of warming. Note the large decrease in highland and upland environments (lime green) and expansion of lowland rainforest environments (blue). The upland and highland environments also become more fragmented. Data from Hilbert *et al.* (2001).

Within the Wet Tropics bioregion, lowland rainforests were very limited in small refugia at the cool, dry Last Glacial Maximum (LGM, c. 18 000 yr BP) but expanded during the Holocene to their peak near the beginning of the Holocene (c. 38 000 yr BP). Highland rainforests were restricted to refugia at LGM but less so than lowland rainforest types. In contrast to other rainforest types, their minimum extent occurs during the warm-wet Holocene Climatic Optimum (c. 5000 yr BP). For these forests, interglacial, rather than glacial, refugia were perhaps the most important (Hilbert *et al.* 2007). Thus, climate has a strong effect on the extent and distribution of rainforests at both regional and continental scales.

European settlement and subsequent land-clearing certainly caused the most rapid change to the landscape and caused further fragmentation within each of the regional rainforest refugia. Anthropogenic climate change now and in the future is likely to be much more rapid than in the past and is likely to pose a significant threat to tropical rainforest biodiversity in Australia.

Potential impacts of global climate change

I have estimated the changes in forest environments in the Wet Tropics bioregion due to 1ºC of warming. The modelling used an artificial neural network that classifies environments (defined by soil, terrain, and several climate variables) into fifteen forest structural types (Hilbert & van den Muyzenberg 1999).

Rainforest environments are predicted to respond differentially to future warming. Lowland, Mesophyll Vine Forest environments increase with warming while Upland, Complex Notophyll Vine Forest environments respond either positively or negatively to temperature, depending on changes in precipitation. Highland rainforest environments (Simple Notophyll and Simple Microphyll Vine Fern Forests & Thickets) are predicted to decrease by 50% with only 1ºC of warming (Hilbert *et al.* 2001b). The potential future distributions of upland and highland rainforest types under a climate change scenario of +1ºC warming and –10% rainfall not only decline, but also become much more fragmented (Fig. 2). If the upper range of predicted warming occurs (>c. 3.5 ^{o}C), no appropriate environments are predicted to remain within the Wet Tropics.

Unfortunately, these upland and highland rainforests are the habitat of most of the bioregion's local endemic species (Williams & Hilbert 2006) and iconic species are at risk (Hilbert *et al.* 2004). Whether and where appropriate climates might come to exist further to the south, say in the Border Ranges, is unknown. However, regional rainfall patterns and topographic constraints imply that such new habitat would be very far removed from the Wet Tropics.

Forest ecosystems have a large degree of inertia because of their long-lived trees, so actual replacement of these forest types by others may take a very long time. Meanwhile, these forests are likely to be quite stressed due to warmer and drier conditions than they are adapted to. Most forests will experience climates in the near future that are more appropriate to some other structural forest type. The strongest response to climate change will be experienced at boundaries between forest classes and in ecotonal communities between rainforest and open woodland (Hilbert *et al.* 2001b; Hilbert *et al.* 2001a). The propensity for ecological change in the region is high and, in the long term significant shifts in the extent and spatial distribution of forests are likely.

I also investigated how the current spatial arrangement of forest types may limit their response to future climate change and how transitions might be constrained by geographic, anthropogenic (clearing), biological, and environmental factors.

Results for the Wet Tropics bioregion indicate that the spatial arrangement of vegetation may impose relatively little constraint on the region's potential change in response to small changes in climate (Ostendorf *et al.* 2001). However, most other rainforests in Australia are much more fragmented than the Wet Tropics and historic clearing may impose limits on their adaptation to climate change

Values and limitations of climate impacts modelling

Projecting the impacts of climate change on vegetation distributions is essential for analyses of regional and global carbon storage (Solomon & Kirilenko 1997; Solomon & Leemans 1997), the conservation of biodiversity (Markham 1996), and the establishment of cost-effective monitoring programs (Baker & Weisberg 1997).

Several types of models are being used to investigate the environmental controls on vegetation distributions and the potential impacts of climate change, including: several kinds of static, equilibrium models of the climatic controls on vegetation (Box 1981; Lenihan & Neilson 1993; Monserud *et al.* 1996; Hilbert & van den Muyzenberg 1999); simulations of succession and gap-phase dynamics (Shao *et al.* 1995); and frame-based simulation models (Chapin & Starfield 1997).

One approach to reduce the complexity and data needs of simulation models is the use of plant functional types that respond similarly to specific perturbations (Smith *et al.* 1997; Kursar 1998). However, species-centred or even community level approaches are rarely possible in the tropics because of the lack of knowledge of both the distribution and ecological responses of individual species (Hilbert & Ostendorf 2001).

All modelling methods have particular strengths and weaknesses and the choice of a particular method is contingent on a number of factors including the specific objectives of the study, the level of understanding of the particular system, availability of data, issues related to the spatial and temporal scale, and, not uncommonly, the past experience of the investigators (Hilbert & Ostendorf 2001).

While empirical or correlational vegetation models have been criticised by some authors, they clearly have been and will continue to be very useful in the context of global climate change. For many tropical regions empirical approaches are the only possible approach at this time or for the foreseeable future. These regions are too rich floristically to take a species-centred approach and appropriate plant functional types have not been defined or their distributions mapped. Careful application of empirical methods, including the artificial neural networks that I have applied and other machine learning techniques, provide the possibility to make very useful contributions to the understanding and conservation of rainforest areas with future climate change.

Management and policy implications

Climate change is a global phenomenon, driven by global patterns of population, fossil fuel use and deforestation. Reducing the rate or extent of global warming is a global challenge.

However, national and local climate response policies and action plans can and must be developed that attempt to minimise global warming's negative impacts on Australia's ecosystems and unique biodiversity.

A fundamental difficulty is that political boundaries like national parks or World Heritage Areas are static while environments and habitats are dynamic, and especially so with rapid climate change. Thus, conservation of ecosystems and the biodiversity within them is not completely ensured by a static network of reserves.

Consequently, policy and management needs to be on a large, biogeographic scale and consider land currently outside the reserve system (Hilbert in press). It is possible that suitable habitat for many Wet Tropics species will only occur hundreds of kilometres to the south in 50 to 100 years time.

Managers and reserve system planners need to anticipate where this habitat might occur and begin considering the implications of such changes. Assuming that research identifies regions within the Wet Tropics that might act as climate refugia - restricted regions where biota can survive despite warming - these must be protected and managed to enhance their stability.

Similarly, connectivity among suitable habitat areas could be improved and efforts made to minimise the interacting effects of other, more tractable, global change processes such as land clearing, linear barriers, weeds and feral animals (Hilbert in press).

Finally, proactive management of the species that are most threatened by warming must be considered. The possibility and desirability of translocating species to distant suitable areas may need to be considered. However, these management issues and actions can not be discussed or implemented before research has begun to fill the current information gaps.

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6. Northern Australia's tropical savannas and rivers: building climate resilience into globally significant assets

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Abstract

This paper presents a case for building climate resilience into Northern Australia's tropical savannas and rivers by establishing a large interconnected network of protected areas and complimentary off-reserve management to mitigate key threats, such as land clearing, weeds and wildfires.

Covering 111 million hectares of tropical savannas, Northern Australia supports the largest ecologically intact tropical savanna system left in the world today. Approximately 9.4% is protected within the National Reserve System, totalling an area of approximately 10.5 million hectares. Eight of the 17 bioregions in the tropical savannas are very high or high National Reserve System Program priorities.

Only a small proportion of the 700 tropical rivers and creeks in Northern Australia receive comprehensive legal protection and effective on-ground management.

A recent study assesses risks from climate change to key ecosystems across Northern Australia as being medium to high, including tropical savannas, rivers and coastal wetlands. Whilst experts assess the adaptive capacity of such ecosystems as being low to medium, Northern Australia's ecosystems are arguably more resilient to climate shocks due to the relatively intact ecological condition of its ecosystems.

Climate change is widely seen as a peculiarly southern Australian phenomenon. Northern Australia, on the other hand, is often seen as escaping the impacts of climate change and a store for many of the natural and mineral resources increasingly in short supply in the south. There is a risk that resources in the "Northern Frontier" will be viewed as substitutes to compensate for declining productivity and increasing scarcity in the south. Some of the major risks to Northern Australia's ecosystems posed by society's responses to climate change are major farm development, piping water to southern Australia, major liquefied natural gas developments, and uranium exploration and mining.

Introduction

This paper presents a case for building climate resilience into Northern Australia's tropical savannas and rivers by establishing a large interconnected network of protected areas and complimentary off-reserve management to mitigate key threats, such as land clearing, weeds and wildfires.

By building a network of protected areas across tenures and including the full range of protected areas types, through strong support and consent from Traditional Owners and partnerships with land

Blanch S. (2007) Northern Australia's tropical savannas and rivers: building climate resilience into globally significant assets. In: *Protected Areas: buffering nature against climate change. Proceedings of a WWF and IUCN World Commission on Protected Areas symposium, 18-19 June 2007, Canberra.* (eds M. Taylor & P . Figgis) pp. 41-46. WWF-Australia, Sydney.

managers, landscape-scale connectivity and migration pathways could be established across 3000+ km from Cairns to Broome to secure the long-term future of these globally significant assets.

Such an initiative would provide governments with a cost effective and practical option for both mitigating the impacts of climate change, by ending major land clearing and abating emissions from wildfires, and adapting to new climate regimes through investing in natural infrastructure and "Caring for Country" actions.

As many look to Northern Australia's water, lands and mineral resources for major development opportunities, this approach provides an alternative vision for maintaining ecological processes and developing sustainable livelihood options and strong communities based on a healthy environment.

WWF is working with Traditional Owners, Indigenous organisations, land managers, governments and other stakeholders to develop this initiative.

Northern Australia's tropical savannas and rivers

Northern Australia is an area of outstanding natural values and a living culture-scape for Indigenous Traditional Owners who maintain the world's oldest living culture. The north is special and unique. Indigenous people have lived in Northern Australia for over 40 000 years, whereas European settlement and colonisation has occurred for only the past century and a half.

Covering 111 million hectares of tropical savannas (WWF 2006a), Northern Australia supports the largest ecologically intact tropical savanna system left in the world today (Woinarski *et al.* in prep). There are 700 named rivers and creeks winding through the tropical savannas between Cairns and Broome. The vast majority remain free-flowing, and unpolluted, and flow through catchments where most of the native vegetation remains uncleared (ATRG 2004). Of the nearly four million hectares of nationally important monsoonal wetlands (DEH 2005) and several hundred estuaries across the north (EA 1996), most retain high levels of ecological integrity.

Protected Areas in Northern Australia

The tropical savannas and river systems of Northern Australia are one of the last great natural areas on Earth. No other developed country supports such large areas in relatively intact ecological condition.

Based on calculations using the Collaborative Australian Protected Areas Database (DEH 2004) and the Northern Australia and Trans-Fly savannas ecoregion (WWF 2006a), approximately 9.4% of the 111 million hectares of tropical savannas is protected within the National Reserve System, totalling an area of approximately 10.5 million hectares. Eight of the 17 bioregions in the tropical savannas are very high or high National Reserve System Program priorities (NRMMC 2004 p. 28, Sattler & Glanznig 2006).

These are:

- Very high priority: Central Arnhem, Central Kimberley, Gulf Coastal, Gulf Fall & Uplands.
- High priority: Einasleigh Uplands, Daly Basin, Gulf Plains, Dampierland.

In general these bioregions retain vast areas of relatively intact ecosystems and areas of high conservation value (Sattler & Creighton 2002). The very high priority bioregions have less than 2% of their area reserved, whilst the high priority bioregions have 2-5% of their area reserved (NRMMC 2004).

Indigenous land ownership is widespread in Northern Australia. They are not just one of many "stakeholders" with an interest in land management. The natural and cultural values of the Indigenous estate are highly significant, but government support for management is often lacking. Indigenous communities in many regions of Australia have established Indigenous Protected Areas (IPAs) to assist them in caring for their country. Ten IPAs have been declared, or are in the process of being established, within the tropical savannas region (DEW 2007). The IPA programme has been found to be highly cost-effective and recent government reviews recommended additional resourcing (Gilligan 2006).

The establishment and management of protected areas, and protected rivers (see below), must respect and support Native Title rights and the rights of Indigenous people as land owners. The creation of protected areas must not be used to alienate Indigenous communities from their ancestral lands.

Protected Rivers in Northern Australia

Only a small proportion of the 700 tropical rivers and creeks in Northern Australia receive comprehensive legal protection and effective on-ground management (Nevill this volume). Some rivers and major creeks are fully or largely protected within protected areas, such as the South Alligator River in Kakadu National Park, Prince Regent River in Prince Regent River Nature Reserve (Kimberley), and the Jardine River in Jardine River National Park (Cape York Peninsula). Yet effective on-ground management for many such protected areas is lacking.

Cross tenure river protection laws and programs exist or are being developed in Queensland, the Northern Territory and Western Australia. Four Gulf Country rivers are currently protected under Queensland's *Wild Rivers Act*, with more soon to be protected on Cape York Peninsula (Nevill this volume). A commitment exists from the Northern Territory Government for a *Living Rivers* program and legislative framework, with the Daly River identified as the first river to be protected under this program (*Hansard*, 18 August 2005, NT Legislative Assembly). The Government of Western Australia's Wild and High Conservation Value Rivers Program has identified 46 rivers and creeks in the Kimberley region warranting protection. However no legislative protective mechanism currently exists (DEC 2005).

Rivers are a major element of connectivity in landscapes by enabling aquatic species to move longitudinally along rivers and laterally onto floodplains (WWF 2006b). River corridors also provide critical habitat and water during the dry season for many terrestrial species which rely on floodplain and riparian habitats for migration and dispersal. Tropical rivers often provide the only source of freshwater for biodiversity during the long dry season (May-Nov). Protecting river systems within the National Reserve System, through river protection laws, or as National Heritage places, provides a significant opportunity for building resilience to climate change by removing pressures on riverine ecosystems. Key threats are dams, weirs and floodplain levees which prevent or reduce the ability of water, fish and other aquatic species to move along a river system and onto floodplains.

Northern Australia at risk due to climate change

Every major ecosystem type in Northern Australia is at medium or high risk from climate change, and that none have high adaptive capacity (Hyder Consulting in prep.).

The report however also lays out opportunities to maintain and build resilience through ensuring decisions made about the north's future do not degrade the natural capacities of the savannas and rivers to withstand climate-related shocks.

The report shows that the story of climate change in Northern Australia is about much more than just the three iconic examples: the Great Barrier Reef, Kakadu wetlands and the Wet Tropics.

These icons are relatively well known, partly due to their economic importance to tourism and fishing industries (PMSEIC 2007), but a conservation focus demands that we consider all ecosystems at risk.

Hyder Consulting (in prep.) is using existing information and expert opinion to assess climate change risk, major impacts and adaptive capacity for major ecosystem types across the north. The key climate change impacts are:

- Coastal low-lying wetlands in general, not just those in Kakadu National Park, which cover perhaps three million hectares across the north, will be mostly impacted by sea level rise and storm surge.
- Tropical coral reefs, not just the Great Barrier Reef but also those in the Gulf of Carpentaria and off the coast of the Top End and Kimberley, are vulnerable to increasing ocean surface temperatures and acidity.
- Tropical savanna woodlands and grasslands covering about 100 million hectares between Cairns and Broome, are at risk from increases in fire frequency and intensity exacerbated by more exotic grasses which benefit from elevated CO_2 concentrations.
- Tropical rivers may be affected by longer and more intense droughts, higher temperatures and extreme rainfall events.
- Tropical rainforest including the Wet Tropics, but also vine forests and other drier rainforest types found across the North could be impacted by increased savanna fire intensity and frequency, increasing temperatures, and increased cloud elevation.
- Small islands face to sea level rise, more and stronger cyclones, and saline groundwater intrusion.

Climate change risk is assessed as high or medium for all these ecosystem types.

The adaptive capacity for each ecosystem type is assessed as being either low or medium. Few of the major ecosystem types are assessed as being at low risk from the broad range of climate change impacts. No ecosystems are assessed as having high adaptive capacity.

Depopulation of remote and rural areas may paradoxically undermine the ability of Traditional Owners to "Care for Country". The ability of Indigenous Traditional Owners, pastoralists and other land managers to manage Northern Australia's lands, rivers and seas will be further challenged by climate change.

Looming development threat to northern ecosystems

Climate change is widely seen as a peculiarly southern Australian phenomenon.

Northern Australia is promoted as a treasure trove of natural and mineral resources to compensate for declining productivity, increasing scarcity and resource exhaustion in the south (e.g. *The Bulletin*, 31 Oct 2006).

Some of the major risks to Northern Australia's ecosystems are:

- Water diversion for irrigated farming: Rivers identified for major farm development schemes include the Ord, Daly, Roper, Fitzroy and Flinders rivers (Australian Government 2007).

- Piping northern water south: Diversion of tropical waters south through massive pipelines has been proposed as "solutions" to climate change-induced water scarcity, over-extraction and inefficient water use in the south. The Kimberley-to-Perth canal proposal consists of a 3700 km long canal to supply Perth's urban and industrial water needs, and those in the mining and irrigation regions in the Pilbara (Kimberley Expert Panel 2006). Proposals to pipe water from the Ord River Dam to Perth have been proposed for many years (Osborne & Dunn 2004 p. 98). Schemes to pipe water from northern Queensland's rivers to Brisbane, central Queensland mines and the Murray-Darling Basin are being investigated by the Australian Government's Northern Australia Taskforce and the Queensland Government.

- Land conversion for farming and pastoralism: Savanna lands are seen by many as an opportunity for a new northern agricultural frontier and a timely replacement for degraded and marginal lands in southeastern and southwestern Australia beset by lower rainfall, higher evaporation and a century and a half of development. For example, a major cotton farm development was proposed for the lower and middle reaches of the Fitzroy River in Western Australia. Subsequently rejected as infeasible by the Western Australian Government, the proposal included extracting 30% of the flow in the Fitzroy River to irrigate 200 000 hectares of cotton (Stateline 2004).
- Natural gas extraction: Growing energy demand and moves to cut greenhouse gas emissions underpin strong demand for liquefied natural gas (LNG) extraction off Northern Australia's coast, with tens of billions of dollars of investment in new projects being planned for the Bonaparte Basin off the Kimberley coast and in the Timor Sea north of Darwin. Fragile coastal ecosystems, coral reefs and islands, some of which have become refuges for medium-sized mammals and other fauna now rare on the mainland, are being targeted for development of LNG processing plants and ports.
- Uranium exploration and mining: Uranium exploration, and potentially mining within the next decade, is booming across much of the north in response to global energy demand and may also become a significant direct threat on natural ecosystems.

Building resilience to climate change in Northern Australia

Northern Australia's ecosystems are at risk from climate change, but are arguably in a better position to withstand the next century of climate change than are most ecosystems in southern Australia, or indeed the many tropical areas of the world that have been, or are in the process of being, unsustainably developed. Intact ecosystems in which native vegetation has been largely maintained and rivers remain free-flowing provide greater capacity for species to migrate seasonally and move over longer time scales as climate patterns change than highly fragmented ecosystems.

WWF is developing a *North of Capricorn Initiative* to promote conservation and sustainable management of Northern Australia's globally significant tropical savannas and rivers. Protected areas must play the leading role, coupled with efforts to establish sustainable livelihoods and development options that complement protected areas, ensure savannas remain protected from land clearing and maintain free-flowing rivers.

A large interconnected network of protected areas conserving savannas, rivers and seas and securing landscape-scale connectivity across the north will maintain resilience for ecosystems at risk of development and permit species to migrate across this vast landscape.

This network could conceivably complement the recently announced Atherton to Alps corridor to be established along the Dividing Range of eastern Australia to assist species to move as climate change pushes many species southwards and to higher altitudes. Such landscape connectivity helps promote adaptation to climate change not only by assisting species migration, but also by enabling the many ecological flows and processes that are necessary for healthy ecosystems and biodiversity over the long-term (Worboys, Mackey this volume).

The initiative is being developed through ongoing consultation and partnerships.

The initiative is of the same scale and global significance as major existing connectivity initiatives around the world, such as the Amazon Region Protected Areas program, Boreal Forest Conservation Initiative, Meso-American Biological Corridor, and the Yellowstone to Yukon corridor.

Protected areas alone will not prevent major loss of habitats and species in Northern Australia as climate patterns change. Major actions required include:

- Maintaining landscape-scale connectivity also requires mitigating and stopping key threats across entire landscapes both in and outside the reserve system such as major land clearing, altered fire regimes and invasive species.
- Reinstating Indigenous fire regimes that reduce late dry season wildfires - already being funded as a carbon abatement scheme.
- Banning the use of highly invasive exotic pasture grasses, such as gamba grass and para grass, is also necessary to reduce fuel loads and habitat loss.
- Removing grazing from sensitive areas such as riparian zones and sensitive habitats, such as native grasslands used by the threatened Gouldian finches, is also essential to recover the integrity of vegetation communities and endangered species habitats.
- Assisting Indigenous communities, pastoralists and catchment groups to conserve and manage ecosystems and species is fundamental to building the resilience of these ecological assets to adapt to climate change.

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7. Climate change: challenges facing freshwater protected area planning in Australia

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Abstract

Temperatures are rising and rainfall declining over much of the Australian continent. Unfortunately, rainfall declines are most pronounced in areas where water resources are most heavily used. In many places the waters of our natural ecosystems have already been over-allocated for human use. Declining rainfall leads to greater declines in stream flow, and this, combined with over-allocation, is placing freshwater ecosystems under extreme pressure. State government stream flow management is now in sharp focus, highlighting issues of ethics, competency and compliance.

Against this alarming situation, Australia's network of freshwater protected areas fails to meet standards and commitments set many years ago in both international agreements and Commonwealth and State government policy, and little is being done to remedy the situation. In particular, our present system is not comprehensive, adequate nor representative. Urgent action is required.

Amongst the recommendations of this paper, five are particularly important:

- Immediate action should be taken to expand Australia's freshwater protected areas in a way which is both ethically responsible and systematic.
- A comprehensive national inventory of inland aquatic ecosystems should be developed, leading to a conservation status assessment of these ecosystems.
- Using information already at hand, action should be taken immediately to increase protection of the nation's freshwater ecosystems of highest natural value. Particular attention should be given to rivers and subterranean ecosystems, partly through the creation of an Australian Heritage Rivers System.
- A precautionary approach should be applied immediately to the management of the cumulative impacts of small scale catchment developments, with the aim of capping water infrastructure development well before the catchment enters a crisis situation.
- Weak development approval planning provisions which are failing to protect important natural values should be replaced with stronger requirements for decision-makers to "seek to protect" identified catchment natural values.

Introduction

Climate projections and their likely impacts on freshwater ecosystems are briefly discussed, followed by a consideration of the problems Australia faces both in terms of protected area management, and in terms of managing the impacts of developments within the wider landscape on these protected areas. Most of this paper is devoted to consideration of the first of these latter two issues.

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There is, however, another issue so important that it demands immediate attention and discussion. It is the wider issue of the ethical stewardship of planet Earth. I suggest that many of the problems which the planet now faces are directly or indirectly the result of a pervasive moral attitude towards the planet: we act as if we own it. The current water crisis in the Murray-Darling has brought this ethical issue into focus.

The paper concludes with a number of recommendations, including the accelerated development of a comprehensive freshwater ecosystem inventory at the national level, and the development of an Australian Heritage Rivers System mirroring Canada's long-established system. While protection of the best is urgent, we should not neglect the need for widespread restoration which is long overdue (Lake 2005). The paper also recommends better planning to protect freshwater ecosystems in the wider landscape, particularly by a precautionary approach to the management of the cumulative effects of incremental catchment development, and the use of planning provisions obliging decision-makers to protect identified high-value ecosystems during the planning approval process.

Terminology

In this paper I use the term "freshwater" as shorthand for "inland aquatic". "Freshwater ecosystems" encompasses the three major categories of lentic (slow moving), lotic (rivers and streams) and subterranean ecosystems. The term "reserve" is used here as shorthand encompassing protected area categories I to IV under the IUCN protected area definition.

The ethics of protected areas

The planet's biodiversity is in decline, and freshwater ecosystems are in urgent need of protection (Revenga & Kura 2003). The three greatest immediate threats to freshwater biodiversity in Australia are: (1) the extraction of water from ecosystems for human use; (2) the destruction of natural values within catchments, leading to water pollution and changes to water flow regimes and pathways; and (3) the introduction of alien plants and animals. In many other nations the harvesting of freshwater plants and animals themselves presents a fourth major threat.

The creation of freshwater protected areas is usually justified in terms of utilitarian needs relating to the conservation of biodiversity, or the protection and enhancement of cultural, visual or recreational amenity. Could such reserves also be justified in terms of ethics? In spite of the general absence of discussion of ethics within areas of aquatic science or reserve management, a substantial and long-standing literature exists from which an ethical basis for the establishment of protected areas can be drawn. The landmarks within this literature are discussed by authors such as White (1967), Leopold (1984) and more recently Callicott (1992).

Australia's *National Strategy for the Conservation of Australia's Biological Diversity* underwent wide agency consultation prior to publication, and, in its final form, was endorsed by the Australian Government, all State and Territory governments, and by local government's peak body. In it we find a simple but articulate ethical statement (DEST 1996 p. 2):

> "There is in the community a view that the conservation of biological diversity also has an ethical basis. We share the Earth with many other life forms which warrant our respect, whether or not they are of benefit to us. Earth belongs to the future as well as the present; no single species or generation can claim it as its own. "

This clear expression in a widely-endorsed government policy document of the beginnings of a land ethic provided Australian scientists and natural resource managers with an opportunity to build discussion and use of deeper ethical positions. Yet almost nothing has happened, and a decade has passed now since this statement was published. We need to accord a right to peaceful coexistence to at least a fair proportion of the other living residents of the planet, an approach which aligns with the scientific recommendations of many conservation biologists.

The recent water crisis in the Murray-Darling Basin, while exacerbated by climate change, is the direct result of government water management regimes which are both incompetent and unethical. Incompetent in so far as the Basin's waters (both surface and linked groundwaters) have been grossly over-allocated for human use (Tan 2000; Grafton 2007) and unethical in the sense that adequate environmental flows, while highlighted in government policy documents, have seldom been delivered in practice. Ladson & Finlayson (2004) discuss problems with environmental flow delivery encountered in Victoria, and other States have similar problems.

Very recently this crisis has led to calls, tacitly endorsed by the very agencies responsible for the crisis, for wetlands to be drained to supply "urgent" human needs within the Basin. This shameful position typifies the unethical, short-sighted views which, at a wider scale, lie behind the ongoing destruction of the world's natural areas and ecosystems, along with the essential life-support services they supply to planet Earth. We must actively promote the expansion and protection of freshwater protected areas, at least partly on ethical grounds.

Climate change projections

Overall, Australian surface air temperatures warmed by around $0.9^{O}C$ over the period 1910 – 2005 (ABS 2006). Analyses of rainfall data for the same period show significant declines over eastern and southern parts of Australia, the zones where most of Australia's human population resides. In the northwest of Australia, rainfall has increased during this period.

Looking to the future, CSIRO climate models predict that rainfall will continue to decline over much of the continent, especially the southwest (Pittock 2003). Temperature projections will increase, especially in inland areas. Moisture balance projections predict drying trends over most of the continent, particularly in inland areas where rainfall declines are expected.

In the southwest of Western Australia, rainfall over the last three decades has been around 15% lower than historic long-term trends, and in some catchments this has translated into a 20-30% decline in surface runoff (IOCI 2006). Further declines are predicted, according to Berti *et al.* (2004): "… an 11% reduction in annual rainfall by the middle of this century could likely result in a 31% reduction in annual water yield".

Where soil moisture is in deficit over the larger part of the year, and where surface aquifers are heavily harvested, declines in rainfall will be amplified sometimes greatly as they translate to declines in runoff and streamflow. Where surface waters have already been over-committed to extractive use through binding water licence entitlements, river ecosystems are placed under extreme pressure. Massive damage to freshwater ecosystems in areas of declining rainfall and high existing extractions, such as the Murray-Darling Basin, is now taking place, and increasing damage is almost inevitable, unless governments undertake licence buy-back to supply adequate environmental flows.

The Council of Australian Governments (COAG) Water Framework 1994 required State water management agencies to undertake integrated management of surface and linked groundwater. However, State agencies were slow to remedy legal and policy issues, and even slower to institute practical reforms. In New South Wales for example, although double-counting of surface water and linked groundwater entitlements has long been recognised, the State government has now been in negotiation with farmers for licence buy-back for six years, with little progress made in retrieving over-allocations. It took the Tasmanian Government five years to change legislative arrangements which had divided management of surface and groundwaters between two separate government agencies (Nevill & Phillips 2004). Many other examples could be found of government inertia and incompetence on these issues.

Implications for aquatic ecosystems

Aquatic ecosystems will respond to various aspects of climate change, particularly changes to levels, seasonality and extreme events, in both temperature and rainfall. Changes to wind, temperature and cloudiness will influence evapo-transpiration levels. Changes to rainfall levels and intensity will influence erosion levels and nutrient inputs to aquatic ecosystems. Both salinity and nutrient levels are likely to increase in some areas, particularly in seasonally land-locked water bodies.

Aquatic vegetation will be reduced in many areas. In the Macquarie Marshes alone, Hassall and Associates (1998) predict that both semi-permanent and ephemeral wetland vegetation will be reduced by 20-40% of their original area by 2030 as a direct result of climate change.

Aquatic and semi-aquatic plants and animals will be directly affected by climate change in various ways. Species with limited mobility, such as obligate freshwater species, will face major problems in moving to colonise new environments as conditions change, and as a result extinctions are likely (Hassall & Associates 1998).

Animals living near the limits of their temperature range will face obvious difficulties. Tasmanian galaxiids, for example, have no southerly habitats available as water temperatures rise, and mountain species are in an even worse situation. Introduced salmonids thrive in cold water and will face similar problems and perhaps this may prove a small blessing. Waterbirds and fish dependent on rising flood levels as breeding stimulus will struggle to maintain populations if flood frequency and intensity decline.

Floods have many positive ecological functions, particularly in lowland ecosystems (Lake *et al.* 2006). Declining river flows will affect native fish, such as the Macquarie Perch, dependent on flowing water to breed. Some natives, however, are well adapted to drought. The introduced carp a major pest, while adapted to slow moving turbid waters, also benefits from high flows which expose floodplain habitat.

Rising sea levels will intrude into low-lying coastal freshwater wetlands, causing major destruction of these ecosystems. While noting multiple causes, Pittock (2003 p. 55) states:

> "In some areas of the Northern Territory, dramatic expansion of some tidal creek systems has occurred since the 1940s. In the Lower Mary River system, two creeks have extended more than 4 km inland, invading freshwater wetlands (Woodroffe & Mulrennan, 1993; Bayliss *et al.* 1997; Mulrennan & Woodroffe, 1998). Rates of extension of saltwater ecosystems inland in excess of 0.5 km per year have been measured (Knighton *et al.* 1992). The saltwater intrusion has had dramatic effects on the vegetation of formerly freshwater wetlands with more than 17,000 ha adversely affected and a further 35–40% of the plains immediately threatened (Mulrennan & Woodroffe 1998)".

There will of course be winners and losers, ecologically speaking, from these climate-driven changes. Overall, however, there is no doubt that a great many of Australia's scarce and poorly protected freshwater ecosystems face catastrophic damage, exacerbated by the pervasive over-allocation of the waters of these ecosystems for human use.

Australia's freshwater protected areas

The history of freshwater protected areas in Australia is, in large part, a story of good intentions not carried through. There is also a plethora of different conservation tools that can be used to protect aquatic ecosystems, but have largely remained under-utilised (Nevill & Phillips 2004 ss.1, 5 & 7; Kingsford *et al.* 2005; Nevill 2007).

Water regulations and licences have been poorly enforced in all Australian States, and the legacy of this lax culture remains today, with unfortunate consequences. Where farmers have invested on the assumption that consumption in excess of licence limits will not be penalised, both users and governments are caught in a no-win situation.

The Australian government can establish protected areas on Commonwealth land, and can encourage or require limited protective action from the States where values of national importance (eg: Ramsar sites) are threatened (Nevill & Phillips 2004 s.6.1).

Australia signed the international Ramsar Convention on Wetlands in 1971, which requires the conservation and "wise use" of all wetlands including rivers, groundwater ecosystems and estuaries. After 34 years, few Australian rivers have been directly protected under Ramsar, although some have been listed in the *Directory of Important Wetlands in Australia* (DIWA) (DEH 2001). The DIWA contains State-by-State lists of nationally (and internationally) important wetlands, including Australia's 64 Ramsar-listed wetlands.

Australia's obligations under the Ramsar convention include the preparation of ecosystem inventories. Although none of the State-wide inventories are comprehensive in the sense of containing up-to-date information on value and condition, work is progressing slowly. New South Wales has digital coverage of all wetlands including floodplains, and their protective status (Kingsford *et al.* 2004). Victoria, Tasmania and the Australian Capital Territory also have reasonably good State-wide inventories of wetlands, with floodplains variously mapped. Other jurisdictions are preparing State inventories, apart from Western Australia and the Northern Territory where the focus is on regional inventories (Nevill & Phillips 2004).

Queensland has embarked on the most comprehensive inventory yet attempted in Australia.

State governments have listed some wetlands as Ramsar sites or included them within the DIWA. Ramsar sites receive limited protection under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999,* as well as some State legislation such as Victoria's *State Environment Protection Policy (Waters of Victoria) 2003.* DIWA listing constitutes a referral trigger in Queensland's *Integrated Planning Act 1997.* While the DIWA itself is not formally linked to any Commonwealth or State protection policies other than in Queensland, it is taken into account by many local government and regional resource planning bodies in making land use planning decisions. Unfortunately, "taken into account" often means little in practice. Also, rivers or underground ecosystems are not considered in a comprehensive way, despite the broad wetland definition of Ramsar. Finally, Ramsar sites have also been subject to deliberate habitat destruction by landholders on a large scale, sometimes followed by court action, and sometimes overlooked by State authorities.

Several discharge springs from the Great Artesian Basin (GAB) as well as four other aquatic ecosystems are listed as "threatened ecological communities" under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), another protective mechanism albeit not very effective at present.

While in theory the EPBC Act can protect against major new developments that may constitute a direct threat to an area's values, it cannot force proactive biodiversity management, nor can it control a multitude of small widespread activities draining water flows from a site. Many GAB springs, known to include endemics (Ponder 2004), are already extinct as a result of drawdown resulting from over-use of artesian water. Failure to effectively control the cumulative effects of incremental water development is causing major problems for biological reserves worldwide (Pringle 2001).

We are not protecting all of our most important aquatic ecosystems. Certainly the existing reserve system includes some important freshwater areas (e.g. Ramsar sites) and other freshwater ecosystems are contained within large terrestrial reserves (Nevill 2005). However the reserve system has not been created with the benefit of a systematic analysis of wetland types, and little published information is available on the extent to which representative freshwater ecosystems are protected within existing reserves with the exception of studies such as those in the Wimmera and northern Victoria (Fitzsimons

& Robertson 2003; Robertson & Fitzsimons 2006) and in NSW where there is an analysis of the conservation status for broad wetland types (Kingsford *et al.* 2004).

A comprehensive assessment would identify the pre-European extent of different ecosystem types at a finer level, their current extent, and the degree to which they are now protected (Fitzsimons & Robertson 2005). The methodology for such studies is well established as similar investigations were undertaken for forest ecosystems some years ago, as part of the Regional Forests Agreement (RFA) process. Such a study, based on a national inventory, is urgent and overdue.

A review of the National Reserve System (NRS) using River Environment Types as surrogate riverine ecosystem types was undertaken by Stein (2006). It is no surprise that this analysis showed that the NRS has not yet achieved its goal of a comprehensive, adequate and representative protected area system for riverine ecosystems. While nearly 7% of the stream length (at a map scale of 1:250 000) falls within protected areas, nearly half of this protected length is potentially threatened by human activities within unprotected upstream areas. Many of these streams are seasonal or ephemeral.

Few protected areas encompass entire river basins. Only around 2% of total river length lies within protected areas, with upstream catchments protected, and no downstream dams. Furthermore, the assessment showed there is significant bias within the NRS (Stein 2006).

While a few river ecosystems are well protected, many others including numerous rare and threatened types, have very limited or no protection. A recent study undertaken by the Fenner School of Environment and Society at the Australian National University (Stein *et al.* unpublished) similarly found many of the rivers within protected areas in NSW were likely to be stressed due to over allocation of water upstream.

A Commonwealth/State committee is currently examining options for protecting high value aquatic ecosystems.

While these issues should be addressed, it will also be important, in the context of climate change, to consider how aquatic ecosystems may need to change, and to try to facilitate natural change through corridors and links between protected areas.

State freshwater protected area programs

All States are in theory at least, committed to the establishment of systems of protected areas which contain representative examples of all major ecosystem types, including aquatic ecosystems. Victoria has the earliest of these commitments (1987) and South Australia the most recent (2003) (Nevill & Phillips 2004). Such programs are in line with Australia's obligations under the *World Charter for Nature 1982* (a resolution of the United Nations General Assembly) and the *Convention on Biological Diversity 1992*. However, it is the *timing* which is at issue. There have been extended delays in implementing policy. With respect to freshwater protected areas, these obligations have not yet been carried through in a systematic way in any Australian jurisdiction other than the Australian Capital Territory.

Protection measures for entire rivers can be devised, but are poorly implemented in Australia. The Victorian government identified 15 "representative rivers" for protection in 1992. Fifteen years later, four of these rivers remain without management plans (Nevill & Phillips 2004). Victoria passed a *Heritage Rivers Act* in 1992, nominating 18 rivers and 25 "natural catchments" to be protected. The Act established a management sequence: (1) preparation of draft management plans; (2) public comment and review; (3) ministerial endorsement of the plans; and (4) implementation. Draft management plans for these 18 rivers were published for stakeholder comment in 1997. However, after 10 years, all river management plans remain as drafts without the required ministerial endorsement (Nevill & Phillips 2004) in spite of a government commitment to have them complete by 1998.

Several States have legislation in place aimed specifically at the protection of threatened species and ecological communities. However, the area-protection provisions of these statutes have rarely been used to protect freshwater environments. The "critical habitat" provisions of Victoria's *Flora and Fauna Guarantee Act 1988*, for example, have not yet been used to protect freshwater habitats (Nevill & Phillips 2004). It is however worth noting that Victoria is the only State so far to extend the concept of "no net loss" to "net gain" in relation to developments impacting on important areas of native vegetation, including wetland vegetation (Nevill & Phillips 2004).

In line with the international *Code of Conduct for Responsible Fisheries* (FAO 1995) Queensland, New South Wales, Victoria, South Australia and Tasmania all have fisheries legislation providing for the establishment of aquatic protected areas. Although there has been progress in the marine environment, none of these provisions have yet been used to protect freshwater habitats (Nevill & Phillips 2004).

Both Western Australia and New South Wales considered legislation similar to Victoria's *Heritage Rivers Act 1992*, but there was inadequate parliamentary support in the face of opposition by farmer and fisher groups. Western Australia developed a *Wetlands Conservation Policy* in 1997 which covered rivers using the Ramsar definition. However, ten years later, the protective provisions foreshadowed in this policy have not yet been put in place in a comprehensive way (Nevill & Phillips 2004).

In the mid-1990s New South Wales amended the *National Parks and Wildlife Act 1974* to provide for the declaration of "wild rivers". No action was taken until December 2005, when the NSW Government announced the listing of five rivers, all within existing terrestrial protected areas (Nevill 2005).

The Queensland Government started work on a rivers policy in 2000, which developed into a commitment to provide legislative protection for wild rivers. Nineteen rivers were proposed for consideration in 2004, and a policy implementation paper was provided to stakeholders. The *Wild Rivers Act 2005* came into effect on 14 October 2005. It is to be hoped that wild river declarations under this statute will be fully implemented and effective. So far six rivers have been nominated and declared under the Act. The recent history of native vegetation protection legislation in several States, as well as Victoria's *Heritage Rivers Act*, has indicated that effective implementation can be a major stumbling-block, even with legislative protection in place.

South Australia and the Northern Territory (NT) both have government policy statements committing to the protection of representative examples of all major freshwater ecosystems. However, at this stage neither jurisdiction has funded a program to carry out these commitments in a systematic way (Nevill & Phillips 2004). The Northern Territory *Parks and Conservation Masterplan* 2006 reinforces earlier commitments, and it is to be hoped that action will now be taken.

In the Northern Territory, as in northern Queensland and Western Australia, significant areas of land (around 50% in the case of the NT) are Indigenous owned. The Commonwealth's Indigenous Protected Area (IPA) program has achieved successes, and could be extended to assist Indigenous groups protect freshwater ecosystems.

The recent Tropical Rivers Program (a Commonwealth initiative under Land and Water Australia) is enhancing knowledge of tropical freshwater ecosystems and measures needed to protect them.

Tasmania's *Nature Conservation Strategy 2000* and the subsequent *State Water Development Plan* established a government commitment to develop comprehensive protection for all freshwater ecosystem values, and the program commenced in a systematic way. The Conservation of Freshwater Ecosystem Values (CFEV) Project undertook the design phase of this work, which, when completed, will establish the scientific basis for the identification and selection of freshwater protected areas across the State, as well as providing information for regional natural resource planning initiatives. The CFEV project was expected to produce its final report in 2005. No specific funds were allocated for project implementation in the 2005/6 or 2006/7 State budgets, in spite of the fact that the project is expected to identify priority sites for protection.

The above discussion indicates that excellent scientific preparation and good policy development do not guarantee effective implementation.

Conclusions and Recommendations

Creation of a comprehensive freshwater reserve system is achievable. Techniques are available for managing highly connected linear reserves (Saunders *et al.* 2002). There are a variety of under-utilised conservation tools for protecting and managing Australia's aquatic ecosystems, including environmental flows, protected areas, natural resource management plans and landholder incentives (Whitten *et al.* 2002; Kingsford *et al.* 2005).

Governments should implement existing State policies to establish systems of representative protected areas for freshwater ecosystems, in line with our international commitments under the *Convention on Biological Diversity 1992* (Dunn 2000; Georges & Cottingham 2001; Nevill 2001). Where rehabilitation is undertaken, restoring water flows and quality must be accompanied by restoration of riparian and flood plain vegetation (Lake *et al.* 2007), along with control of alien species if practical.

Urgent action by all three levels of Australian government should encompass:

- Major rivers where ecosystems remain substantially intact should be protected (Morton *et al.* 2002; Wentworth Group 2002, 2003). Several models of protection have been proposed such as "heritage rivers" and "conservation rivers" which would both receive special protection (Cullen 2002; Wentworth Group 2003). There is potential for introducing an Australian Heritage River system loosely based on the Canadian Heritage River System (Kingsford *et al.* 2005). This system has worked well in Canada and there is no doubt that it would work effectively in Australia, with Commonwealth and State government commitment. Some whole catchments already receive some protection from specific agreements (e.g., Lake Eyre Basin Agreement, Paroo River Agreement). The inclusion of "representative rivers" within the Ramsar framework should also be promoted (Nevill & Phillips 2004).
- Ecosystem inventories also need accelerated development to underpin protected area identification and selection, but also to support sympathetic management of biodiversity values within bioregional planning frameworks. Classification and mapping techniques must be used thoughtfully in reserve design and selection (Fitzsimons & Robertson 2005) to ensure an adequate CAR protected area system. Inventories should be constructed to support a variety of classification methods (Blackman *et al.* 1992; Finlayson *et al.* 2002; Ramsar Secretariat 2002). Aquatic bioregionalisations should be developed, partly based on a national freshwater ecosystem database.
- The control of cumulative effects, particularly within catchment-scale management frameworks, needs much greater attention (Pringle 2001; Collares-Pereira & Cowx 2004). The precautionary approach, widely accepted but seldom applied, needs strong support especially where high conservation values remain intact (Nevill 2003).
- Planning procedures where decision-makers are obliged, by law, to "seek to protect" the values of identified high-conservation status ecosystems, during assessment of proposed developments, needs to replace existing planning requirements that impacts merely "be taken into account" (Nevill 2007).
- All Australian jurisdictions should accelerate the development of freshwater protected areas as recommended by the 2004 Sydney *Conference on Freshwater Protected Areas* (WWF Australia and the Inland Rivers Network) (Kingsford & Nevill 2006)**.**
- The rehabilitation of significant aquatic sites should remain a priority (Koehn & Brierley 2000; Rutherfurd *et al.* 2000). Restoration of Australia's degraded aquatic ecosystems, not just significant sites, is long overdue.

- Stakeholders with common interests need to start building consensus and raising awareness. Adequate stakeholder consultation in the selection of protected areas is essential to allow for the inclusion of local and regional values, and to build community support for protected area programs and the wider sympathetic management of utilised ecosystems (Kingsford *et al.* 2005).
- Follow through on the *Directions for the National Reserve System* (NRMMC 2005), direction seven of which committed governments to:

  > "Review the current understanding of freshwater biodiversity in relation to the NRS CAR reserve system, and finalise an agreed approach, which may include future amendments of the NRS Guidelines, to ensure freshwater ecosystems are appropriately incorporated within the NRS".

  This initiative needs to be followed through, as does the Murray Darling Basin Commission's native fish strategy (MDBMC 2003). The recommendations of Phillips and Butcher (2005) for the development of "river parks" within the Basin need urgent additional funding, especially with regard to community awareness and involvement.

The need to establish comprehensive and representative freshwater protected areas is urgent, given increasing concerns about limited water availability for Australia's cities, industries and agriculture and the ongoing degradation of aquatic ecosystems. This should be accompanied by effective land and water management that is reoriented to the environmental requirements of aquatic ecosystems.

The most urgent initiative appears to be a National Reserve System gap analysis which would identify those ecosystems most at risk. A comprehensive national assessment of the conservation status of freshwater ecosystems should be undertaken immediately. Such a study would provide a platform for the systematic expansion of the nation's freshwater protected areas, as well as a catalyst for innovative bottom-up conservation approaches driven by local stakeholders. This should include establishment of an Australian Heritage River system, coordinated by governments, and supported by regional communities.

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8. Protected area planning and management for eastern Australian temperate forests and woodland ecosystems under climate change – a landscape approach

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Abstract

The ecological effects of rapid global warming are predicted to be dramatic with mass species extinctions worldwide. For temperate eastern Australia, a drier and warmer environment will affect survival, distribution and abundance of species, including exotics, and ecological processes within and outside reserves. Ecological connectivity and fragmentation, already major conservation issues, will be exacerbated by climate change and migration will be inhibited where suitable habitat connectivity is poor or non-existent.

The potential effects of global warming on the reserve system within the eucalypt forests and woodlands of temperate eastern Australia are examined from ecological and land-use perspectives. Species may adapt allowing persistence within their existing ranges or be pressured to migrate to new climatically suitable areas. The current reserve system may be inadequate for one of its key purposes: long-term conservation of biodiversity assets and ecological processes. Other key findings are:

- Maximise health and robustness of native vegetation using natural processes (e.g. re-colonisation, natural selection) to facilitate resilience of affected biota.
- Conservation of woodland environments, already very highly depleted and fragmented, require urgent land-use/management change.
- The reserve system should be expanded and/or augmented through land management change.
- A system of biolinks (restoration of the ecological connectivity, between reserves and climate refugia), a major new land-use at a continental scale, is required. Ecological space for natural adaptation requires land-use change.

Adaptation to climate change will become a societal imperative and management of the reserve system will be seen in the landscape and intergenerational contexts. Emerging trends that may improve the capacity of the reserve and off reserve systems include the decline of the relative economic importance of agriculture and emerging socio-economic trajectories of rural landscapes and ecosystem services.

Biolinks are ecological infrastructure to manage a major new risk of this century and provide part of a new landscape vision - carbon source landscapes of past agriculture would become carbon sinks with enhanced biodiversity assets.

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Introduction

Climate change is expected to induce major changes to global ecosystems and biodiversity with 15-37% of the world's species likely to be "committed to extinction" (Thomas *et al.* 2004; IPCC 2007). Bioclimatic modelling suggests that species losses in eastern Australia will fall in this range (Brereton *et al.* 1995; Newell *et al.* 2002). Climate is an abiotic variable that is a major determinant of the distribution and abundance of biota. Increases in atmospheric CO_2 concentration and changes in the spatial distribution of climate variables (temperature, precipitation) will induce changes to a range of biological and ecological processes in the terrestrial biota including:

- The structure and function of ecosystems;
- The physiological, genetic and/or behavioural make up of species;
- Phenology (flowering, breeding etc.);
- Growth rates, nutritional value and community structure;
- Fire and water regimes; and
- The spatial distribution of species/communities.

Empirical evidence from across the globe indicates many of these changes can now be observed from the warming of the past five decades, e.g. phenology (Menzel *et al.* 2006) and gene frequency change (Umina *et al.* 2005).

Eucalypt forests and woodlands are the dominant biomes of temperate eastern mainland Australia supporting a wide range of vegetation communities and variation in this relatively wetter and more fertile part of the continent (Hobbs & Yates 2000; NLWRA 2001b). Their distribution is coincident with the most populous and agriculturally rich regions of the continent. Over the past 200 years, agriculture and forestry have depleted and fragmented natural environments, particularly eucalypt woodland where there has been a loss of the broad fabric of the landscape (Hobbs & Yates 2000; NLWRA 2001b).

The southeastern Australian woodland biome has a concentration of bioregions under environmental stress (NLWRA 2002). The reserve system, although increasing in recent times, was established from land available only after the needs of agriculture, forestry and settlement were satisfied. Protected areas thus remain fragmented and include areas that are far from pristine condition as a result of previous land-uses (e.g. ECC 2002).

This paper examines the potential effects of climate change on eucalypt forest and woodlands in the reserve system from a broad land-use and management perspective. Using a conceptual framework of species response and predicted climatic changes it is suggested that although there will be capacity for adaptation within the reserve system, restoration of the ecological connectivity and habitat matrices between reserves and climatic refugia are required, to prevent further depletion of native biodiversity (Soulé *et al.* 2002). Other environmental factors associated with a warmer and drier climate, such as changed fire regimes and reduced water availability, will affect the spatial expression of vegetation and habitats over time.

In 2005 agriculture produced 16.8% of Australia's greenhouse gas emissions (Australian Government 2007). Since 1990, "forest land converted to crop and grassland" provided a substantial input to the net emissions. However, Victoria and Western Australia have converted this sector from source to sink in 15 years. Agriculture has declined in relative economic importance (see NLWRA 2001a) and current socio-economic trends in land-use toward "amenity landscapes" (Barr 2005) may be able to promote improvement in habitat connectivity post-agriculture which could also convert carbon source landscapes to sinks. Markets for ecosystem services and carbon sequestration and new foci for reserve management such as water production will be part of adaptation.

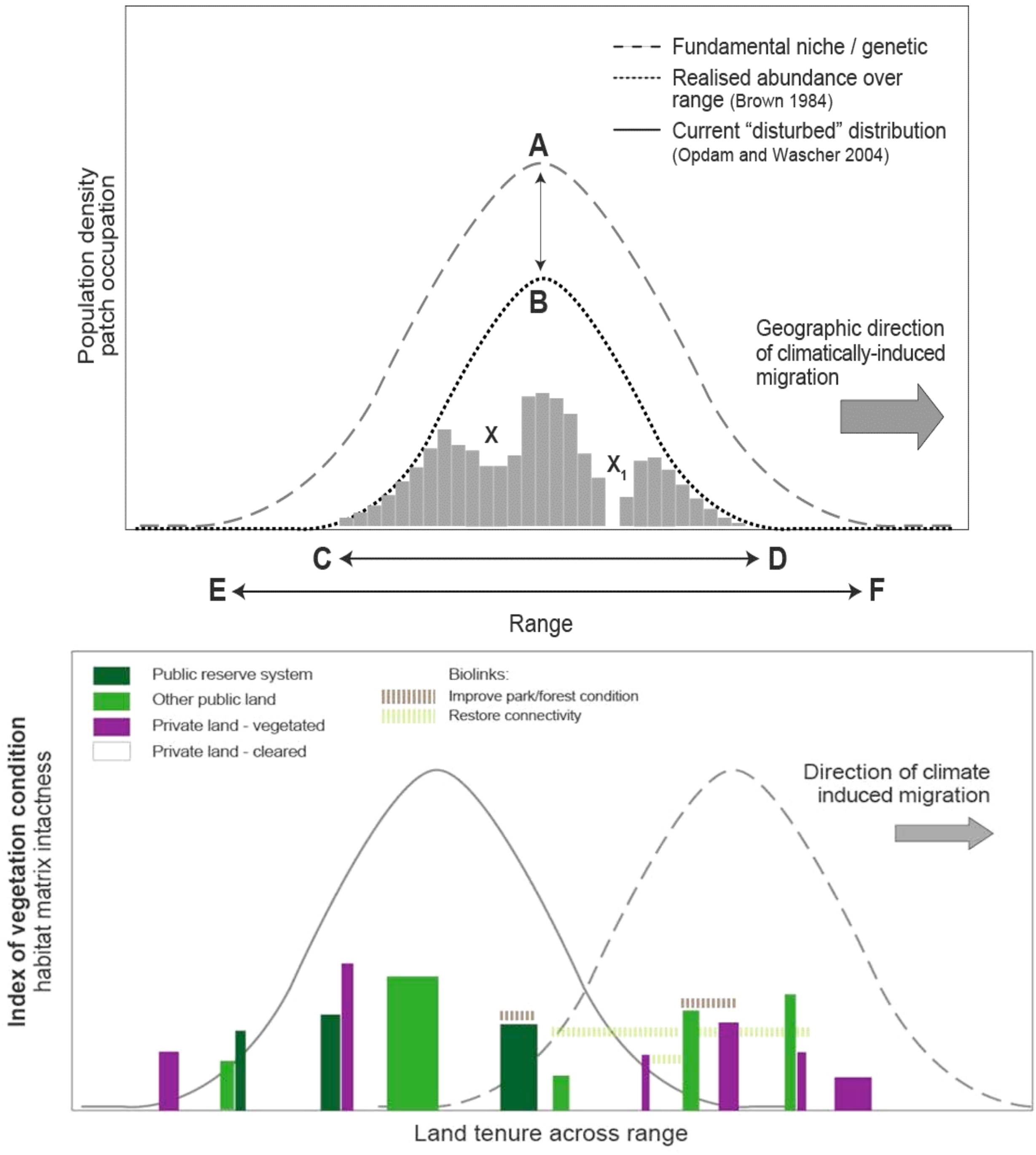

Fig. 1a (top). An idealised north-south cross transect through a species range showing fundamental niches, realised abundance distribution in absence of disturbance and actual distribution following disturbance (see also Opham & Wascher 2004). A-B amplitude of the full potential capacity to adapt phenotypically or genetically; C-D undisturbed distribution, indicated for example by bioclimatic modelling. Populations at extremes of range may have different genetic structure with D being more likely to adapt to climate change; E- F extent of the fundamental niche of the species (unknown for most species); X habitat loss or fragmentation drives down abundances.

Fig. 1b (bottom). An idealised north-south transect through a species range showing vegetation, land-use and habitat condition (y-axis). Optimal climate for the core population may change distribution.

Species responses to climate change

A conceptual model of species responses to climate change is shown in Figs 1a and b. The response of ecological communities is likely to be more than the sum of species responses due to interactions and dependencies among species.

The distribution of a species across its realised range is idealised as a normal distribution with the majority of the populations in the central parts of the range (Brown 1984). Habitat loss or fragmentation, introduction of a novel predator or disease within or throughout the range drives down abundance (Opham & Wascher 2004; Fig. 1a,b). Within the range species fitness (behavioural, physiological, genetic) is continually being tested and explored through re-colonisation etc. Within a population there will be genetic or phenotypic variability that allows adaptation to changes in the biotic and abiotic environment. Australian species have evolved on the driest human-inhabited continent with highly variable climates. However, vegetation in the southeast already appears water stressed in a global context (Woodward & Rocheforte 1991). Behind the realised range lies the potential range. Kearny and Porter (2004) viewed the "fundamental niche" as the set of conditions and resources that allow a given organism to survive and reproduce in the absence of biotic disturbance. The range within a fundamental niche (Fig. 1a items e-f) is likely to be broader than existing ranges due to untapped plasticity and genetic variability.

Under changed climate, populations of a species may respond in two broad ways or a combination of these at the same time. Firstly, a species may adapt to changed conditions within the existing range through phenotypic plasticity or evolution (Fig. 1a,b). Umina *et al.* (2005) have observed frequency changes in climate sensitive genes of *Drosophila* equivalent to a 4^{o} latitude southward movement under the warming that occurred since the 1970s. In the absence of adaptation, populations may contract to refugia or go extinct within the present range.

Secondly, a species may migrate to keep pace with shifting climatic range (Bennett *et al.* 1992). This option is *only* available if suitable habitat matrices are, or become available, that allow such movement (Fig. 1b). Brereton *et al.* (1995) modelled shifts in bio-climatic envelopes of 42 vertebrate species of south eastern Australia and observed significant range shifts. Changes in species distribution and abundance will change interactions in the biotic environment (e.g. diseases incidence, flowering time and breeding, predator-prey interactions).

Each species can adapt only within the potential available to it (Fig. 1a, b) and in interaction with its biotic community. The relative magnitude of *in situ* adaptation (including contraction) versus migration remains unknown for any species.

Changes have already been observed in a range of biological and ecological phenomenon across a range of environments, both *in situ* and in experimentally induced elevated CO_2 and temperature regimes (e.g. Opham & Wascher 2004). For example, forbs (C3) and grasses (C4) respond differently to elevated CO_2. As a result, the floristic composition of the ground cover under grassy woodlands will likely favour grasses relative to forbs in a warmer world, with cascading affects up the food chain to grazers and predators.

About a quarter of eucalypts have a narrow modelled bioclimatic range ($<1^{O}$C) , with a similar percentage in a narrow rainfall band (Howden & Gorman 1999). Conversely, common woodland canopy associates, White box (*Eucalyptus albens)* and Yellow gum, (*E. melliodora*), extend from southeastern Queensland to South Australia (see Landsberg 2000) suggesting a broader plasticity.

These examples suggest a two-tiered risk management approach. Firstly, to make current habitats including reserves as healthy as possible to reduce the effect of unnatural perturbations and protect source populations and refugia. Secondly, to ensure connectivity and permeability between habitats. These two primary strategies are likely to be more effective than reliance on active translocations (see below).

Climate change scenarios for southeastern Australia and ecological implications

Within the overall context of global warming, regional climates are difficult to predict with precision, however, modelling indicates southeast Australia will become warmer and drier. Suppiah *et al.* (in press) indicate that by 2070, the low global warming scenario gives widespread mean increases of 1°C to 1.5°C, while under high global warming increases of 3-4°C occur within 200 km of the coast, and 4-5°C over most of the rest of the continent. Under the high 2070 scenario most of Victoria would receive 10-20% less rainfall than at present, including 20-30% less in spring.

The climate changes will affect basic ecological processes. The most favourable outcome for mean annual runoff in Victoria (2030) was a decline of up to 20% in the east and south of the state (a single catchment showed a small probability of an increase) and at worst, a 5-45% reduction in the west of the state. By 2070 the worst case scenario indicated changes that exceed a 50% reduction in all catchments (Jones & Durack 2005). Although precipitation may decline, it may fall in more intense "events", thus perhaps, ironically, flooding may increase in some areas. In southeastern Australia, days of high-extreme fire risk are predicted to increase by 4-25% in 2020 and by 15-70% by 2050 (Hennessy *et al.* 2005). Temporal windows for autumn and spring management burning will shift and narrow toward winter (Hennessy *et al.* 2005).

The predicted warmer and drier future (Suppiah *et al.* in press) varies from the paleo-ecological record which shows that warmer inter-glacials are on average wetter than the cool dry glacial periods (Gill 1965; Barlow 1981). The first half of the 20th century was generally drier than the second half thus the period when most ecological studies were conducted and when major resource allocations were made or increasingly exploited (e.g. water, forestry) was perhaps an abnormally wetter period.

Geography of the eastern temperate eucalypt forests and woodlands

The eucalypt forests and woodlands dominate the vegetation of the Bassian and Bassian/Eyrean bio-climatic regions, centred around the relatively high altitude (>500m but to 2000m a.s.l.) and watered (>400 to >1400 mm annual isohyet) temperate zone of eastern Australia (Blakers *et al.* 1984; Hobbs & Yates 2000; NLWRA 2001b). They occupy a broad north-south range between 27^{o} and 38^{o} S with forests along the elevated Great Dividing Range, woodlands occur throughout but dominate on the drier inland slopes until replaced by other vegetation as the climate becomes more arid further from the coast (Blakers *et al.* 1984; Hobbs & Yates 2000. For detailed mapping see Ecological Vegetation Class maps at www.dse.vic.gov.au). Woodlands appear bounded by the semi-arid /dry sub-humid demarcation of the Bailey Moisture Index (BMI).

Historical fragmentation and degradation

The past and present distribution and extent of vegetation (Table 1) show that eucalypt woodland has been vastly depleted since European settlement predominantly for agriculture, wood products and settlement. For over 200 years, agriculture, cropping and pastoralism consumed natural vegetation on the most fertile and accessible lands (AGO 2000; Landsberg 2000; Mansergh *et al.* 2006 a,b). As a result highest continental concentration of bioregions under high environmental stress in Australia is within the previous distribution of eastern temperate woodlands (NLWRA 2001b) and the extreme of this concentration is in Victoria (Mansergh *et al.* 2006b).

Reservation of land for conservation, in the form of parks and reserves, became significant only the 1970s when available public land was already depleted in Victoria and NSW (Clode 2006; Mansergh *et al.* 2006b). A national strategic plan was developed to create a national reserve system that was to be comprehensive, adequate and representative (CAR).

Table 1. Eucalypt forest and woodlands of temperate southeastern mainland Australia: pre-European and current extent ('000km^2, data from NLWRA 2001b), and notional estimates of broad vegetation condition and net stock (see text).

	Extent and condition of native vegetation						
	Pre-European		Present		%remaining	Condition estimate[1]	Estimated Net stock[2]
Veg type	NSW	Vic	NSW	Vic			
Tall open forest	-	21.0		16.8	80.0	70 - 85%	55 - 65%
Eucalypt open forest	138.6	23.1	91.0	15.0	65.6	45 - 60%	30 - 40 %
Eucalypt Woodland	208.0	78.3	68.3	25.0	32.6	35 - 45%	10 - 15%

[1] Mean value % These are gross estimates derived from broad literature, see text.

[2] Net Stock = (Pre-european extent /current extent x 100) x estimate of current condition.

Fitzsimons (1999) provides a recent assessment of the reserve status of Broad Vegetation Types in Victoria where parks and reserves comprise about 17% of the land area but are only 7% of New South Wales. The current reserve system remains disjunct, with habitat fragmentation (NLWRA 2002) and ecological connectivity being major conservation issues throughout Australia (Soulé *et al.* 2004). However, Parks and reserves are now significant assets to regional economies (Tourism Victoria 2007).

Bennett *et al.* (1992) found the Victorian parks system relatively well located in relation to climatic refugia but with a major gap in central Victoria and along the Murray River. The elevated areas of central Victoria and its east-west orientation appear significant at the continental level, particularly for woodlands if connectivity could be restored. Subsequent reserves and proposed reserves have assisted conservation, eg Box-Ironbark forest (ECC 2001; VEAC 2007). In the absence of detailed studies, the north-south orientation of the parks system in NSW along the Great Dividing Range provides a reasonable strategic framework for restoration of ecological connectivity particularly for forests. Biota and reserves in woodlands appear vulnerable at present and climate change will exacerbate this risk (Tables 1 & 3).

Condition of forests and woodlands and supporting reserves

Extent of habitat contains ecological thresholds (for woodland birds see Radford *et al.* 2005) but the condition of the vegetation and habitat within and between reserves is an important factor in resilience to climate change. Ecological condition is the major factor in the capacity of an ecosystem's resilience to perturbations.

A warmer, drier climate with increased storm events and fire risk indicate that there will be a continual and directional change in the frequency and type of perturbations. Improving the condition of native vegetation will improve robustness and biological inertia to resist "sudden" change (Graetz *et al.* 1988; Mansergh & Bennett 1989).

There is no national standard or data base on ecological condition of the forest and woodlands (NLWRA 2001b). The condition metric of "habitat hectares" has enabled comprehensive condition assessments, comparable across many vegetation communities that are benchmarked on the floristics and structure of mature undisturbed vegetation type and its current landscape context (AcroMap and Land Information Group 2004; Parkes *et al.* 2002). A notional estimate of the condition and "net extant stock" of the woodlands and forests was developed with reference to literature (Prober & Thiele 1995; Hobbs & Yates 2000; NLWRA 2001b, 2002; AcroMap and Land Information Group 2004). This assessment suggests that woodlands are currently in a very depleted situation to face the further perturbations under climate change (Table 1).

The reserve system was created by changing prior land-uses and each land-use type carried an environmental legacy. The modelled condition of open forest and woodlands around Euroa (Victoria) shows that although some reserves had relatively high habitat hectare scores, old trees are actually more common *outside* the reserve system on roads, stream-sides and private land due to the history of timber harvesting (ECC 2001; Newell pers. comm.). Old trees are keystone species in the landscape providing nesting hollows for many species (Manning *et al.* 2006) and thus have an important role in re-establishing connectivity and restoration of habitat matrices.

Climate change - speed and distance

The speed and magnitude of potential climate change in the 21st century is dependent on the magnitude of future greenhouse gas emissions. However, even current best-case scenarios suggest a rapidity that may be extremely difficult for biota to deal with (Thomas *et al.* 2002; Hilty *et al.* 2006; IPCC 2007). The rapidity of change will vary from region to region and biome to biome. Species in flatter, lower, drier areas will face more pressure than those in wetter, higher hills and mountains. On the lower inland plains the inland spatial shift will be much more rapid than on the uplands of the Great Dividing Range (Table 2). The BMI shows the semi-arid zone moved 130 km south under a +3^{o}C and -10% rain scenario (Bennett *et al.* 1992).

The topography of mountains and foothills provide relative higher potential for habitat diversity (altitude, aspect) per unit area than the plains. Forest communities have migrated at rates of kilometres per year, however, over centuries or longer (Pitelka *et al.* 1997). Woodlands face greater climate zone shifts relative to forests (Table 2). A reserve system that is spatially disparate could face depletion of its flora and fauna complement and the vacuum remaining is at risk of invasion by exotic species.

Table 2. Distance and altitude change shifts in bioclimatic envelopes for broad vegetation types expected from different rates of warming (R.E. Jones, CSIRO pers. comm.)

Bio-geographic element		Temperature rise (C^{o}) / decade			
		+ 0.2	+ 0.2	+ 0.5	+ 0.5
Geographic range	Vegetation type	Distance (km)	Altitude (m)	Distance (km)	Altitude (m)
Plains	Woodland	25-100	-	60 - 250	-
Foothill/ central hills	Woodland / Open forest	4 – 10	-	10 - 25	-
Central Highlands	Open Forest, Tall open forest	1 – 2	50-100	3 – 5	125 – 250

Other implications of climate change

Pests, pathogens and exotic species

Climate change will also effect the distribution and abundance of pests, pathogens and exotic species and their potentially adverse effect on native species of the climatically stressed forests and woodlands may be greatly enhanced (Sutherst & Floyd 1999; Fig. 1). Two responses are indicated.

First, maintaining or restoring all habitats to a naturally resilient condition that resists invasion or spread of diseases and exotic species invasions.

Secondly, restoring ecological connectivity through "biolinks" (see below) maximises the chance for species to adapt to climate change. Damschen *et al.* (2006) reported a long-term scientific field experiment that demonstrated statistically that corridors *did* increase native plant species richness and did *not* enhance the spread of exotics.

Fire and water

Fire and consequent vegetation management represents a major challenge to reserve and off -reserve management. Fire regimes (frequency, intensity, seasonality, patchiness) are an important factor in the species and community ecology of eucalypt forests and woodlands (canopy, understorey and ground cover). Noble (1999) observed that in the short-medium term, fires usually cause little direct change in composition of tree species. However recruitment may be more critical than mortality. Major fires are associated with drought conditions which are expected to increase as is the frequency of high and extreme fire risk days (Hennessey *et al.* 2005).

Fire regimes in all Australian landscapes have changed since European settlement. Fires in southern forests and woodlands are illustrative of some issues related to climate change, vegetation, landscape and water. Fires in the southern mountain regions became more frequent from the 1830 to 1960's and less frequent after 1970 (Banks 1989). Major fires occurred in this region in 1851, 1896, 1924, 1926, 1939, 1962, 1983, 2003 and 2007 (Cairnes 2004). Wareing and Flinn (2003) consider that the 1939 fires were a major perturbation and shaped the forests of today.

The large fires of 2003 and 2007, 2 M ha and 1.1 M ha respectively, burnt major catchments, much of the Alpine Park, the largest national park in Victoria a largest climatic refugium in southeast Australia and large areas of tall open forest (Brereton *et al.* 1995; Wareing & Flinn 2003; Fig. 2, 4). Tall open forest eucalypt ash forests dominated by *E. regnans* and *E. delegatensis* regenerate after an intense burn, but a subsequent fire before the trees can reach reproductive age favours regeneration by *Acacia* species (e.g. *A. dealbata*) (Noble 1999), thus changing the forest type.

Variable fire severity over the landscape will result in differential natural regeneration and habitat heterogeneity. Both 2003 and 2007 fires had large areas of severe crown scorch. Changes in fire regimes throughout the landscape may modify vegetation and perhaps soil characteristics, which affect future water run-off from site as the vegetation regenerates post fire.

After rainfall, type and condition of vegetation and soils are major determinants of run-off with fire regimes a compounding factor (Noble 1999). Parks and other public land will become increasingly important and valued for water production in a warmer and drier future. The 2003 and 2007 fires occurred in the mountainous areas of open and tall open forest which supply 45% (up to 60% in droughts) of the Murray River flow (not including Goulburn and Murrumbidgee catchments which also rise in the mountains) (Trevor Jacobs, River Murray Water, pers. comm.). Downstream environments depend on environmental flows, e.g. Murray floodplain forests (VEAC 2007) and productive agriculture is becoming increasing dependent on irrigation (e.g. dairying and horticulture along the Murray River) (NLWRA 2001a).

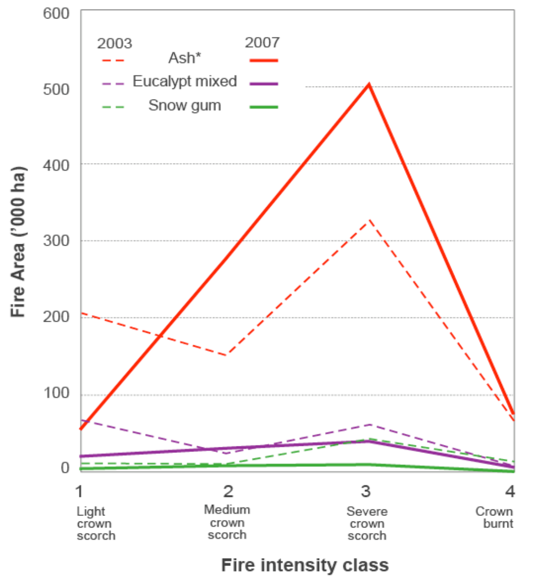

Fig. 2. Area of fire severity (ha) by vegetation type of 2003 and 2006-7 alpine/montane fires in Victoria (Data from Department of Sustainability and Environment, Victoria).

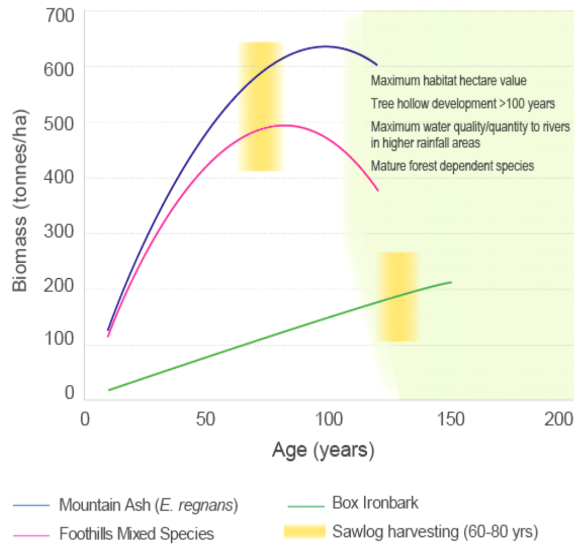

Fig. 3. Biomass accumulation curves by age of forest and woodland showing carbon sequestration and optimal time of ecosystem services (timber harvesting, water in high rainfall areas, habitat attributes of "old growth"). Soil carbon sequestration is also substantial (Data from Grierson *et al.* 1993).

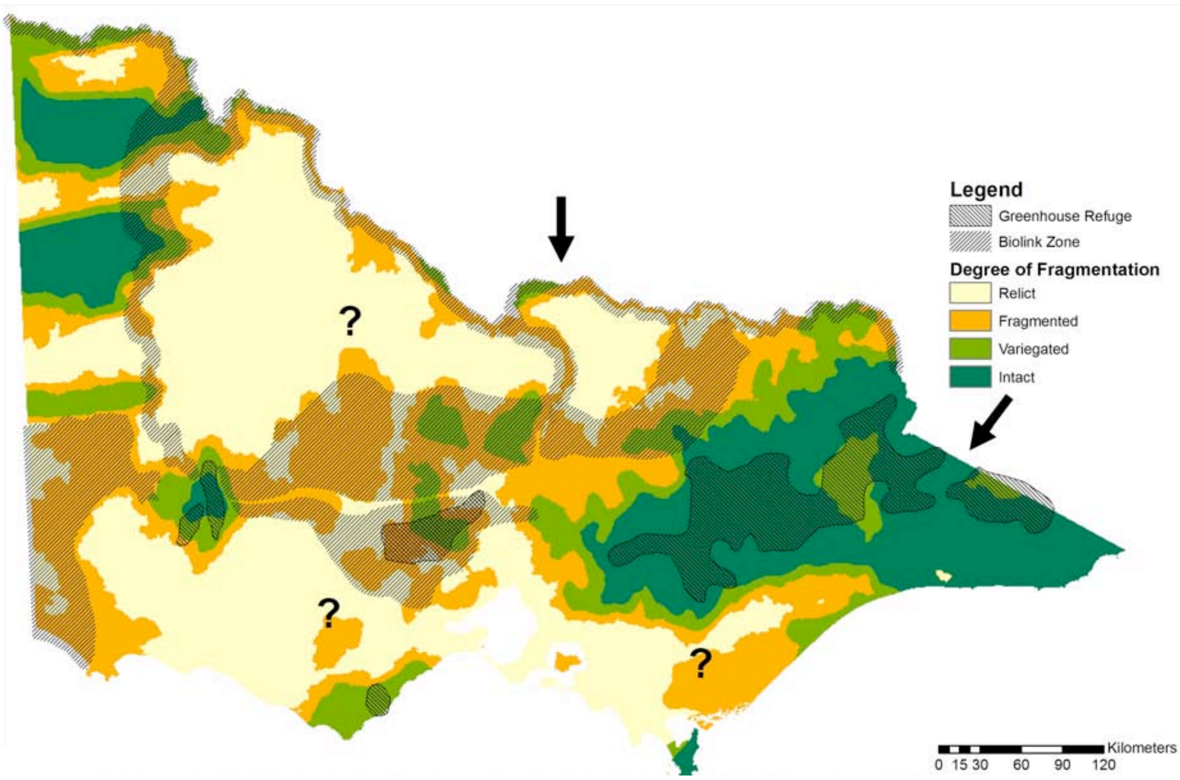

Fig. 4. Broad biolinks showing refugia areas in Victoria and modelled habitat fragmentation. The arrows show the presumed direction of biodiversity climate induced migration. The (?) indicate areas of possible future biolink zones. Broadly the intact vegetation equates with public land. Biolinks must link with similar zones in NSW (data from Bennett *et al.* 1992; Brereton *et al.* 1995)

Melbourne's closed water supply catchments support mature tall eucalypt forests and cool temperate rainforests that maximise water yield quality and quantity, both of which may decline following fire. These catchments are managed for "old growth" and water production and have very high economic value as an ecosystem service (Fig. 3; Young 2003).

Conversely, in landscapes that need restoration, particularly woodlands, water will be required for regeneration in the medium term. In key areas, such as riparian zones, native vegetation will improve water quality. The ecological inter-relationships between water, fire, vegetation and sustainable landscapes are important issues under climate change and as water becomes better appreciated as a societal limiting factor (e.g. Crooks & Chamley 2007) responses will become more sophisticated. New catchment models assist in examining the "stocks and flows" of these issues in the context of economics and investment (Eigenraam *et al.* 2005).

Planning and management responses

Translocations and replantings

Translocating species as or when required is frequently viewed as primary responses to climate change. However, these may be of higher risk and more resource intensive as primary strategies compared with protection and restoration of intact habitats.

Translocation assumes:

- Appropriate host habitats are available, correctly identified and will not be disrupted;
- Ecological relationships are fully understood and can be catered for;
- Resources will be available for hundreds, if not more, species.

Mass plantings based on climatic predictions assume complete climatic and biological knowledge, which is usually lacking. Plantings should focus on key areas (e.g. riparian) where natural resilience has been lost. Elsewhere natural regeneration, particularly of eucalypts, is likely to be a more effective approach to recovering resilience. In contrast to plantings, natural regrowth selects for genotypes adapted to climate trends (currently +0.7 ^{0}C) relative to parental stock. Extant vegetation is often called *remnant* (from past). Perhaps it is better defined as *reservoir* vegetation (future).

Biolinks

There is widespread policy and ecological recognition of the need for restoration of ecological connectivity to prepare for climate change (e.g. DCE 1992; Soulé *et al.* 2002; NRMMC 2004; Opham & Wascher 2005; Stern 2006). In eastern Australia, restoring ecological connectivity between major areas of native vegetation, reserves and climatic refugia has been seen as a critical for over 20 years (Mansergh & Bennett 1989). In the eastern intensive zone in Victoria the term "biolinks" was coined in the early 1990s in the context of species migration and climate change (Bennett *et al.* 1992, Brereton *et al.* 1995).

Subsequently, large-scale landscape connectivity programs such as WildCountry (Mackey *et al.* 2007) and Gondwana link have been initiated. The Alps to Atherton climate corridor, others across northern Australia (Blanch this volume) are, in part, responses to future climate. These are all variants on the biolink theme. Biolinks are national ecological infrastructure that form part of an adaptive response to climate change and include all land tenures.

Biolinks differ from the traditional concept of "wildlife corridors" in many ways; their scale (tens to hundreds of km wide or long); their multi functional nature; boundaries that are not harsh but permeable; appropriate human settlement and use encouraged; and they more fully embrace the broad view of emergent ecosystem services and sustainable landscapes (Mansergh *et al.* 2005a; Mansergh *et* *al.* 2007). An expectation of >30 % native vegetation (canopy, understorey, ground cover) mosaic within the biolink is required rather than a totally uniform cover or conversion.

The spatial extent and configuration of habitat heterogeneity affects the capacity of a species to persist or recolonise and we can model and plan these aspects both in reserves and in areas for restoration. Landscapes supporting diverse habitat matrices with high spatial cohesion are crucial as sources of re-colonisation (Opdam & Wascher 2004). Ecological studies are illuminating key environments within the habitat matrices (Manning *et al.* 2006; Martin *et al.* 2006; Soderquist & McNally 2000; Vesk & Dorrough 2006). Landscape preferencing models (e.g. Ferwerda 2003) allow efficient and effective design and catchment models effective investment in multiple outcome (Eigenraam *et al.* 2005).

Biolinks in the temperate eastern intensive zone

Biolinks connect refugia and large areas of native vegetation through landscapes where the intactness of native vegetation is highest (Brereton *et al.* 1995; Mansergh *et al.* 2005; Fig. 4). Biolinks in Victoria need to be coordinated with those yet to be delineated in adjacent States. Intervening land-uses are predominantly agriculture (private land) and forestry (public land). Harvested forests retain relatively more natural elements and resilience than land cleared such as a skeletal connectivity network due to retention of stream-sides, percentages of ecological vegetation classes and sites of significance.

Less public land or large reserves and more agriculture is characteristic of woodlands. Intensification of agriculture (pastoral/ley to cultivation) in this region is a major issue which may degrade or preclude future land-use options (Dorrough *et al.* 2006; Mansergh *et al.* 2006 a,b). On the other hand, Dorrough and Moxham (2005) found that in relict pastoral landscapes (some with only 2.7% tree cover), 40% of the total area retained a high probability of supporting natural regeneration if livestock were removed within the next 30 years.

Fortunately, there is a high correlation of Victoria's biolinks with landscapes moving away from agriculture. Fifty-five percent of private land is moving toward amenity or lifestyle uses and transitional landscapes rather than domination by agricultural production (Barr 2005).

Current biodiversity assets are a crucial part of the amenity of these landscapes and their enhancement will increase amenity value and use. It is highly likely that amenity zones extend up the western slopes through the converted woodlands and forests to Queensland. This provides the opportunity for continental scale landscape change that can pro-actively protect biodiversity.

The space required for biolinks may appear substantial but it is not in the context of land-use history or future scenarios. For the first 120 years Victoria was cleared at a mean rate of 1150 km^2 p.a. ; between 1972-87 at 107 km^2 p.a. From 1999-2001, 1140 km^2 p.a. of plantations were established (Mansergh *et al.* 2006 a, b).

Increased production could be possible using 30% less land and 20% less water and retention of 40% native vegetation in catchments (Kefford 2002; Victorian Catchment Management Council 2002). Australia-wide agricultural production is becoming increasingly concentrated within irrigation areas - a relatively small area of agricultural produces most of the wealth (NLWRA 2001a).

Agriculture's relative economic contribution has declined over the decades and is now <4% of the GSP of both Victoria and NSW which helps explain and the socio-economic landscape trajectories observed by Barr (2005).

Climate change makes carbon a new "commodity". Land-use change is a component of the national greenhouse gas emissions and both Victoria and Western Australia have turned this sector from a source in 1990 to a sink in 2005 (Australian Government 2007). Biolinks are part of an adaptive strategy for climate change as they efficiently and permanently store carbon including soil carbon, and they make a contribution to mitigation and sound risk management (Attiwell & Leeper 1987; Jones *et al.* 2007; Khanna *et al.* 1999; Fig. 3).

Conclusion

In the 21st century, eastern Australian temperate woodlands and forests face a warmer and drier climate which has potential to have profound effects on the distribution and abundance of species and ecological processes. Threatening processes such as fragmentation of habitat, exotic species and changed fire regimes, are likely to be exacerbated. Some species may have capacity to adapt *in situ* and within range through behavioural, physiological and in the longer term, genetic changes.

However, there will be pressures for migration generally southward and to higher elevations. Building ecological health and resilience through development of the reserve system and the restoration of ecological connectivity of the landscape through biolinks are major adaptation priorities.

Forests and woodland biomes in the undisturbed state likely had great resilience to enable adjustment to a warmer climate. However, historical land-use has fragmented and degraded such capacity. Adaptation to climate change in the natural environment is best left to evolutionary forces such as natural selection, re-colonisation and re-configuration where natural resilience remains. In some landscapes such as pastoral woodlands, recovering resilience is time-bound and large-scale protection and restoration is needed urgently. Availability and allocation of space for this is a critical issue for the vitality and viability of the reserve system in the 21st century.

The percentage of land area of reserves in NSW (c. 7%) is less than half than that of Victoria (>16%) with woodlands being under-represented. The parks system for forests appears reasonably well located in relation to known climatic refugia, however, this is not so for woodlands, the biota of which are vulnerable currently with climate change exacerbating risk. The north-south orientation of the parks system in NSW along the Great Dividing Range and into Victoria provides the potential for enhanced ecological connectivity. Ecological connectivity between reserves is poor however. The elevated areas of central Victoria and their east-west orientation show potential continental connectivity, particularly for woodlands. However, this presupposes ecological permeability and connectivity (biolinks) with woodlands further north which is yet to be restored. Land-use planning and management focussed on restoring ecological connectivity *across* the landscape is imperative.

The relative importance of agriculture has declined over the last 50 years and new socio-economic landscapes (e.g. lifestyle, amenity) are evolving with values potentially more compatible with biodiversity conservation. Demand for ecosystem services such as amenity, carbon sequestration and tourism in sustainable landscapes may provide new resources to improve biodiversity outcomes with naturally regenerated vegetation changing landscapes from CO_2 sources to increasing sinks, a desirable characteristic for this century.

Biolinks have a major part to play in restoring resilience in the context of climate change. The area required for biolinks is substantial and restoration needs to begin as soon as possible. Priority should go to regeneration of natural forest and woodland communities.

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9. Challenges facing protected area planning in the Australian Alps in a changing climate

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Abstract

Current models of climate change for the Australia Alps are suggestive of higher mean temperature and less precipitation, especially in the form of snow. In many parts of Australia, a change in climate will move optimal habitat latitudinally or altitudinally. In the Alps however, plants and animals reliant on snow cover and low temperature will have no alternative habitat to move into. In this paper we present an approach to planning for climate change in the Alps, which involves prediction, monitoring, research, management, coordination and adaptation. Managers in the Alps are well placed to make predictions about the impacts of climate change and evaluate changes when they occur because of a long history of monitoring and research. Based on climate models there will be a contraction of treeless vegetation, snowpatch and feldmark communities, and invasion of shrubs into grasslands. Fauna that are restricted to snow-covered habitats or depend directly on snow cover within the alpine extent of their range (e.g. the mountain pygmy-possum and broad-toothed rat) are likely to be especially affected.

Mountain plants and animals will probably face their greatest threat from indirect consequences: increased exposure to frost, low temperatures and predation in areas once protected during winter by snow, increased fire frequency because of drier fuels and more frequent dry thunderstorms, increased herbivore activity as native and feral herbivores move to higher altitude, and decreased runoff to lower streams and wetlands. Invasion of treeless areas by trees and shrubs and increased predation on fauna by feral animals has already been observed but most other impacts of climate change are yet to be detected or are difficult to distinguish from natural change. Biodiversity in the Australian Alps faces an uncertain future. A targeted program of research into the ecology of key plants and animals, and their habitat is urgently required.

Introduction

The Australian Alps National Parks are reserved for the protection of a large range of natural and cultural features and provide numerous opportunities for recreation and tourism. The parks cover a broad altitudinal range (from c. 300-2228 m a.s.l.), with distinct alpine zones at the highest elevations. As with many mountain areas, the degree of endemism increases with altitude, with several plant communities and flora and fauna species endemic not only to the alpine zones generally but to specific mountain tops within the region (e.g. Green & Osborne 1994; Costin *et al.* 2000; McDougall & Walsh 2007).

It is predicted, and already becoming evident, that alpine ecosystems will be among the first to experience impacts of climate change, with expected upslope migration of flora and fauna or shifts to

McDougall K. & Broome L. (2007) Challenges facing protected area planning in the Australian Alps in a changing climate. In: *Protected Areas: buffering nature against climate change. Proceedings of a WWF and IUCN World Commission on Protected Areas symposium, 18-19 June 2007, Canberra.* (eds M. Taylor & P. Figgis) pp. 73-84. WWF-Australia, Sydney.

cooler aspects and loss of the coldest climatic zones at the summits (Halpin 1994; Price & Neville 2003; Pickering *et al.* 2004; Steffen 2006; IPCC 2007).

Based on current climate models, the projected change in mean annual temperature in the Australian Alps to 2050 will be between +0.6 and +2.9°C (Hennessey *et al.* 2003). The projected change in precipitation is between +2.3 and –24.0%. With such change there is likely to be a contraction in the area receiving persistent snow and a reduction in the duration of snow cover.

Past threats to plants and animals in the Australian Alps have included agricultural use, mining and broadscale landscape alteration for hydro electricity production. Current threats include tourism pressure, feral animals, weeds, and most notably climate change. Unlike many other ecosystems, bioregional approaches to conservation are not an option for the Alps. Alpine species are situated in a largely flat ecosystem with a precariously narrow altitudinal band of snow cover (c. 1400-2228 m) and very little room to move.

Planning for a changing environment

Planning for detrimental impacts on plants and animals in a changing climate will be a challenge. There are no formal plans yet for tackling the impacts of climate change in the Australian Alps. The current short-term planning process (e.g. plans of management, fire management plans) does not easily allow for addressing such long-term issues.

An additional constraint on planning is that plant and animal populations are dynamic. Because of periodic perturbations (e.g. fire, drought, pathogens), they will change continually regardless of changes in climate. Disentangling natural changes from those attributable to global climate change (and those caused by other anthropogenic threats such as weeds and feral animals) is currently beyond our capacity for most species. However, understanding and doing something about climate change impacts on plants and animals is not insurmountable.

A logical planning process to address impacts of climate change on biodiversity might have the following steps:

- Prediction: Changes in local climate have been modelled and much is already known about the biology and ecology of some mountain organisms. We are in a position to make predictions about the impact of climate change that go beyond mere speculation.
- Monitoring: The Australian Alps have some of the longest-term flora and fauna monitoring projects in the world that should enable the detection of changes when they occur. This will help with the acceptance or rejection of predictions and, where predictions are rejected, with the development of better predictions. It will also identify the biodiversity elements that are changing most rapidly and therefore help with resource prioritisation.
- Research: Separating natural processes from changes caused by climate change will be a challenge worldwide. In the Australian Alps these is a good understanding of some species and processes (e.g. shrub/grass cycles in alpine areas) but very little is known about many of the biota that are likely to be most at risk in a changing climate.
- Management: Monitoring and research will help to identify biota most at risk. In some cases, especially if the changes are understood, it will be possible to ameliorate or manage for the impact. In some cases, tough decisions will have to be made about what can be protected and what cannot.
- Coordination and adaptation: Ideally, the monitoring, research and management will be part of a coordinated program. Monitoring will be a critical component of a management program and research will often be guided by management uncertainties. Above all, the components should be adaptable and adequately resourced.

An important challenge for addressing the impacts of climate change in the Australian Alps and elsewhere will be the expected duration of the problem. Natural resource planning traditionally occurs in cycles or 5-10 years at most and funding of actions is typically annual. The planning approach described above for detecting and responding to the predicted changes is decadal. Responding adequately to climate change impacts will probably require a long-term and far-sighted approach to planning and resourcing.

How might the predicted changes in climate affect plants and animals?

The consequences of global warming may be both direct, as a result of increased mean temperature and decreased snowfall and precipitation, and indirect. Indirect consequences may include increased exposure to frost in areas once covered during winter by snow; increased fire frequency because of drier fuels and more frequent dry thunderstorms; increased herbivore activity as native and feral herbivores move to higher altitude; and decreased runoff to lower streams and wetlands. Some of the changes are difficult to predict because so little is known about the reproductive biology and physiology of Australian mountain plants and animals.

Predicted impacts on flora, fauna and vegetation and evidence of change

Treeline

An increase in the long-term mean temperature should allow the invasion and persistence of trees in areas that are currently treeless (i.e. the alpine zone and subalpine frost hollows) because tree establishment is controlled by low temperature in the growing season (Harwood 1980; Slatyer 1989). Germination of snow gum seed beyond the treeline does naturally occur but germinants are commonly killed by frost or at least severely retarded in growth.

However, under current models of temperature change, treeless areas will not disappear. Natural frost hollows are found on the NSW Southern Tablelands low elevations (to about 600 m a.s.l.). Their occurrence is a function not of landscape-wide mean temperature, which is expected to rise, but of topographically induced diurnal temperature inversions, which produce extremely low temperatures in the growing season (Williams & Ashton 1987).

The worst-case scenario temperature increase of 2.9°C by 2050 could potentially allow tree establishment above 2000 m in NSW. However, the alpine treeline may take centuries to reach that elevation because of the limited dispersal capacity of snow gum seed and the greater exposure of juveniles to frost in winter, which is likely to occur where there is reduced snow cover.

The expansion of frost hollow tree islands and treelines last century has been detected on aerial photographs of the Bogong High Plains and Kosciuszko National Park (KNP). In KNP, the rate of spread into frost hollow plains appears to have accelerated since 1970, which is consistent with recent increases in mean temperature associated with global warming. No invasion of trees into the alpine zone of KNP has been detected using aerial photography (McDougall unpublished data).

Vegetation and animal habitat

Mountain vegetation may be directly affected by increased temperature and decreased precipitation as these will benefit some species and inhibit others. However, many of the greatest changes in vegetation are likely to be a consequence of indirect effects. Less severe winters may allow native and feral herbivores (e.g. deer, rabbits, wombats, macropods, pigs) to survive at higher elevations. This would probably lead to shifts in the abundance of palatable species and trampling of moist vegetation, as occurred when cattle and sheep were brought to the high country during summer months last century (Wimbush & Costin 1979; Wahren *et al.* 1994).

Some types of vegetation are likely to be especially affected. Ridge-top feldmark appears to be reliant on low temperature and sporadic snow-cover. Whilst it may benefit from less snow cover in a warming climate, higher temperatures will allow invasion of species from surrounding communities. Although there is no indication yet of areal change in feldmark (as judged using aerial photography), invasion has occurred on a small scale where entrenched walking tracks have created sheltered micro-habitat (McDougall & Wright 2004).

Alpine snowpatch communities are snow-dependent. There is a good spatial correlation between the extent of snowpatch vegetation and persistence of snow into late spring or summer. Snowpatch vegetation is generally surrounded by heath, the dominants of which are absent from snowpatch communities. A reduction in the duration of snow cover could allow invasion of species, especially shrubs, from surrounding communities. Although there is no indication of areal change in alpine snowpatches in KNP, high subalpine snowpatches on the Bogong High Plains in Victoria have been invaded by shrubs (McDougall 2003) and the invasion continues. The skeletal soils of snowpatch feldmark, a community endemic to KNP, will inhibit the invasion of species from other communities but may well allow the expansion of *Celmisia costiniana*, a rhizomic forb, from within, so that KNP snowpatches will look more like alpine snowpatches in Victoria.

A reduction in precipitation and snow-melt should lead to a contraction of groundwater communities. Although there has been much drying of bogs and fens during the dry periods of the past five years and some localised death of mesic plants, the contraction has not been detectable from aerial photography (McDougall 2003, unpublished data) nor on-ground monitoring (Clarke and Martin 1999; Wahren *et al.* 2001; McDougall 2007). Past monitoring, however, has focused on subalpine wetlands. To detect the first changes in mesic communities resulting from a reduction in run-off, future monitoring might be better directed at communities in the highest parts of catchments such as short alpine herbfields. Many of these are reliant more on snow-melt than on perennial groundwater discharge.

Drier fuels should enable the more frequent spread of fires into habitat that has experienced a very low fire frequency in the past, leading to a general decline of long-lived obligate seeding species and a proliferation of woody resprouters, which are favoured by fire. The impact of more frequent fires on vegetation is likely to be great but the broadscale impact on plant species composition may not be detected until the change is permanent. In KNP, many fire-sensitive communities were burnt in 2003. A fire interval of decades is needed for most of these communities to allow obligate seeding dominants to reach reproductive maturity. If there are no further fires in such communities burnt in 2003 for many decades, there will have been no impact from fire. If there are several fires over the coming decades that remove the patchiness of the 2003 fire and eliminate regeneration of obligate seeders, the change will be permanent.

Alpine ash *Eucalyptus delegatensis* requires an interval of at least 15 years to reach reproductive maturity but much longer (120-200 years) to form tree hollows that provide shelter for fauna (Gibbons & Lindenmayer 2002). Fires of greater frequency will dramatically alter the landscape of the Australian Alps as they have done locally in the Cabramurra area following fires in 1986 and 2003.

Mountain plum-pine *Podocarpus lawrencei* shrubland, the primary habitat of the mountain pygmy-possum *Burramys parvus*, will be destroyed by frequent fire (perhaps as infrequent as twice in two decades). This shrub is very slow-growing and regeneration from seed was poor after the 2003 fires in KNP with many seedlings succumbing to drought.

A fire frequency of less than a decade is likely to be highly detrimental to alpine and subalpine bogs. Regeneration after the 1984 fire at Mt Buffalo in Victoria took more than a decade. One key obligate seeder, *Richea continentis* appears to need an even longer fire interval (Wahren & Walsh 2000).

Impacts of an increased fire frequency on fauna are likely to be more immediate because many species face the added threat of predation by feral animals. For example, populations of the broad-toothed rat *Mastacomys fuscus* declined sharply following the 2003 fires from habitat loss and increased predation in unburnt areas. Monitoring of recovery of shrubs on burnt areas of habitat indicates that it may take 15 years for shrubs to provide sufficient structural strength to support snowpack and again provide habitat for the broad-toothed rat on a year-round basis (Green & Sanecki 2006).

A documented increase in shrub cover in arctic and alpine vegetation worldwide has been attributed to the effects of global warming (e.g. Sturm *et al*. 2001; Sanz-Elorza *et al*. 2003). The more rapid growth of some shrub species than of herbs in cold environments with increasing temperature has also been demonstrated experimentally (e.g. Press *et al*. 1998). A major shift from grassland to heathland during the 20th Century was noted on the Bogong High Plains in areas grazed by cattle (Bruce *et al*. 1999; McDougall 2003) and in Kosciuszko National Park after 1970 in areas not grazed by domestic stock since the 1960s (McDougall unpublished data). The shift is therefore independent of grazing regime. It is probably also independent of burning regime because the Bogong High Plains sites were long-unburnt whereas the sites studied in Kosciuszko National Park had a range of burning history, including fires in the 1960s. An increase in shrub cover will make treeless areas more vulnerable to burning. Shrubby communities were the vegetation types in treeless vegetation most frequently burnt in 2003 (Williams *et al*. 2006). High mountain shrubs are well-adapted to fire. Most are capable of resprouting after fire and the bare ground created by fire favours the establishment of shrub seedlings (Williams 1990). The shift from grassland to heathland is therefore likely to continue.

Flora

The threat to individual plant species will be greatest for those directly or indirectly threatened by one of the expected consequences of global warming (described above) and which have a narrow altitudinal or habitat range. Of 710 native taxa recorded in treeless vegetation in the Australian Alps (McDougall & Walsh 2007) for instance, 288 taxa are endemic to the alpine and subalpine regions of mountains in Australia (including Tasmania). Despite this high level of endemism, only 43 of these have highly restricted distributions (or altitudinal range) and are likely or known to be threatened by frequent fire, increased herbivory, reduced snow cover or drying of wetlands in the upper catchment, or occur only in habitat likely to be at risk from predicted changes in climate. For the remainder of species, even if some habitats decline areally or disappear altogether, other habitats will provide refuge. Importantly, with very few exceptions, the refugia are entirely within the reserve system, highlighting the importance of having reserves with a great diversity of habitat. Although 43 species is a small proportion of the Australian Alps flora (c. 2%) their loss would represent a significant reduction in the alpine and high subalpine flora (c. 6% of taxa from treeless vegetation and c. 15% of the alpine flora).

Increased herbivory may reverse the recovery of palatable species in the alpine zone after grazing by cattle and sheep last century. *Ranunculus anemoneus* for instance was brought close to extinction by grazing but is now relatively common in a range of habitats (Costin *et al*. 2000). Global warming may also favour some rare species. Several species thought to be extremely rare in KNP appeared in abundance after the 2003 fires (Walsh & McDougall 2004). *Haloragis exalata*, a species listed as vulnerable under the NSW *Threatened Species Conservation Act 1995*, also regenerated well after the 2003 fires and appears to prefer areas where the canopy has been removed.

There has been no evidence to date that plant species have declined in the Alps because of global climate change. However, the majority of monitoring has been of vegetation rather than species populations, so detrimental change would not necessarily be detected. Monitoring of species predicted to be at risk will be required if such species are to be adequately managed for the adverse effects of climate change.

Weeds

There is an inverse correlation between altitude and the diversity of exotic plants in native vegetation in Australia (McDougall *et al.* 2005). This is likely to be a function of the lower capacity of exotic species to establish and persist at high altitude and lower temperatures rather than of lower propagule pressure.

A small increase in mean annual temperature could facilitate a large increase in the invasive flora at high altitude. Currently, only 17% of invasive species recorded in treeless vegetation in the Australian Alps occur in the high alpine zone (between 1800 and 2228 m) (McDougall *et al.* 2005). However, a further 32% have their maximum recorded elevation in the high subalpine zone (between 1600 and 1800 m). Invaders may also be native. Two species, *Ammobium alatum* and *Bothriochloa macra*, have been detected recently along roadsides in KNP, well above their normal altitudinal range (McDougall & Walsh unpublished data). A subalpine shrub, *Cassinia monticola,* appears to be invading the alpine zone through gradual encroachment along Kosciuszko Road.

Despite many surveys of exotic species in the Australian Alps (e.g. McDougall & Appleby 2000; Johnson & Pickering 2001; McDougall *et al*. 2005), there is no evidence that global warming has contributed to invasion or enabled species to invade at higher altitude. In fact, separating normal levels of invasion from those assisted by a warming environment will be extremely difficult. Better understanding the processes of invasion and the environmental constraints on invasion by particular species, as proposed by the Mountain Invasives Research Network (of which Australia is a core member) may help to identify exotic species that pose the greatest risk to alpine environments in a warmer climate.

Fauna

The effects of climate change are most likely to be observed initially on fauna that are restricted to snow-covered habitats or depend directly on snow cover within the alpine extent of their range.

The broad-toothed rat *Mastacomys fuscus* is a herbivore dependent on a cool, wet climate (Happold 1995). It is not restricted to alpine areas but reaches its greatest density above the winter snowline (Green & Osborne 2003), where snow cover provides insulation, cover for foraging in winter and protection from predation (Green 2002; Green & Sanecki 2006). Brereton *et al.* (1995) predicted that the range of the broad-toothed rat would decrease by 36% with a 1ºC rise and 75% with a 3ºC rise.

Decreased depth and duration of snow cover, and early spring snowmelt is predicted to have a devastating effect on the mountain pygmy-possum *Burramys parvus*, which is restricted to habitat

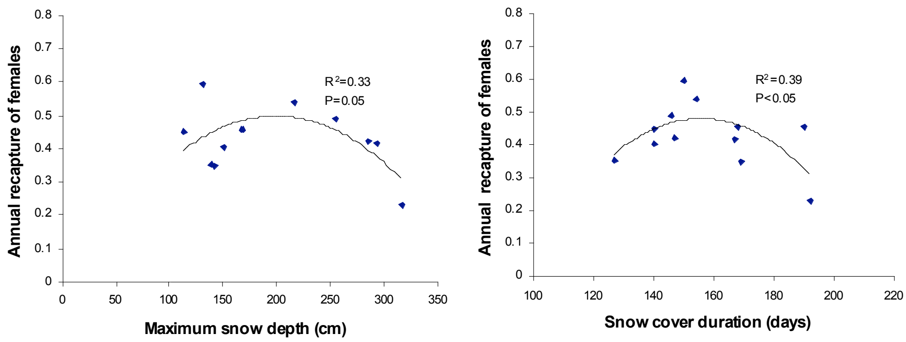

Fig. 1. Annual recapture (survival) rates (1986 – 1998), means from four sites of adult female mountain pygmy-possums as a function of (left) maximum snow depth and (right) snow cover duration measured at the Snowy Hydro snow course at Spencers Creek, in KNP.

above the winter snowline *c.* 1400 m (Mansergh & Broome 1994; Heinze *et al.* 2004). The possum depends on snow cover to provide insulation and a steady temperature during hibernation (Geiser & Broome 1993; Broome & Geiser 1995; Körtner & Geiser 1998). Brereton *et al.* (1995) predicted that the bioclimatic range of *B. parvus* would disappear with a 1ºC rise in temperature. However its distribution is not necessarily determined by bioclimatic tolerances. Competition or predation from other terrestrial fauna species, such as *Antechinus agilis* which does not occur above the snowline may also be a major factor (Mansergh & Broome 1994; Heinze *et al.* 2004).

Data from 1986-1998 for monitored populations of *B. parvus* in KNP indicate decreased survival and recruitment with declining snow depth and snow cover duration (Fig. 1). Optimal snow cover duration (measured at Spencers Creek; altitude 1830 m) is about 150 days for survival of adults (Fig. 1b) and 140 days for recruitment of juveniles (Broome unpublished data). Hennessey *et al.* (2003) predict that under best-case scenarios the duration of snow cover of greater than 100 days decreases substantially with a 1ºC rise in temperature and is non-existent with a 3ºC rise. In 1998, the shortest snow cover duration in the analysis, survival was 19% and recruitment 28% below the mean. McCarthy and Broome (2000) predicted that long-term reduction of the then current survival and recruitment rates by more than 15% was likely to lead to severe population declines. It was predicted the most dramatic declines would occur in the more marginal habitats at lower elevations or on westerly aspects.

Population trends since then show declines in monitored populations not in the more marginal habitats as predicted (McCarthy & Broome 2000; Broome 2001) but in the larger, previously more stable populations in the ski resorts. The average population size at Mt Blue Cow has declined by 76% and at Charlotte Pass by 30% since 2000, while populations in two smaller populations outside resort areas have not changed significantly (Broome unpublished data). Whilst synergisms between low snow cover and impacts of resort activities may contribute to this anomaly, it appears to be in large part due to increased numbers of feral cats that are abundant around resort areas (Watson 2006).

It is possible that cat numbers have increased during the last 10 years due to the absence of seasons with deep snow cover that are likely to decimate cat populations. Populations of the broad-toothed rat have been monitored on a site near Smiggins Hole since 1978. The population declined suddenly in 1999, the habitat was burnt in 2003 and the population became extinct in 2005 (Happold 1989; Green unpublished data). Green (pers. comm.) attributed the decline to observed early snow thaws in 1998 and 1999 and suggested that because there was no correlation between population size and time of snow thaw the decline could not be predicted, so either a physiological threshold was reached during the extended cold spring or some additional event triggered the response.

The decline of the broad-toothed rat was followed by that of *B. parvus* on the other side of the resort in 2000 and may have resulted from increased predation by foxes and feral cats as a result of the reduced snow cover. Both predators prey heavily on broad-toothed rats (Green 2002; Watson 2006) but cats are likely to be a greater problem than foxes for *B. parvus*. The situation is complicated by the possibility that the initiation of a fox control program at Charlotte Pass in 1996 and over the entire area in 1999 may have led to increased numbers of cats (Risby *et al.* 2000).

Predicted changes in rainfall, snow cover, temperature and resultant changes in hydrology are also likely to affect distribution and abundance of subalpine frogs, notably the endangered corroboree frogs *Pseudophryne corroboree* and *P. pengilleyi* and the alpine tree frog *Litoria verreauxii alpina*. Osborne and Davis (1997) investigated a possible link between the decline of *P. corroboree* and changes in rainfall patterns in the preceding years. They concluded that declines observed until the early 1990s were likely to have been contributed to by changes in weather patterns, particularly summer droughts causing drying of pools during the preceding decade. However, they were unable to explain the continuing decline in the mid 1990s when rainfall increased. It is now recognised that the major cause of declines in the corroboree frogs is the introduced chytrid fungus *Batrachochytrium dendrobatiidis* (Berger *et al.* 1999; Hunter *et al.* 2006). Drought and changes in weather patterns are contributing factors but not the ultimate cause of these catastrophic declines.

Possible impacts are not confined to within the alpine area. The annual, spring influx of migratory bogong moths *Agrotis infusa* from the western plains contributes a large amount of nutrient and organic matter (and possible contaminants; Green *et al.* 2001) to the high alpine area and forms a substantial part of the summer diet of alpine small mammals such as the mountain pygmy-possum and birds (Common 1954; Green & Osborne 1994; Mansergh & Broome 1994). Drought in the winter breeding grounds of the moth throughout the Murray-Darling basin has the potential to greatly impact the ecology of these species. In 2006 early snow thaw resulted in the mountain-pygmy-possums emerging from hibernation before the arrival of the bogong moths, their main spring food source resulting in food shortages early in the breeding season (Broome unpubl. data). Mis-timing of reproduction and food supply has caused population declines in migratory flycatchers in Europe (Both *et al.* 2006) due to different rates of change of climatic cues e.g., early peaks in caterpillar abundance prior to the arrival of birds from Africa, and similar implications for mountain pygmy-possums and other alpine fauna requires further investigation.

These examples illustrate that interactions between fauna populations, climatic factors and predators, competitors, pathogens or disease are likely to be complex and non-linear. Even in three of the most well-studied small mammal and frog populations in Australia, population trends cannot be predicted with confidence, therefore ongoing, regular monitoring is essential. Pickering *et al.* (2004) provide a summary of predicted and observed changes in abundance and range of other alpine fauna species in response to predicted warming scenarios, including increasing altitudinal ranges of birds and native and introduced herbivores. They point out that little or no information is available on the possible responses of invertebrates and soil fauna, the most abundant fauna assemblages in the Alps. There is also little information on distribution, abundance and likely resilience of other groups such as the 15 species of skink.

Much more research needs to be carried out on fauna species in the Alps to provide information on likely ecological tolerances, in conjunction with regular monitoring to enable rapid management responses to population declines, which may or may not be attributable to climate change.

Management actions to lessen the impact

Despite the inadequate knowledge of mountain biota and the impact that climate change will have on it, there are many management actions that will benefit biota even if climate change is not the primary cause. The focus of these actions should be on maximising the resilience of alpine species and communities by reducing or controlling threats not directly related to climate change (e.g. increased fire frequency, predation, invasion of exotic species); identifying species most at risk and likely refugia, setting priorities (e.g. between species or conflicting management objectives, conservation vs recreation, resource allocation), deciding what can and can't be protected, devising innovative ways to assist manageable entities and setting time frames.

Increased fire frequency

Current fire management uses fuel reduction burning to manage fuel loads and back burning and the creation of ploughed breaks to contain wildfires and protect Park assets. The approach is reactionary.

Future fire management, where the probability of wildfire is higher, may need to focus more locally on the biota that are at most risk from frequent fire. This might mean maintaining permanent breaks around populations of fire-sensitive species. It would certainly mean the more judicious use of ploughed breaks, which have a great potential for spreading weeds through the Park system.

Identification of priority species, populations or communities that are at most risk from repeated fires, and strategies to enable their identification and protection is currently being undertaken for KNP and will be incorporated into an updated fire management system.

Weeds, feral animals and invasive native species

Effective weed and feral animal control will rely on early detection and effective response. Adequate training of field staff in the identification of native and exotic species, vigilance from adequate staff on the ground to detect new invasions and adequate resources to control invasions when they occur could stem the tide of weed invasion.

Of these three management initiatives, training and vigilance will be cheapest and most rewarding. The reactive approach can be very expensive and of limited success, as the control of *Hieracium aurantiacum* is proving to be in the Victorian high country (Williams & Holland 2007). Consideration may also have to be given to the control of invasive native species where these threaten alpine endemics. No thought has yet been given to the possible diseases or pathogens that both feral animals and invasive native species may introduce to alpine species and how this may be monitored and managed.

Treeline

Trees are already encroaching into subalpine frost hollows and may begin invading the alpine zone if the climate continues to warm. There is no urgency for action on tree encroachment but, if it were to occur at an accelerated rate, invading trees might have to be physically removed to slow the rate of invasion. Drastic intervention of this nature should be the subject of debate well before it becomes necessary.

Changing hydrology and snow cover

Drying of the upper catchment because of less rainfall, snowfall and snowmelt will potentially affect the most species and may prove to be the most difficult to do anything about. The solutions are not obvious, but now is the time for testing novel measures. These might involve reducing the rate of snow melt using coverings that reflect radiation, much as thick dust does naturally (Drake 1981), erecting weirs to slow water movement or creating habitat at lower elevations. Judicious placement of snow fences to increase the depth and duration of snow cover could possibly be used effectively in areas of mountain pygmy-possum habitat or in other small, sensitive communities such as snow patches.

Recreational impacts

Diminishing snow cover and retreating snow lines will potentially concentrate recreational impacts in areas of habitat and plant communities that are the identified refugia for those species. For example, the largest areas of habitat and populations of the mountain pygmy-possum are at high elevations and/or on southeast aspects. Due to their snow-retaining capacity, many of these areas are in ski resorts (Heinze *et al.* 2004; Broome *et al.* 2005). A greater emphasis on management of biological diversity in ski resorts is required and priorities between conservation and recreation may need to be reviewed. Visitor impact from skiers and snowboarders is also increasing outside resort areas and may need to be directed away from sensitive areas (Pickering this volume).

Ex-situ conservation

Whilst there have been recent attempts at captive breeding and re-release of endangered species (e.g. corroboree frog and alpine tree frog), current programs under way such as captive breeding of mountain pygmy-possum and seed banks for mountain biota, have had varied success and face an uncertain future because of limited knowledge of the full diversity of genetic and physiological traits. Can an Alpine Ark be sustained for 200-300 years (the required time to turn around the current global warming trajectory)? No one knows. This course of action must be a last resort for mountain biota.

Research and participation in regional and global programs

Land managers have a choice when it comes to dealing with the impacts of climate change: use research to understand and manage the impacts or use our current knowledge to further speculate on the impacts and manage in a hopeful or reactive manner. The funding of targeted research will probably be the most cost-effective approach but such decisions should be made as part of an integrated planning, research and management program for dealing with climate change impacts.

Australian Alps parks will not be alone in managing for a changing environment. Our active participation in global programs of research and monitoring will help us to understand and deal with the changes we detect. Cooperative research and management between States and Territories with high mountains in Australia, such as that currently under the Australian Alps Liaison Committee for mainland jurisdictions, will enable the more efficient use of resources.

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10. Conservation planning for a changing climate

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Abstract

A crucial objective for the selection and spatial design of conservation areas is to promote the adaptation of species and natural processes to changing climates.

Key considerations include:

- New patterns and combinations of threats;
- Adjustment of conservation targets to account for climate-related issues; and
- Identification, protection and/or restoration of climatic gradients to promote spatial adjustments by species.

These issues are discussed with examples from regional planning in South Africa. The paper ends with a list of unresolved issues that need to be addressed if conservation planning is to deal effectively with climate change.

Introduction

Conservation planning is the process of locating, configuring, and maintaining conservation areas, areas of land, sea or freshwater that are managed for the persistence of natural values. This management includes strict reservation, a wide variety of off-reserve mechanisms, and restoration. Systematic conservation planning (Margules & Pressey 2000) identifies configurations of complementary areas that achieve explicit, and generally quantitative, objectives.

Since its origin in the early 1980s, systematic conservation planning has influenced decisions by major organisations such as The Nature Conservancy (Groves *et al.* 2002), shaped policy, legislation and conservation on the ground (Knight *et al.* 2006), and has featured in well over 200 presentations at meetings of the Society for Conservation Biology.

The field's hundreds of publications reflect not only advances in ideas, techniques and relevance, but also its short history and main limitations (Pressey *et al.* 2007). Most publications concern biodiversity pattern, that is, the elements of biodiversity that can be mapped and regarded as static (Pressey 2004). Planners have done less well at promoting the persistence of the myriad ecological and evolutionary processes that maintain and generate biodiversity (Balmford *et al.* 1998). Most systematic methods have also assumed implicitly that threats to biodiversity are absent or static (Pressey *et al.* 2004). Previous losses of biodiversity might be recognised, even perhaps the legacies of continuing loss from past threats, but the rates and patterns of dynamic threats have often not been anticipated. These limitations are being addressed, but still present important challenges to conservation planners.

Pressey R. L. (2007) Conservation planning for a changing climate. In: *Protected Areas: buffering nature against climate change. Proceedings of a WWF and IUCN World Commission on Protected Areas symposium, 18-19 June 2007, Canberra.* (eds M. Taylor & P. Figgis) pp. 85-89. WWF-Australia, Sydney.

The context for conservation planning as a response to climate change is shaped by several considerations:

- The need to deal with uncertainties in predictions of climatic changes, species adjustments to these changes, and the effectiveness of planning responses;
- The potential for conservation planning to address not just adaptation but also mitigation (e.g. carbon sequestration, carbon trading, planting for biofuels); and
- Limitations on resources and space that require conservation planners to make difficult choices between conflicting conservation objectives because not all can be achieved.

Three broad aspects of conservation planning are relevant to adaptation to climate change: (1) spatial design, or the configuration of individual conservation areas and whole systems of conservation areas; (2) the application of conservation mechanisms, recognising constraints and opportunities related to tenure, land use, budgets and other factors; and (3) management, or the maintenance and monitoring of established conservation areas, recognising progressive changes within and outside these areas (e.g. fire, weeds, surrounding land uses).

Spatial design for climate change

This short paper outlines some aspects of the selection and spatial design of conservation areas to promote the adaptation of species and natural processes (Pressey *et al.* 2007) to changing climates. There are several important issues for selection and design.

First, conservation planning must address new patterns of threats (e.g. projected rises in sea level, spatial changes in agricultural suitability) and new combinations of threats (e.g. altered fire regimes combined with the spread of invasive species).

Second, conservation targets the quantitative interpretations of conservation objectives (e.g. hectares of each vegetation type, numbers of populations of rare species), will need to be adjusted to account for climate-related issues. Some of these are: altered vulnerability of species to new threats; population sizes required for genetic adaptation to climate and associated changes; and identification of populations within the ranges of species that might be pre-adapted to make the required changes for genetic adaptation and shifts in distributions.

Third, is the need for identification, protection and/or restoration of climatic gradients to promote spatial adjustments by species. These gradients vary in steepness (change in climatic parameters per horizontal kilometre). Very steep, short gradients are likely to be easiest to maintain. Long gentle gradients are likely to present serious difficulties in many regions.

Examples of spatial design for climate in South Africa

Some examples of spatial design for climate change come from an exercise in conservation planning in the Cape Floristic Region of South Africa, a global biodiversity hotspot (Fig. 1). The planning exercise targeted parts of the region believed to be important for promoting the adjustment of species distributions to a changing climate (Cowling *et al.* 2003; Pressey *et al.* 2003). These included major riverine corridors crossing mountain chains to allow dispersal and provide climatic refugia, upland-lowland gradients (Fig. 1a), and macroclimatic gradients (Fig. 1b). The approaches in the Cape region were refined during later work in the Thicket Biome of South Africa (Fig. 2a) with the design of major conservation corridors (Fig. 2b) based on climatic gradients, representation of vegetation types and species, existing protected areas, threats, constraints, and opportunities for conservation (Rouget *et al.* 2006).

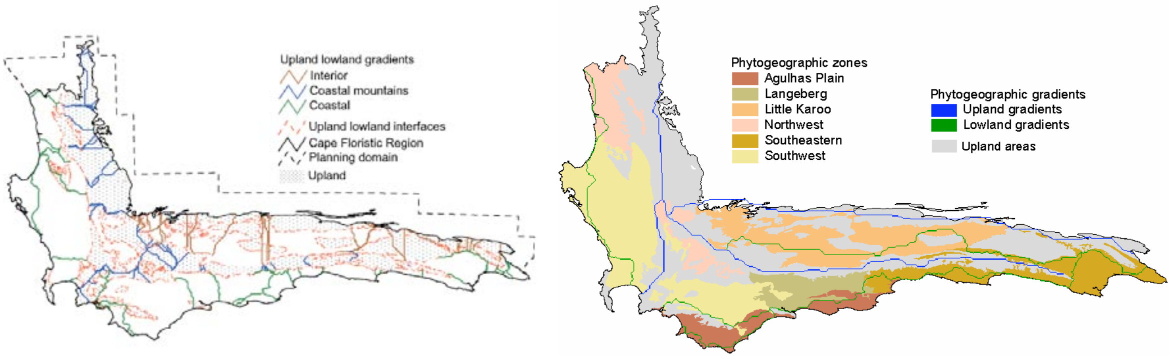

Fig. 1. (a, left) Upland to lowland environmental gradients in the Cape floristic region of South Africa; and (b, right) Macroclimatic or phytogeographic gradients (reprinted with permission from Blackwell Publishing)

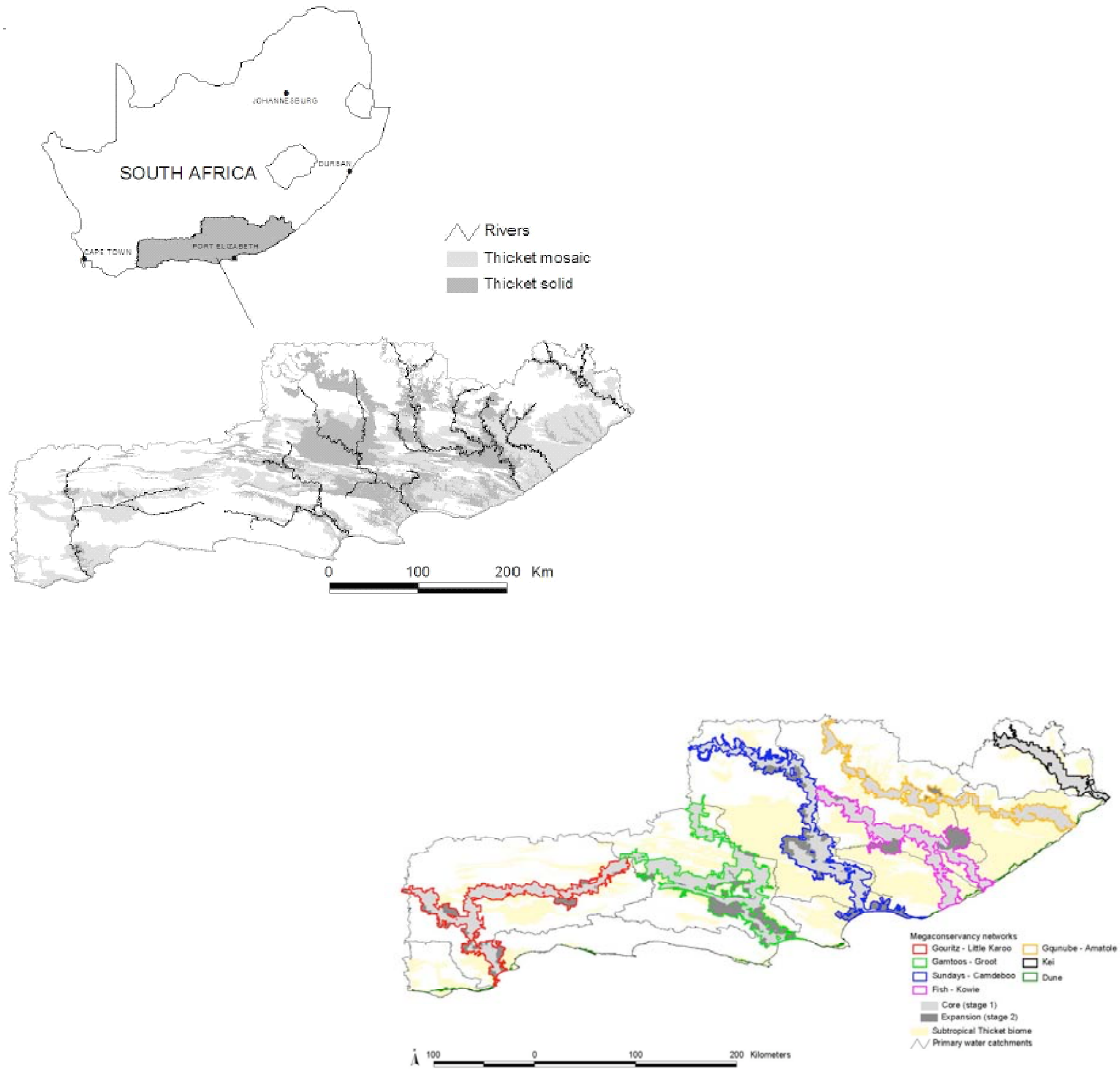

Fig. 2. (a, top) The Thicket Biome of South Africa; (b, bottom) Large-scale conservation corridors in the Thicket Biome designed to achieve several conservation objectives, including promoting the adjustment of species distributions to climate change (reprinted with permission from Blackwell Publishing).

Other aspects of spatial design are now also receiving attention. For several reasons, much of this work has also focused on the Cape Floristic Region. The reasons include its global significance for biodiversity, narrow endemism of many plant species, steep climatic gradients, and very good biological data, at least for some plant groups such as the Proteaceae. Williams *et al.* (2005) addressed the problem of species-specific design for climate change, recognising predicted range shifts each decade, dispersal distances per decade, and the need to plan for adequately connected patches of native vegetation to allow for range shifts.

Planning ahead for climate change

Hannah *et al.* (2007), working both in the Cape and Mexico, demonstrated the efficiencies of planning ahead for climate change, rather than planning for biodiversity patterns as they are now and then later adding further conservation areas to deal with range adjustments. Work is also underway to understand how patch dynamics such as fire (Syphard *et al.* 2006) and coral bleaching (Hughes *et al.* 2007) might respond to climate change and how the spatial design of conservation areas will need to take these altered dynamics into account.

Some remaining challenges for selection and spatial design include:

- The variable effectiveness of corridors or spaced patches of native vegetation along climatic gradients in terms of dispersal rates of species and the possible need for translocating plants and animals;
- The variable effectiveness of corridors or spaced patches of native vegetation along climatic gradients in terms of their inherent suitability for dispersal interacting with the effectiveness of management mechanisms and restoration;
- Important questions about how planners should respond to the inevitable uncertainties of predicting the directions and magnitudes of climatic changes and biological responses;
- The need to address spatial design for climate change in generalised ways because actual responses to climate change can be predicted only for a small minority of species;
- The inevitable lateral gaps between corridors or sequences of patches of native vegetation along climatic gradients mean that not all species will be located near them and have access to them, especially in regions, such as the Cape Floristic Region and South-Western Western Australia, that have many localised endemics;
- The need for difficult tradeoffs between multiple conservation objectives, of which design for climate change is only one, competing for limited resources and space (Pressey *et al.* 2007). These tradeoffs are exacerbated by the need to commit substantial resources to protect or create entire corridors or sequences of patches of native vegetation that are functional for species range shifts.

There is considerable potential to address these challenges in Australia and to develop and implement planning approaches here that promote the persistence of biodiversity in the face of climate change.

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11. Climate change, connectivity and biodiversity conservation

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Abstract

The reality of human-forced rapid climate change presents an unprecedented challenge to the conservation of biodiversity. In this paper I review the interactions between natural climate change and biodiversity, the reason why species have persisted through past climate change, and the break down in natural adaptation processes now being experienced due to human impacts on habitat and key ecological processes. I then explain the role of connectivity conservation and protected areas in promoting the long term conservation of species and ecosystems in the face of climate change.

Is climate change a threatening process?

About the only things constant in the history of Earth is that occasionally asteroids hit, the lands shift, life evolves, and climate changes.

Since Earth formed around 4.5 billion years ago the climate has changed continuously, experiencing periods of heating or cooling and wetting or drying. However, within this natural variability two mega-trends are apparent from the geological record:

- First, there has been an overall cooling of Earth's average planetary temperature and notably, since the early Eocene around 55 million years ago (Zachos *et al.* 2001).
- Second, since life first emerged on Earth some 3.5 billion years ago, the average planetary temperature has maintained a dynamic equilibrium ranging between 15-25^{0}C (Williams 2007). This range represents the ideal conditions for living organisms, suggesting that living organisms have helped generate and sustain the very conditions for their existence (Gorshkov *et al.* 2000).

Evidence suggests that global climate change has been associated with increased speciation (Beninda-Emonds *et al.* 2007). Of course, extinction processes operate alongside those driving speciation, and rapid environmental change has also lead to the extirpation of species unable to tolerate or adapt to the new conditions.

Evidence from glacial ice cores has revealed severe climatic oscillations over the last 500,000 years (Petit *et al.* 1999). About every 120,000 years, average planetary conditions have oscillated between glacial periods with low levels of atmospheric CO_2, low temperatures and dryness, and inter-glacial "highs" that experienced high levels of atmospheric CO_2, higher temperatures and wetness. We are currently in an inter-glacial "high". The ice core record also shows that the transition out of glacial troughs has been extremely rapid; as much as 5-10^{0}C warming in 20 years (Taylor 1999).

It is very relevant therefore to consider whether these prior rapid climate change events caused the creation of new species or the extinction of existing species.

Mackey B. (2007) Climate change, connectivity and biodiversity conservation. In: *Protected Areas: buffering nature against climate change. Proceedings of a WWF and IUCN World Commission on Protected Areas symposium, 18-19 June 2007, Canberra.* (eds M. Taylor & P. Figgis) pp. 90-96. WWF-Australia, Sydney.

Analysis of molecular data has shown that Australia's plant and animal species are of ancient lineage, aside from dingoes and recent invasives. The last great vertebrate animal speciation event (songbirds) was during the Pliocene (2-4 million years ago) (Norman *et al.* 2007), while most extant mammal species have an origin spanning the mid to late Miocene (~20 million years ago) (Osborne & Christidis 2002).

Our plant species are of similar ancient lineage, with the origin of many being traced back to when Australia was part of the super-continent Gondwanaland (White 1998). Therefore the often rapid climatic oscillations of the last 500,000 years evidently precipitated neither major speciation nor extinction events. All extant native species persisted through these oscillations, despite changes in average planetary temperatures of 5-10^{0}C and swings in wetness the equivalent of "droughts to flooding rains" lasting millennia.

Given the natural climatic variability shown by the ice core record, and the ancient lineage of Australia's native species, why should we be concerned now about the impact of climate change on the conservation of biodiversity? Given that species have persisted through millions of years of dramatic climatic change, could we not reasonably assume that species are pre-conditioned to persist through the current regime of human-forced rapid climate change? In order to answer this question, we need to first consider how species and ecosystems are affected by and respond to climate change.

How does biodiversity respond to climate change?

Climate change has both direct and indirect effects on species and ecosystems.

Direct effects on species include changes in the physiological niche conditions experienced by a species. All species are genetically programmed such that they can function physiologically and successfully complete their life cycles only within specific ranges of acceptable environmental conditions (defined by the concentrations of heat, light, water and nutrients), and optimally within a subset of these conditions.

The primary inputs of water and energy into these primary environmental regimes are dictated by the climate. Indirect effects on species include changes in the availability of vegetation-based habitat resources for food, shelter, and nesting, not to mention the geographic ranges of other animal and plant species on which they depend.

Climate, through the inputs of energy, water and nutrients, determines the rates of key ecosystem processes, especially photosynthesis and biological decomposition, and the rates of nutrient recycling. Therefore, as climate changes so does ecosystem composition and structure. Rates of plant photosynthesis are also regulated by the concentration of atmospheric CO_2, with decreasing concentrations resulting in decreasing gross primary productivity (GPP) and subsequent biomass production (Berry & Roderick 2004).

Before the Anthropocene (Crutzen & Stoermer 2000), the ecosystem types covering the land would simply change as a result of climatic impacts on biological, ecological, and associated ecosystem processes. Thus, forests would geographically expand or shrink with increasing/decreasing temperature, wetness and atmospheric CO_2 concentrations. When the climate became hotter and wetter (such as during the interglacial "highs"), land that was shrubland, would become woodland, and woodland would grow into forest, all other factors being equal.

Given the above, it follows that in the past rapid climate change could have resulted in either local extirpations or global extinctions if:

- The primary environmental regimes changed beyond a species physiological tolerance (niche) limits; or
- Ecosystem characteristics changed so that habitat resources especially food, were no longer available.

Conversely, species would have survived rapid climate change (if not in the same location, then elsewhere) through some combination of the following adaptation mechanisms:

(1) The evolution of new, fitter traits;

(2) Phenotypic plasticity in their physiology, behaviour or life history strategies;

(3) Dispersal to country that met their physiological niche and habitat resource requirements; and

(4) By taking refuge in micro-habitats or refugia that retained the necessary niche and habitat requirements.

What is different now?

The current climate change event is different from previous ones in a number of ways.

First, it is human-forced as the result of a strengthening of the greenhouse effect caused by humans burning fossil fuel for energy, and deforestation (IPCC 2007). Whereas, the glacial-interglacial oscillations revealed in the ice core record are considered to be driven by the Milankovitch Cycle, changes in the amount of solar energy reaching Earth due to long term "wobbles" in Earth's orbit (Muller & MacDonland 1997). However, the proximate cause is the same: a change in Earth's net energy budget, the direct driver of global climate change.

Second, and probably more importantly, the current rapid climate change coincides with the sixth mass species extinction event in the history of Earth.

This extinction event is being driven by a combination of:

- Habit loss, degradation and fragmentation;
- Over-harvesting of wildlife;
- Artificially introduced invasive species; and
- Changes to ecosystem function through, among other things, humans diverting water resources and altering fire regimes (WRI 2005).

It is the interaction between rapid climate change and these extant threatening processes that will cause problems for species and ecosystems in the coming decades and centuries.

In addition to the global extinction of species, we are also witnessing massive regional extirpations (Mackey *et al.* 2006), resulting in a potential loss of intra-species genetic diversity. This loss reduces prospects for many Australian species to persist in the face of rapid climate change through either natural selection and evolution or phenotypic plasticity (adaptation mechanisms 1 and 2 above).

Habitat loss, degradation and fragmentation means species will find it more difficult to find suitable locations to which they can migrate or take refuge (adaptation mechanisms 3 and 4; see Soulé 1990).

Modern land use activities, along with feral animals and weeds, are changing the composition, structure and functioning of Australian terrestrial ecosystems. These activities and invasives are interfering with natural processes that would otherwise result in ecosystems responding optimally (*sensu* Odum 1995) to changing climatic and associated environmental conditions. As a result, the production and availability of wildlife habitat resources are being severely impaired, further limiting options for species in the face of rapid climate change.

Prior to the Anthropocene, ecosystem processes were intact and there was always a dynamic continuum of ecosystem types in existence for species to explore. Thus, in the past, the full compliment of natural adaptation mechanisms (1- 4 above) were potentially available to a species. This is no longer the case. Conservation planning and management must seek to help restore and facilitate the natural evolutionary mechanisms that will enable species to persist, and ecosystems to develop, in the face of the rapid climate change we are now experiencing.

Among other things, unless significant changes are made to land management, speciation of large animals is highly improbable in the foreseeable future, given the huge impact that human beings and their technologies are having on the planet; as such speciation requires extensive, undisturbed populations and landscapes (Soulé 1980; Frankel & Soulé 1981).

A necessary caveat here is that for some plants and animals, fragmentation may actually promote speciation by artificially subdividing populations into smaller independent units. Speciation in small populations is not unknown on islands and in rainforest, though it is usually associated with a high risk of extinction.

The role of connectivity conservation

The term "connectivity" has been conventionally thought of as referring to retaining or constructing narrow corridors of native vegetation between two or more local habitat patches. Michael Soulé and colleagues helped redefine the scope of the term in conservation biology by considering the conservation requirements of top-order predators (Soulé & Terborgh 1999). In North America, their long term viability demands consideration of movement and dispersal at continental scales and hence the development of continental-scaled connectivity of protected area networks.

In Australia, the need for a broad re-conceptualisation of connectivity conservation has been argued by Soulé *et al.* (2004) and Mackey *et al.* (2007). "Connectivity" can be considered more broadly again as referring to the maintenance or restoration of key, large scale ecological phenomena, flows, and processes critical to the long term conservation of biodiversity. Of this set of connectivity processes, amongst the most important to consider for climate change are (a) dispersive fauna and (b) hydro-ecology.

Dispersive fauna

There are 535 vertebrate species in Australia (including 342 land and freshwater birds) that are recorded as "dispersive", in that they are known to travel large distances to obtain the necessary habitat resources or to optimise physiological niche requirements (Gilmore *et al.* 2007). Such dispersive behaviour has presumably been a crucial life history strategy in the persistence of these species on a continent such as Australia which is characterised by extreme natural variability and comparatively little vertical relief. For many of these species, their long term survival depends on protecting geographically extensive networks of habitat patches, the ongoing productivity of source areas, or the maintenance of ecosystem types on which they are seasonally dependent (Woinarski *et al.* 1992). Many if not most of the habitat resources are not necessarily found in or do not persist reliably in protected areas, but are distributed across many categories of land use.

While the capacity of dispersive species for long distance travel will be advantageous in the face of rapid climate change, even their future is uncertain given the extent of land clearing in eastern and southern Australia, unsustainable pastoral practices in the rangelands, the introduction and proliferation of invasive and feral species from other continents, the intensification of logging and land clearing in native forests and woodlands, and lack of systematic conservation planning and management in the extensive and relatively intact woodlands of Northern Australia, the Western Australian Goldfields (the Great Western Woodlands), and the tall *Eucalyptus tetradonta* woodlands of Cape York Peninsula (Mackey 2006).

Hydro-ecology

The distribution and availability of water is the principal environmental determinant of biology and ecology in Australia, where about 70% of the continent is climatically arid/semi-arid.

Water availability determines rates of photosynthesis and biomass production, the "fruits" of which propagate through the entire food chain (Berry *et al.* 2007). This upward trickle of energy and material is called a "bottom-up" effect by ecologists. The vegetation cover in turn influences water infiltration, soil water storage, and catchment water budgets. Throughout Australia, but particularly in the rangelands and the seasonally dry tropical north, ground water resources are biologically critical, enabling deeply rooted perennial plants to flourish, and sustaining springs, water holes and streams during dry periods.

Hydro-ecological processes sustain biodiversity at scales ranging from catchment (e.g. the chains-of-ponds originally found along the valley floors of the southern tablelands in NSW; Starr 1999) through to the basin-wide seasonal flooding of the channel country from tropical monsoonal rains. Both surface water catchment boundaries and groundwater recharge/discharge zones transcend protected areas boundaries and demand a whole-of-landscape approach to their maintenance and for the persistence of the flora and fauna that they sustain over broad areas.

The role of protected areas

Protected areas have a pivotal role to play in enabling species and ecosystems to persist in the face of rapid climate change. Protected areas can remove or control many of the threatening processes driving the current mass extinction crisis, in particular, habitat loss and fragmentation, depending on legal provisions. If selected according to ecological criteria or obtained through good fortune, protected areas can protect source habitats that provide an ongoing supply of organisms for dispersal to locations suffering local extirpations. Many of our protected areas also contain refugia where micro-climatic conditions and associated habitat resources persist despite global and regional shifts in climatic regimes (Mackey *et al.* 2002). Large or strategically placed protected areas can conserve critical hydro-ecological processes, including ecologically significant water discharge points, catchment headwaters and groundwater re-charge zones.

Given the possible scale of the projected climate change Australia may experience in the coming decades (CSIRO 2007), a key contribution of protected areas will be to function as biological "stepping stones" and "stop-over" points that span continental gradients; thereby facilitating the necessary migration of species (and their propagules) seeking physiological niche optima or essential habitat resources.

However, the current network of protected areas lacks geographical and ecological connectivity, limiting its capacity to function in this way for many species that are less mobile than dispersive birds. Most protected areas, even large ones, remain islands in "oceans" of land cover and land uses unsympathetic to biodiversity conservation.

Landscape-wide planning and management is needed to better buffer and link existing protected areas through mechanisms such as creation of protected areas over important intact linkages, whether as national parks or conservation covenants on private land, changes to land management such as through leasehold conditions, or allowing regrowth of native vegetation. In this way, biological permeability can be enhanced at scales commensurate with the likely impacts of global warming.

The NSW government's A2A (Alps-to-Atherton) connectivity conservation initiative is an example of the kind of response needed in the coming decades. Similarly, the *WildCountry* initiative aims at whole-of-landscape approaches to conservation (Soulé *et al.* 2004). Protected areas are the core around which cross-tenure, connectivity conservation planning and management can be designed and implemented.

Conclusion

Ultimately, it is the natural adaptation mechanisms evident during past global climate change events that will enable species to persist in the face of the current human-forced, rapid climate change. However, these are being massively degraded and interrupted by the same destructive forces driving the biodiversity extinction crisis.

Large scale conservation planning and management, as exemplified by the *A2A* and the *WildCountry* initiatives, is needed to protect and restore ecological connectivity and biological permeability at scales from patch to continental and beyond. The protected area network will remain the cornerstone of connectivity conservation programmes, and indeed of all our collective endeavours to ensure our rich biodiversity persists into the future.

Acknowledgements

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12. How to integrate cost, threat and multiple actions into conservation planning for reserves and stewardship

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Abstract

Reservation and stewardship are two of the most widely applied conservation interventions in Australia and globally. Systematic conservation planning tools such as *Marxan* can be used to support cost-effective spending on these or other interventions by determining efficient options in a landscape that meet conservation targets. We describe the appropriate problem formulation for spatial systematic conservation planning and summarise advancements in current approaches. We focus on three important features that have improved the applicability of *Marxan* (and some other tools) to real world conservation planning. These are (1) incorporating spatially variable costs and multiple costs, (2) accounting for threats such as climate change, and (3) integrating multiple conservation interventions or actions within a single step of the problem. Our findings suggest that omission of costs, threats and multiple actions where they should be included can result in poor efficiency and hence the misallocation of funds. We are continually testing these ideas on real world problems.

Introduction

Systematic conservation planning has become the international norm for making spatially explicit decisions about reserve systems (Margules & Pressey 2000). Conservation planning tools such as *Marxan* (Possingham *et al.* 2000) have provided transparent, defensible and repeatable decision support in a range of marine and terrestrial systems worldwide (for examples see www.ecology.uq.edu.au/*Marxan*).

The traditional aim of conservation planning is to find sets of sites that meet a suite of biodiversity targets while minimising a cost, usually area. However conservation planning tools can consider other parameters that improve their applicability and cost-effectiveness in real world planning situations. For example, *Marxan* can account for the financial cost of different conservation actions, can favour spatial compactness, choose conservation areas that have minimal threats, and allow a range of conservation actions to be prioritised, not just reservation. We have developed other approaches for maximising returns on investment from conservation spending by quantifying the cost and benefits of a range of conservation actions (Wilson *et al.* in press).

We argue that the key to effective conservation planning is proper problem formulation and integration of disparate factors without using flawed scoring systems. Here we provide an overview of the appropriate problem formulation to generate cost-effective conservation decisions for real world planning. Many new ideas have recently emerged and are being trialled on real problems.

Game E., Carwardine J., Wilson K., Watts M., Klein C. & Possingham P. (2007) How to integrate cost, threat and multiple actions into conservation planning for reserves and stewardship. In: *Protected Areas: buffering nature against climate change. Proceedings of a WWF and IUCN World Commission on Protected Areas symposium, 18-19 June 2007, Canberra.* (eds M. Taylor & P. Figgis) pp. 97-99. WWF-Australia, Sydney.

Incorporating cost

Until recently most systematic conservation planning exercises attempted to meet biodiversity targets in the smallest area. This approach makes the implicit assumption that all sites have the same cost, or that cost doesn't matter because funding is unlimited. Given these situations are unlikely, we aim to minimise the costs of achieving our biodiversity targets.

Our research on an Australian spatial prioritisation project (Carwardine *et al.* 2006) found cost-effective options for conducting two alternative conservation actions: land purchase and stewardship. We generated an acquisition cost layer using unimproved land value, and a stewardship cost layer using data on agricultural profitability, or the net present value of possible compensation required to farmers for reduced production (both in $/ha). We used a range of biodiversity data – from vegetation types, to environmental domains, birds, and threatened species – and set representation targets to 15% of the extent of each feature.

We discovered that regardless of the biodiversity data used, our targets were 1.5-2 times more expensive to achieve if we ignored the cost of the planned conservation action when setting priorities. Therefore we can conserve more biodiversity for less money if we use the right cost surrogate.

This highlights the importance of clearly stating the conservation objective. If the objective is to purchase land then using area as a cost surrogate will not identify the most cost-effective planning units to be purchased. Nevertheless, a subset of planning units was given a high priority regardless of the cost or biodiversity data used. Our approach enables the representation of biodiversity features cheaply where possible, but while ensuring that planning units containing rare features that are needed to meet targets are prioritised regardless of cost.

Incorporating threat

Our work on marine protected area networks has demonstrated that ignoring threats such as climate change when selecting areas for reservation results in almost certain failure to meet our biodiversity targets. When threat is properly treated during the reserve selection process, it is possible to substantially improve the likely persistence of conservation features for a negligible increase in cost. When the budget was allowed to increase slightly, the funds were best spent acquiring many cheap sites, thereby greatly increasing the number of reserved sites and the overall redundancy of the system. An increased investment of 10% or greater, however, was best spent acquiring the more expensive sites with low threat, leading to an overall reduction in the number of reserved sites. This suggests that some low threat but high cost sites are simply too expensive to be included in cheaper reserve systems but are important if we have more resources.

Given the threats that a changing climate pose to many habitats and groups of organisms, designing a reserve network ignorant of this risk will almost certainly result in the failure of that reserve system to meet our biodiversity goals. We provide an explicit and efficient framework that allows the probability of disturbances to be included into conservation planning without creating additional biodiversity targets or imposing arbitrary presence/absence thresholds on existing data.

Incorporating multiple conservation actions

Previously in conservation planning problems our potential conservation areas can be in only one of two states, in or out of a reserve system. This problem has been expanded within the tool *MarZone* (developed for Ecotrust by Ian Ball, Matthew Watts and Hugh Possingham) to consider different management categories, where planning units are assigned to one of several different types of use (i.e. zones).

For example in a marine system, planning units might be allocated to zones of strict reserve, no-take, recreation, and commercial fishing. The aim is still to represent biodiversity targets at a minimal overall cost, but each zone can vary in their relative contribution to biodiversity targets and costs of implementation, depending on the level of protection they provide (e.g. high protection zones may make the greatest contribution to biodiversity targets). Targets can also be set for each zone to ensure that a sufficient area is designated, for example, to fishing.

Work in this area shows that accounting for different conservation actions, or zones, opens up the realms of applicability of planning tasks. It allows conservation managers to choose between doing any number of conservation actions, and any number of combinations of actions – for example, should a manager control for predators or manage fire, or should they do both, which might have an overall benefit of more than the sum of the individual actions? Efficiency is gained by this approach because the costs of individual actions are synthesised *a priori* – there is little sense choosing a priority area based on the cost of land purchase when a better biodiversity benefit to cost ratio could be achieved by paying an amenable landowner to manage for invasive species.

Summary

Our research demonstrates that ignoring costs, threats and multiple actions *a priori* is inefficient because (1) conservation areas chosen without the consideration of cost are bound to be more expensive, (2) if we ignore threats then we could be focussing on areas not requiring protection, or those that may not maintain their biodiversity values if they are protected, and (3) many planning situations are amenable to a range of conservation actions - reservation alone is expensive, and infeasible in some places, and the biodiversity benefit provided will vary, along with the financial and social costs of their implementation. From an international perspective this research is at the cutting edge of spatial conservation planning.

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13. The CAR principle of adequacy of the National Reserve System in the context of climate change

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Abstract

The National Reserve System (NRS) covers over 11% of the land area of Australia. A commonly agreed set of criteria and principles, known collectively as CAR (Comprehensiveness, Adequacy, Representativeness), have been used to guide the development of the NRS.

In practice, Comprehensiveness and Representativeness have been easier to implement than Adequacy in selection of new reserves and in reporting progress towards meeting reserve targets.

Adequacy addresses the complex question of extent, i.e. what area of reserve is required to ensure the long-term survival of biodiversity. A target of at least 15% of land area in reserves has been suggested as a starting point for Adequacy. Targets can then be further refined based upon knowledge of the functional requirements of key species, practical limitations on how much land can be dedicated to conservation in a region and the extent to which good levels of biodiversity remain outside the reserve system.

It is now widely acknowledged that climate change should be routinely addressed in biodiversity conservation planning through initiatives that maintain and restore landscape connectivity. In this context, Adequacy can play a significant role as Adequacy recognises the importance of sustaining ecological processes and functions and providing for the maintenance of natural patterns of speciation and extinction. While identification of critical parts of the landscape requiring protection and/or restoration may require new knowledge, there is sufficient information in many parts of Australia to guide commencement of planning activities.

For example, in the eucalypt forests and woodlands of southeast Queensland, it is possible to identify refuges and source areas for fauna and flora species, areas containing suites of species that may be resilient to some level of predicted changes in rainfall and temperature regimes and, conversely, potential stress points in the landscape. Potential stress points may include areas with concentrations of species at geographical and climatic limits of range. All of these features are amenable to spatial analysis that could determine some retention and protection targets, current reservation levels and priority areas for addressing gaps.

Young P. (2007) The CAR principle of adequacy of the National Reserve System in the context of climate change. In: *Protected Areas: buffering nature against climate change. Proceedings of a WWF and IUCN World Commission on Protected Areas symposium, 18-19 June 2007, Canberra.* (eds M. Taylor & P. Figgis) pp. 100-111. WWF-Australia, Sydney.

Introduction

It is a decade since the report *Nationally Agreed Criteria for the Establishment of a Comprehensive, Adequate and Representative (CAR) System for Forests in Australia* (JANIS 1997, widely known simply as "JANIS") provided a detailed evaluation of the planning requirements for a systematic conservation reserve system. JANIS adopted and expanded upon principles in the *National Forest Policy Statement* (Commonwealth of Australia 1992), namely:

- Comprehensiveness: includes the full range of forest communities recognised by an agreed national scientific classification at appropriate hierarchical levels.
- Adequacy: the maintenance of ecological viability and integrity of populations, species and communities.
- Representativeness: those sample areas of the forest that are selected for inclusion in reserves should reasonably reflect the biotic diversity of the communities.

While CAR-type criteria have been used in reserve planning across Australia since the 1970's (Stanton & Morgan 1977; Kirkpatrick 1983; Purdie 1986; Pressey & Nicholls 1989), JANIS provided a succinct and widely supported basis for establishing reserves that remains central to the objective of establishing and maintaining a conservation reserve system across Australia, the National Reserve System (ANZECC 1996, 2001).

Applying CAR principles invariably raises the critical question of how much reserve is enough? In most instances there will be constraints on the amount of land will that can be dedicated to conservation. This places a requirement on reserve selection to be efficient, starting with Representativeness. An efficient design for a reserve system will sample the full range of required features within a relatively small total area (Pressey 1993).

Consideration of Representativeness and Adequacy can be expected to substantially increase the required area. In terms of an overall reserve target, JANIS proposes 10-15% of each ecosystem. JANIS also acknowledges that a CAR reserve system needs to be considered in a broader landscape context as the degree of modification of a landscape and the potential for a good level of biodiversity to survive outside of reserves should have some bearing on the overall size of the reserve system.

In the broader landscape context, minimum retention targets of 30% of each habitat type (e.g. James & Saunders 2001) or well above that (Possingham & Field 2001) have been proposed based upon observed faunal population declines in fragmented landscapes. In these examples the areas retained or re-established would need to be managed in a way that maintains biodiversity values. Pressey (1993) suggests that up to 20% of the landscape may be required based on use of reserve selection algorithms, and it could be met through a combination of formal reserves and complementary measures.

In highly fragmented regions, developing a biodiversity conservation system that occupies at least 10-15% of the region may take considerable time and may entail a degree of ecosystem restoration. In contrast, targets of at least 15% should be readily achievable in regions with high levels of relatively intact native vegetation and high levels of public land.

Adequacy can be considered as a form of insurance against loss of biodiversity within a geographical area as a consequence of catastrophic or episodic events. JANIS indicates that there are many approaches for incorporating Adequacy into reserve planning including use of surrogates such as ecosystems and ensuring they are replicated across their range and more sophisticated approaches based upon the functional requirements of species.

As reserve systems develop it is desirable to be able to assess how well they are meeting CAR criteria and other policy objectives (NLWRA 2002). Comprehensiveness is used for reporting at a range of scales using regional ecosystem mapping or equivalent (Sattler & Glanzing 2006). Representativeness can also be measured to some degree by considering the extent to which regional ecosystems are sampled in reserves across their range. However, there is presently no robust and practical measure of Adequacy.

The National Reserve System

The National Reserve System (NRS) Programme, established by the Australian Government in 1997 as part of the Natural Heritage Trust, helps to establish and maintain land for Australia's National Reserve System. The programme has resulted in the acquisition of 7.5M ha of land across the continent.

The NRS currently occupies in excess of 11% of the continent. There is considerable variation in the percentage of land area across jurisdictions (Table 1) with >20% land area reserved in the ACT, Tasmania and South Australia. However, there are still some bioregions with <5% land area in reserves in all states and in the Northern Territory (NLWRA 2002).

Table 1. Australia's terrestrial protected area estate, 2002 (DEH 2003).

State/territory	Total area in reserves (M ha)	% state/territory in reserves
ACT	0.1	54.4
NSW	5.3	6.7
NT	6.5	3.2
Qld	7.1	3.9
SA	25.2	25.7
Tas	2.5	37.3
Vic	3.4	11.4
WA	27.2	10.8
Total	77.5	10.1

Since JANIS there have been substantial shifts in environmental policy across Australia such as the regulation of land clearing associated with agricultural and pasture development. The social and economic fabric of Australia has also evolved substantially in the past decade. Some of the disparate topical issues that have the potential to influence the future direction of the NRS include:

- Focus on whole of landscape management and increased emphasis on conservation outside of protected areas (ANZECC 2001), particularly through the Natural Heritage Trust;
- Major nature conservation initiatives involving non-government organisations (e.g. the co-operative approach between Bush Heritage Australia, Greening Australia and The Nature Conservancy to establish the 1000km Gondwana Link in Western Australia);
- Management of existing reserves and the capacity to manage new ones;
- Rapid change in land use in parts of the Australian landscape including (a) the retirement of traditional agriculture from marginal lands within 1-200 km of the coast and replacement with peri-urban and amenity land uses (e.g. Mansergh *et al.* 2006, CRRIQ 2005), and (b) urban expansion and strip development along parts of the Australian coastline (e.g. Queensland Government 2003);

- Diffuse but broadscale landscape pressures arising from the intensification of agriculture and grazing as well as the long term impacts of grazing regimes (Landsberg *et al.* 1999; Fisher & Kutt 2007; Maron & Fitzsimmons 2007);
- Implications of the prolonged drought during the past decade over parts of Australia including incidence of wildfire (e.g. ACT Commissioner for the Environment 2003);
- Increasing commitment to the use of market based instruments for emissions trading that have potential benefits for biodiversity conservation (e.g. COAG 2007);
- Improved understanding of implications of increased CO_2 and climate change on ecosystems and species (e.g. Berry & Roderick 2006; Williams 2007) and universal incorporation of climate change into government policy across Australia (e.g. NRMMC 2004; Queensland Government 2007).

This above list suggests that further expansion of the reserve network can capitalise on a range of opportunities on offer, provided fundamentals such as reserve management are addressed. It also indicates that broad scale landscape restoration is becoming feasible in some highly fragmented regions. However, the trend in coastal and pastoral regions is for continued loss of biodiversity through intensification of land use which increases the urgency for substantial completion of a reserve network whilst options remain.

The Scientific Advisory Sub Group and Adequacy

An inter-government technical working group, the Scientific Advisory Sub Group (SASG) was formed in 2006 with a key objective to take at fresh look at the CAR principle Adequacy in the context of the NRS and to investigate the development of a metric capable of assessing Adequacy on a bioregional basis across Australia.

Since its inception, the Scientific Advisory Sub Group has been investigating the development of a workable measure of Adequacy following an appraisal of current and anticipated progress on the NRS. The current reserve system has been founded to a large degree on application on Comprehensiveness and to an increasing extent Representativeness.

There has been some experience with addressing Adequacy particularly through implementation of the National Forest Policy in forested regions. Consequently, the group is of the view that Comprehensiveness and Representativeness, given effect through reserve selection tools, provide the foundation for the reserve network with Adequacy adding levels of refinement. Where possible Adequacy should be addressed through detailed bioregional planning approaches and utilise sophisticated levels of information, for example functional requirements of significant and key species (e.g. McFarland 1998; Lindenmayer *et al.* 1999).

However, the group recognises that a measure of Adequacy may need to operate at a fairly basic level if it is to be applied across Australia in the foreseeable future. Two proposals are under consideration - a combined metric using attributes that contribute to Adequacy that are measurable or assessable at a subregional scale (Table 2), or an approach based upon consideration of viable population sizes and functional requirements of vertebrate species.

Adequacy and adaptation to climate change

Adequacy through the goal of sustaining ecological processes and functions and providing for the maintenance of natural patterns of speciation and extinction (JANIS 1997) should go some way to meeting the challenges facing biodiversity as a consequence of climate change.

Table 2. Summary of the features that could be used to assess the CAR principle Adequacy and how they would be measured, based upon work in progress by the NRS Scientific Advisory Sub Group.

	Attribute	Measure
1.	Total area in reserves	Total area of reserves within the subregion measured against a target total area.
2.	Reserve Shape	The shape of reserves in relation to an optimal condition for Subregion.
3.	Connectedness	The extent to which reserves in the subregion are connected within the broader landscape.
4.	Geographic spread	The spread of reserves in the subregion based on an optimal condition.
5.	Surrounding threats and land uses	The level of impacts on reserves in subregion from adjoining land uses based upon intactness of vegetation and land use type.
6.	Replication	The level to which populations are replicated within reserves in the subregion, using ecosystems as a surrogate and considering their distribution and extent

However, some refinement of the way Adequacy is addressed will be necessary as conservation planning explicitly acknowledges and responds to pressures as they become better understood. As Mackey (this volume) notes, the Australian biota has a history of persistence but is presently facing rapid human-induced climate change. This is occurring in conjunction with a range of other impacts and is highlighting gaps in existing knowledge.

Maintaining and restoring connectivity of native vegetation/habitat in the landscape is prominent among the current proposals for dealing with climate change that acknowledge the need to take into account large scale ecological processes, for example:

- Landscape/ecosystem processes associated with geological, edaphic, altitudinal and climatic gradients;
- Evolutionary/genetic processes such as allowing for natural change in distributions of species, connectivity between populations of species over long periods of time and ecological diversification of species; and
- Species processes such as large scale migration/seasonal movement of fauna and provision of drought refuges (EPA in prep. based upon Rouget *et al.* 2003).

In addition to connectivity, size of any area of natural vegetation managed for biodiversity should be another primary consideration. Large patches of habitat have high levels of connectedness and improve the likelihood of survivorship of species by supporting large populations and a range of microhabitats.

Broad principles established for climate change adaptation such as maximising the level of connectedness and retaining and restoring large patches of habitat need to be linked with relevant information at the ecosystem and species-level if they are to achieve satisfactory outcomes for a broad range of biota (e.g. Lambeck 1999).

Some suggested examples of detailed inputs to biodiversity conservation planning addressing climate change at the species and ecosystem levels include:

- Habitat requirements of key species and species assemblages likely to be most resilient to climate change;
- Potential stress points, ie. parts of the landscape likely to be least resilient to climate change. While this includes obvious examples such as the habitat of high altitude species, there are many other potential stress points associated with current patterns of distribution of biodiversity and pressures from land use;
- Current and predicted climate refuges;
- Trigger units (Herbert 1960) and source populations, i.e. species and species assemblages with the potential to radiate from a localised point in response to changing climate;
- Taxa/features of special biodiversity conservation significance, for example narrow endemic species; and
- Knowledge of patterns and processes associated with past climate events.

Examples of each of these inputs are provided in Table 3 for the eucalypt forests and woodlands of southeast Queensland which includes the Southeast Queensland bioregion and part of the Richmond-Tweed Subregion of the New South Wales North Coast bioregion that extends into Queensland along the McPherson and Main Ranges (DEW 2007). A recent report indicates that this area potentially faces major challenges as a result of the impacts of climate change coupled with the effects of extensive coastal development and rapid population growth (Queensland Government 2007).

To focus discussion, southeast Queensland was grouped into four units based upon broad vegetation types and plant and animal species distributional patterns (Fig. 1). These include:

- Uplands over 450 m in altitude which correspond to Nix's (1993) Mesotherm archipelago;
- The high rainfall southern coastal lowlands;
- The drier rainfall northern coastal lowlands; and
- Subcoastal hills and valleys.

The Mesotherm archipelago has a large proportion of remnant vegetation and high levels of internal connectivity. The other three areas are more fragmented with several IBRA subregions close to or below the threshold of 30% remnant vegetation and connectivity with the Mesotherm Archipelago across pronounced climatic gradients is limited in many places.

The eucalypt forests and woodlands of southeast Queensland contain around eighty named tree taxa belonging to *Eucalyptus* and other genera within Myrtaceae including *Angophora*, *Corymbia*, *Lophostemon* and *Syncarpia.* Patterns of species distribution within the region are relatively complex although there is a high degree of correlation with temperature, rainfall, substrate and topography (Ridley 1961; McDonald & Elsol 1985; Nix 1993; Williams *et al.* 1999; Young & Dillewaard 1999).

Hughes *et al.* (2003) suggest that substantial changes in the Australian tree flora may be expected in the future as a consequence of climate change, whilst acknowledging that the climatic tolerances of many species may be wider than the climatic envelope they currently occupy. Ridley (1961) suggests that eucalypts in the central part of southeast Queensland could survive some decrease in rainfall as the species are adapted to an environment in which there are long periods of water stress. However, reduction in rainfall in the order of 20-30% may result in a considerable shift in species composition. Declines in local populations linked to intervals of drought and severe moisture stress have been observed among eucalypts within national park monitoring plots in western parts of southeast Queensland during the past fifteen years (W. Drake, Queensland Parks and Wildlife Service pers. comm.).

Table 3 provides some specific examples at the species level for each of the biodiversity conservation planning inputs suggested above. Significantly, over half of the eucalyptus forest and woodland tree species present reach northern limits of range within southeast Queensland and the majority of species do not extend westward into the drier Brigalow Belt bioregion. The importance of rainfall and temperature in controlling current distributions of many species (Williams *et al.* 1999) suggests that specific areas in the region are potential stress points if trends in rising temperature and decreasing rainfall continue. These areas include*:*

- Zone 1: eastern part of the region from 25^0-27^0 latitude*;*
- Zone 2: elevated parts of the Border and Main Ranges; and
- Zone 3; western parts of the region particularly where the rainfall gradient is gradual and where mixing of species from Southeast Queensland and the adjacent Brigalow Belt is evident (Fig. 1).

The CAR reserve system presently occupies 13% of southeast Queensland (Fig. 1). If lands owned by private landholders and local government are taken into account the total area managed for nature conservation in the region is likely to be around 15%.

It is conceivable that a mature CAR reserve system would cover at least 20% of the region, based upon known gaps and taking into account constraints imposed by settlement and land use. Planning for climate change can play a major role in future development of the CAR system especially when considered in the context of Adequacy. While the level of information on which to base biodiversity conservation planning in the context of climate change needs to be refined, there is sufficient current knowledge to make a start.

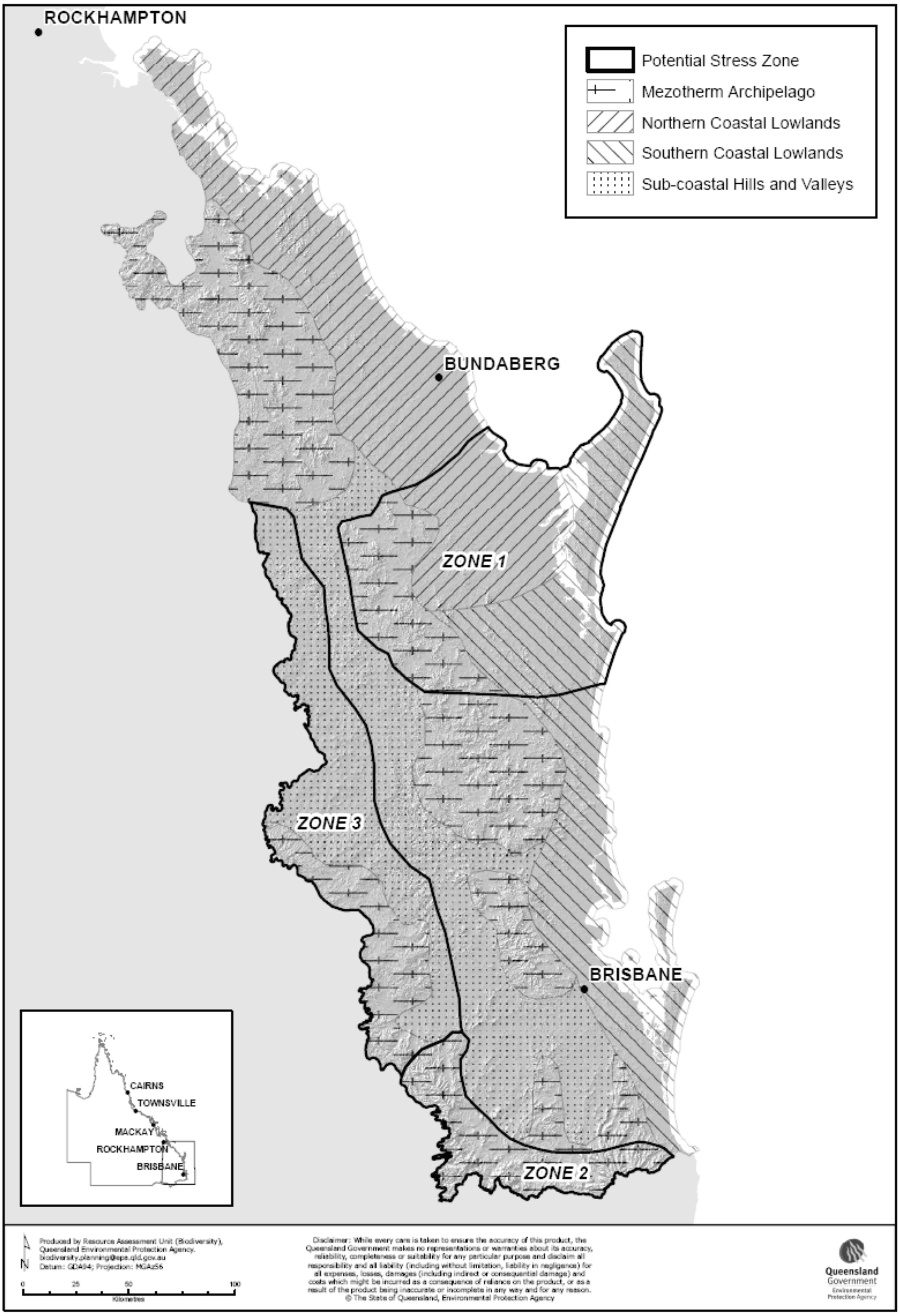

Fig. 1. Potential landscape stress zones in the context of climate change in southeast Queensland.

Table 3. Suggested inputs to biodiversity conservation planning that take climate change into account. Specific examples are provided for each input based on the larger Myrtaceous tree species that grow in the wide range of eucalypt forests and woodlands in southeast Queensland. Mapped ecosystems could be used as a surrogate to simplify planning for most of the examples provided.

Climate change planning input	Examples	Potential implication for CAR reserve system
1. Key species likely to be resilient to some increase in temperature and reduction in rainfall throughout main area of present distribution in SEQ.	Subcoastal hills and valleys, drier parts of Mesotherm archipelago and Northern coastal lowlands - *Angophora leiocarpa, Corymbia citriodora, C. trachyphloia, Eucalyptus acmenoides, E. crebra, E. dura, E. fibrosa, E. latisinensis, E. longirostrata, E. major, E. moluccana, E. tereticornis.* Southern coastal lowlands – *Corymbia gummifera, C. intermedia, E. grandis, E. pilularis, E. racemosa subsp. racemosa E. siderophloia, E. tindaliae, Lophostemon confertus.* Mesotherm archipelago - *Corymbia intermedia*, *Eucalyptus acmenoides, E. eugenioides, E. saligna, L. confertus*.	Mesotherm archipelago well represented in reserves but requires CAR assessment to determine gaps. Requirement for determining Adequate reserve network for other parts of region.
2. Key species likely to be sensitive to some increase in temperature and reduction in rainfall throughout main area of present distribution in SEQ.	Species at high altitude along McPherson and Main Ranges (listed below) and *Eucalyptus montivaga* further north. Northern limits of range along coast and adjacent ranges between $25^0 – 27^{0\ S}$: *Corymbia gummifera*, *Eucalyptus bancroftii, E. grandis* (lowland populations), *E. microcorys, E. pilularis, E. propinqua, E. racemosa subsp. racemosa, E. siderophloia, E. tindaliae* Northern limits of range along McPherson and Main Ranges: *Eucalyptus approximans, E. banksii, E. campanulata, E. dunnii, E. fusiformis, E. nobilis, E. notablis, E. obliqua, E. oreades, E. quadrangulata* Species known to have declined locally from drought stress: *Eucalyptus eugenioides, E. helidonica* Disjunct populations considered to reflect climatic sifting in past e.g. *Eucalyptus racemosa subsp. racemosa* (Coaldrake 1961). Taxa known to be susceptible to stress associated with changes in temperature/rainfall in present habitats, e.g. members of eucalypt sub-genus *Monocalyptus* (Brooker & Kleinig 1994) in western part of region (W. Drake QPWS pers. comm.).	Identify potential stress points. .
3. Refuges and Potential Refuges.	Tall open forest +/- *Eucalyptus cloeziana* on old red soils along western margins of SEQ. Disjunct populations of "temperate-adapted taxa") e.g. *Eucalyptus dalrympleana subsp. heptantha and E. conica* in cold valleys. Refer also to 6, below.	Incomplete knowledge especially with respect to potential refuges. Management main issue for known areas, both on and off-reserve.

Table 3. Cont'd

Climate change planning input	Examples	Potential implication for CAR reserve system
4. Trigger units	Localised populations of dry tolerant species at harsh sites in high rainfall areas, e.g. *Eucalyptus crebra, E. dura.* Species that extend into SEQ from west and north e.g. *Corymbia clarksoniana, C. erythrophloia*, *Eucalyptus apothalassica, E. decorticans, E. populnea, E. portuensis.*	Management main issue for known areas, both on and off-reserve.
5. Potential stress points.	The habitat of species populations likely to decline that has been fragmented by clearing and/or impacted by other threatening processes such as changed fire regimes See 2. above for species	In parts, complex to address spatially because of intensive land use and CAR approach of limited use. Other potential stress points are in CAR reserves and management is main issue.
6. Species and populations of special conservation interest.	Regional endemic species with narrow or restricted ranges: *Eucalyptus conglomerata, E decolor ,E. hallii, E. kabiana, E. taurina, Syncarpia verecunda.* Disjunct populations and populations with pronounced phenotypic variation, e.g. *Syncarpia hillii, Eucalytpus planchoniana* on southern sandmass islands and localised occurrences of *Eucalyptus baileyana, E. bakeri*, *E. curtisii, E. psammitica* on sandstone.	Incomplete knowledge especially with respect to likely responses to climate change (W. Drake QPWS pers. comm.). Management of existing populations is a key issue both on and off-reserve.

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14. What do you do when the biodiversity you bought gets up and leaves? Challenges facing protected area planning for the private land trust sector due to climate change

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Abstract

Climate change threatens the viability of biodiversity managed through a "static" reserve design world view. Conservation strategies now need to emphasise, not just incorporate, the permeable nature of reserves in their assessments.

A future looking conservation strategy that prioritises integrated adaptive management, overcoming the current gap between rhetoric and practice, is crucial.

Therefore, to ensure continued conservation "market share", private nature conservation groups and trusts should probably focus on adaptation as a primary climate change planning strategy.

This will generate institutional challenges that will need to be overcome for the sector to continue to flourish.

Introduction

> "Incorporat[ing] the threats posed by climate change to the existing reserves and also design of any reserves in the near future … is crucial or else it is quite likely that in the next 50 years we will have protected areas without the valued biodiversity" (Gitay 2004).

Mirroring international trends, the Australian private land trust sector is a growing part of the armoury of Australian conservation strategy, and a central part in the response to climate change. This sector is known collectively as Private Nature Conservation Groups and Trusts, after Cowell & Williams (2006), who describe it as:

> "an emerging 'industry sector' that sees its role as facilitating improved biodiversity conservation on private land in Australia; whether through acquiring and managing land as reserves or using other tools to assist private landholders protect biodiversity on their own properties" (p. 6).

These include national and state organisations, non-government organisations (NGOs) and statutory authorities.

Cowell S. (2007) What do you do when the biodiversity you bought gets up and leaves? Challenges facing protected area planning for the private land trust sector due to climate change. In: *Protected Areas: buffering nature against climate change. Proceedings of a WWF and IUCN World Commission on Protected Areas symposium, 18-19 June 2007, Canberra.* (eds M. Taylor & P. Figgis). pp. 112-116. WWF-Australia, Sydney.

All organisations in the sector aspire to actively manage the properties for which they are responsible, guided by strategic planning and management. They have developed a significant and growing focus on working with neighbours and other landholders in the broader landscape matrix (Cowell & Williams 2006), and initiating and participating in multi-tenure reserve networks (see for example Fitzsimons & Wescott 2005). Many make a substantial investment in conservation planning for their own properties and in the landscapes surrounding them, using well understood reserve design principles.

This paper discusses the challenge of climate change to this developing sector, and the way the sector can and is responding. In doing so it presents one perspective of climate change impacts on conservation strategy, and how the sector can adapt its actions.

The paper contends that the challenges posed by climate change are an extension of the core challenges faced by the sector, indeed all sectors:

- The need to make resource allocation decisions to maximise conservation benefits in the face of a changing climate;
- Complex relationships between systems and species;
- Uncertainty about the trajectory of change; and
- Limited information about the impacts of change or actions in response to change.

Our conceptual challenge is to work towards a planning horizon that is at once much further away than we typically look, yet too close for exhaustive analysis before we act and one that is apparently moving closer.

Background

Studies in Africa, Canada, the United States and Great Britain all indicate significant biodiversity loss through climate change, particularly through its interaction with existing threatening processes such as fragmentation, invasive species, inappropriate fire regimes, loss of available water (WWF 2003). The effects of climate change, to the degree they can be predicted currently, look to be especially serious for mid-latitude countries, such as much of Australia.

Many Australian species have limited climatic ranges, with iconic landscapes and ecosystems such as the Australian Alps, southwest Western Australia, upland tropical rainforests (Wet Tropics), coral reefs (e.g. the Great Barrier Reef), arid and semiarid habitats, freshwater wetlands and riverine environments being particularly vulnerable (NRMMC 2004). These remain under threat because even if we could instantly halt anthropogenic greenhouse gas emissions, we will not escape a further 0.4°C to 0.5°C rise in global-average surface temperature (Bierbaum *et al.* 2007).

Irrespective of our immediate or future mitigation actions these changes will impact on species distribution, community composition, ecosystem function, ecosystem services, and disturbance regimes, and see extinctions of species not able to adapt.

As a consequence existing protected areas may lose species and communities through extinction or migration, if migration is possible. The same areas will receive new cargoes of immigrant species. Natural barriers to movement (e.g. soil type) and a landscape matrix that inhibits migratory capacity of species and systems are a key determinant of extinction risk (NRMMC 2004; Bomhard & Midgley 2005).

These challenges are not new to conservation planning or management. Poiani *et al.* (2000) make clear that even without a climate change overlay, our understanding of the needs of conservation has expanded substantially from single-site or single-species approaches to ones that include genes, species, populations, ecosystems, landscapes and processes, with strategies focused on attributes such as composition, structure and function. A clear implication of this understanding is the need to:

"conserve dynamic, multi-scale ecological patterns and processes that sustain the full complement of biota and their supporting natural systems" (Poiani *et al.* 2000 p. 133).

Given the likelihood of shifting species and ecosystem distributions under climate change we need to add an essential additional focus to our current focus on preserving species and ecosystems in their current locations (WWF 2003; NRMMC 2004). Conservation planning based on climatic and biogeographic stability, a questionable assumption in general, is untenable in an era of global climate change (Lemieux & Scott 2005).

Response

Conservation planning and strategy therefore need to focus on supporting species and system adaptation and survival, working with the changes that are predicted rather than having our planning constrained by the inertia of our land tenure system.

Supporting or reinstating the resilience of natural systems should therefore be a core goal in our response, through two familiar approaches (IPCC 2001):

- Adaptation: "activities that reduce a system's (human and natural) vulnerability to climate change" (CBD 2007) and "often (involve) measures to increase the capability of a system to cope with impacts of climate change" (AHTEGBACC 2005 p. 10); and
- Mitigation: "…reducing the greenhouse gas emissions from energy and biological sources or enhancing the sinks of greenhouse gases" (CBD 2007).

Protected area planning will need to incorporate both responses of mitigation and adaptation (Thomas 2007), and in many cases can combine them. For example, revegetation projects achieve mitigation through carbon sequestration as well as linking isolated protected areas and assisting adaptation through increasing system resilience by expanding habitat. There is a great deal of consistency in the literature about the principles that should underpin a response in protected area planning for adaptation (*inter alia* IPCC 2002; CBD 2003; AHTEGBACC 2005; Bomhard & Midgley 2005). We need to:

- Model present and potential future ranges (envelopes) of species and systems to identify target locations where climate envelopes overlap;
- Target natural refuges, environmental gradients (e.g. latitude, altitude, soil moisture), habitat heterogeneity, genetically-diverse populations, species-rich ecosystems, and highly productive landscapes;
- Systematically plan multi-tenure landscape to include habitat and land use matrices that have migration potential useful to target species and systems;
- Plan for a greater area and numbers of reserves, including protected area extension and relocation, involving both public and private land;
- Buffer (pattern and process) existing reserves through developing partnerships to link on- and off-reserve conservation; and,
- Incorporate an assessment of the effectiveness of management responses to climate change into routine outcomes monitoring programs across all landscapes, and ensure feedback of the results into subsequent management action.

Climate change highlights the paradoxes inherent in many of our current views about "best practice". For example, reconnecting habitat using "corridors" or "stepping stones" may allow dispersal and survival of target species and communities, but also may increase the threat of the establishment of new competitors, predators or pathogens (NRMMC 2004). More controversial and higher-risk tools such as *triage* and *ex situ* conservation strategies (eg translocation of species and systems) will need to be considered more seriously as a key part of an overall strategy.

There are a number of key ways for organisations to pursue mitigation in the absence of a national framework of carbon markets:

- Assess whole-of-organisation sustainability practices and potential to operate in an ecologically sustainable manner eg use of renewable energy and efficiency of energy use in protected areas;
- Targeting those areas where the causes of climate change are continuing i.e. land clearing;
- Establishment of markets that support carbon trading to support management of areas for conservation value; and
- Explore options to raise environmental awareness for climate change mitigation and adaptation in collaboration with others.

Challenges

The challenges facing Private Nature Conservation Groups and Trusts as a result of the recent government acceptance of climate change and the possible responses we might need to have are not necessarily specific to the sector, nor new. Indeed, projects and partnerships such as those formed by a number of these groups (eg Gondwana Link in Western Australia) already demonstrate many of the principles outlined above for adaptation and mitigation.

Bush Heritage and internationally The Nature Conservancy are investing significantly in developing outcomes monitoring and reporting programs.

This is both to close the management loop and improve practice, driven in part by the need for efficiency in resource use and accountability to donors and supporters. Programs such as Bush Heritage's *Beyond the Boundaries* target partnerships across multiple tenures to create ecologically permeable landscapes buffering existing protected areas and targeting conservation values outside the reach of formal reserve tools.

If the sector seeks to move beyond the relatively simple formula of soliciting donations to be able to buy a property with significant conservation values that is then protected forever, it will need to make some significant changes to the way it operates. The following issues arise, albeit made more significant by the challenge of climate change:

- Generating income: The ability to continue to generate income and support through the use of less direct conservation tools such as development of landscape partnerships, increased monitoring and management.
- Incorporating risk: Related to the above, acquisition of title is relatively low risk with a greater degree of certainty of outcome than many alternatives. However, while critical it is a tool with relatively limited scope and less certain or more risky conservation tools may be needed to achieve widespread landscape change – organisations will need to spread their risk across a portfolio of responses.
- Disposing of property: Emphasising the above two points, as environments change and species and communities shift then there may be the need to dispose of property to free up capital to move into new areas of greater urgency for action. This will call into question the assumption that acquiring fixed property rights is low risk.
- National collaboration: A clear message is that collaboration, not competition, is central to an effective response to climate change. While not unproblematic and requiring careful consideration, international models show that groups can pool scarce resources for sectoral issues, while allowing individual organisations to retain their independence and flexibility (Cowell & Williams 2006).
- Socio-cultural systems: Most Private Nature Conservation Groups and Trusts have expertise in ecological systems, but for many of the needed responses that involve multiple partners and land users, we will need to include expertise in socio-cultural systems. A greater level of sophistication in decision making will also be required to incorporate human dimensions.

Conclusion

Climate change is becoming the most significant influence on conservation planning and strategy, and will be so for many generations. Consideration of its impacts will become central to conservation planning and management into the future. Private Nature Conservation Groups and Trusts will be a core part of that response, as they are perhaps more able to adapt to some of the landscape management needs than more established state-based conservation networks. However, this will not be without challenges to their role.

Private sector conservation planning will be challenged by the same issues confronted by all conservation sectors in addressing climate change: lack of sufficient resources, data, knowledge, certainty, and time. While important, these are not novel, nor are they a reason not to act, and the sector's response will no doubt mirror that of the broader conservation *milieu*. The institutional challenges will likely be more significant and will need to be overcome if the sector is to contribute effectively to a climate change response.

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This paper presents the views of the authors, which incorporate the thoughts and wisdom of those with whom we discussed this topic. Any errors are entirely the responsibility of the authors.

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15. Directions for the National Reserve System in the context of climate change

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Abstract

Australia's National Reserve System is not fully representative of its biodiversity. Many priority bioregions for expanding the protected area estate occur within marginal rangeland areas and the intensively used semi-arid pastoral zone where land degradation pressure will be exacerbated by climate change and is likely to lead to acute loss of biodiversity.

The protection of refugia as part of the climate change response is discussed in terms of evolutionary, ecological and European induced refugia and examples given of proposed protected areas for each type. A national program to further identify key refugia is proposed. Ideally, the protection of refugia should be part of systematic bioregional conservation planning to establish protected areas within their landscape matrix, to protect environmental gradients, establish greater connectivity and allow the management of other threatening processes. This would provide valuable input for regional natural resource management processes.

The introduction of carbon trading nationally should be designed to maximise opportunities for both biodiversity and greenhouse objectives. Biodiversity objectives should extend beyond plantation design and could include partnerships with industry in securing protected areas. Such opportunities exist where properties acquired include parts that allow for the encouragement of regrowth and the re-establishment of soil carbon. These restoration activities should be accommodated in the design criteria for carbon trading. This is a significant opportunity for northern Australia and could include partially degraded rangelands where large areas are involved to create significant greenhouse sinks.

A greatly expanded protected area program is called for to build resilience and adaptive capacity as a priority response to the direct impact of climate change and to help address the extensive decline in biodiversity that will occur across the wider landscape from the interaction of climate change with other threatening processes. Particular attention is drawn to priority bioregions within the semi-arid and arid zones of Australia.

Introduction

The National Reserve System is Australia's premier investment in nature conservation. The system includes public reserves, protected areas on private lands and Indigenous Protected Areas totalling 10.5% of Australia's land mass in 2004. Unfortunately, these protected areas are not fully representative of the continent's biodiversity with only 67% of ecosystems in public reserves (IUCN reserve categories I-IV) with a further 5% in other protected areas (IUCN V-VI) (NLWRA 2002). Approximately half (42) of Australia's 85 bioregions are considered a high priority (priorities 1 and 2) for consolidating the protected area system.

Biodiversity continues to decline across Australia at all levels from species to landscapes. The

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existing primary threats to biodiversity excluding climate change, based on the number of subregions where the threat has been recorded, are: fragmentation of habitat, overgrazing, weeds, feral animals and changed fire regimes (NLWRA 2002, note that there has been significant reduction in broad scale tree clearing over recent years as a result of legislation in Queensland and New South Wales). Changed hydrology is also a significant threat to wetlands and riparian zones across most of Australia.

Climate change is predicted to cause significant impact to Australia's biodiversity particularly in montane tropical forests, alpine areas, low-lying coastal areas, coral reefs and for species occupying relatively narrow bioclimatic envelopes (e.g. Hughes 2003). However, many of these systems are already extensively included in the protected area estate and other conservation strategies to protect species such as translocation may need to be considered to ensure species survival.

Climate change will interact with other threatening processes causing acute impacts in many areas. Many of the above threats to biodiversity are associated with current land uses which also will be directly affected, particularly pastoralism and agriculture in various parts of the continent. Thomas *et al.* (2004) argue that the most severe impacts of climate change are likely to flow from interactions between threats rather than climate change in isolation.

In large parts of Australia's rangelands, pastoralism is a marginal economic activity due to either low productivity and/or structural factors such as property size. It is expected that these lands will become further degraded with increasing stress on biodiversity chiefly associated with increasing drought as a result of climate change. This paper reviews the location of the priority bioregions to consolidate the National Reserve System in relation to where accelerated threats due to climate change interacting with marginal pastoralism may occur.

Refugia are critical habitats for the protection of biodiversity and their protection will become even more critical with climate change to build resilience and adaptive capacity for biodiversity. Morton *et al.* (1995) categorised refugia as evolutionary, ecological or European-induced. The systematic identification of these different types of refugia across bioregions should be a key criterion for the identification of proposed protected areas to consolidate the National Reserve System. A number of proposed protected areas in Queensland containing each type of refugia are described from WWF's report *Treasures for Humanity* (WWF 2003).

With the proposed introduction of carbon trading in Australia, biodiversity should be considered a key component or criterion in designing greenhouse credits that involve the biosequestration of carbon. Opportunities for the protection and restoration of biodiversity including the acquisition of lands for the National Reserve System as part of procuring a greenhouse credit are discussed.

Priority bioregions for consolidating the National Reserve System

The identification of priority bioregions to consolidate the National Reserve System is based upon three criteria:

- Extent of the protected area estate in each bioregion based on the *Collaborative Australian Protected Area Data Base (CAPAD) 2002* (DEH 2003);
- Bias of the protected area estate in sampling ecosystems across bioregions; and
- Degree of threat to biodiversity (NLWRA 2002).

This prioritisation was developed by State and Territory conservation agencies that modified the Collaborative Australian Protected Areas Database (CAPAD) 2002 map showing extent by considering bias and degree of threat (Fig. 1). For example, Brigalow Belt South was elevated in priority because of the disproportionate representation of the Carnarvon sandstone ecosystems and the limited representation of the fertile clay plains and alluvial ecosystems.

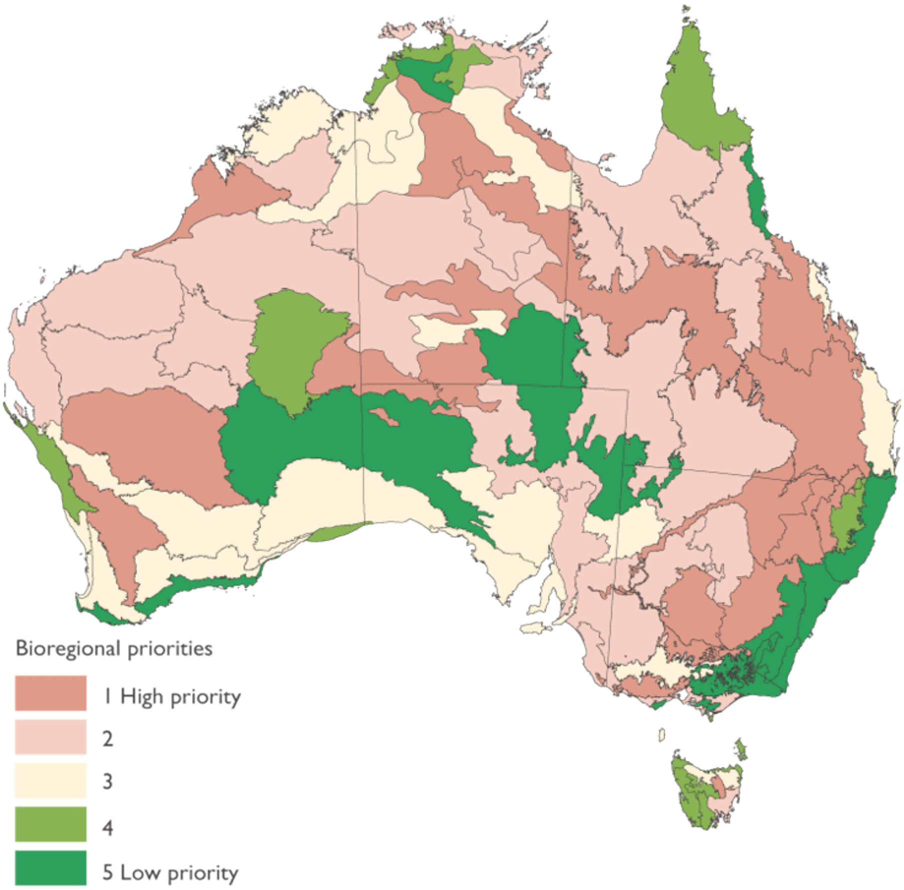

Fig. 1. Bioregional priorities for consolidating Australia's protected area system (Data from NLWRA 2002).

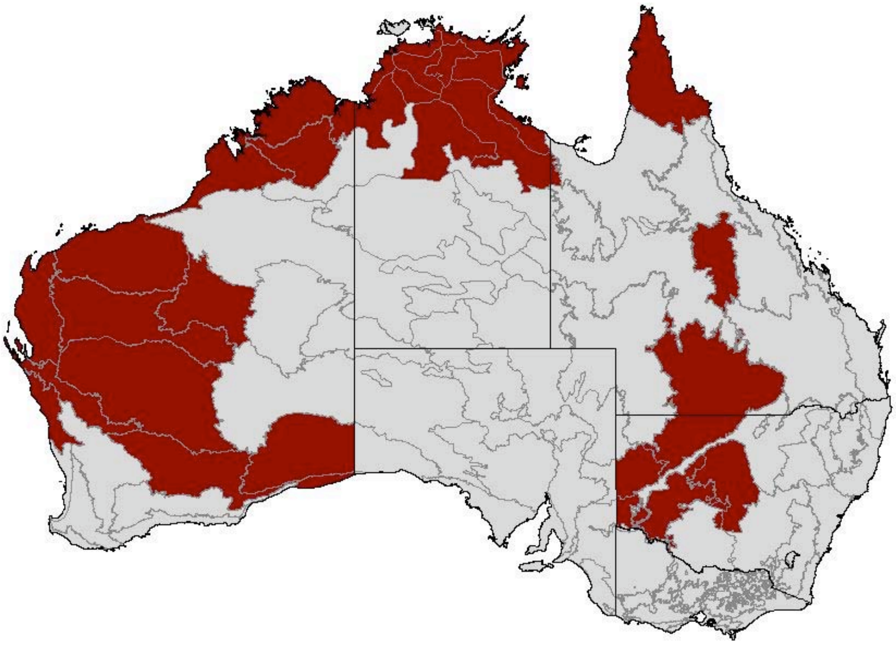

Fig. 2. Australian rangeland bioregions (excluding South Australia and Victoria) displaying generally marginal economic status at the enterprise scale (Data from Dames & Moore - NRM 1999).

Fig. 3. First level of degradation in overgrazed semi-arid lands (Mulga Lands bioregion): dominance by woody weeds, loss of perennial species and soil carbon (Photo: P.Sattler).

Fig. 4. Second level of degradation in overgrazed semi-arid lands (Mulga Lands bioregion): loss of top soil and ecosystem collapse (Photo: P.Sattler).

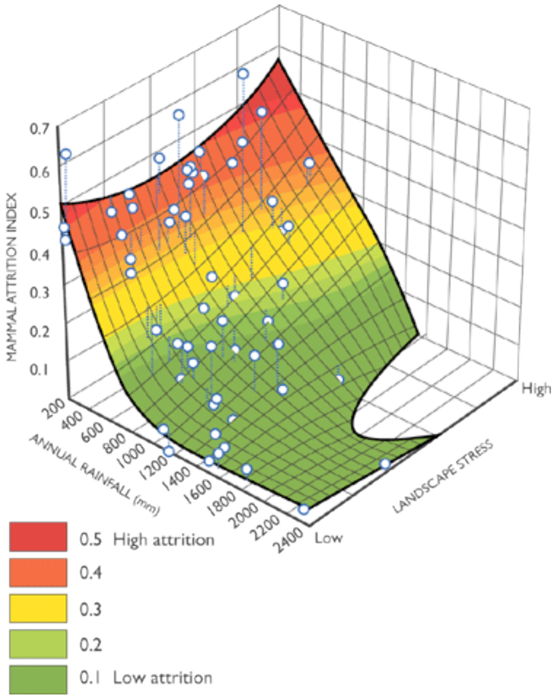

Fig. 5. Scatter plot of mammal attrition versus annual rainfall (mm) and landscape stress across Australia's bioregions (reprinted with permission from McKenzie & Burbidge 2002).

Similarly, South East Queensland and was elevated due to the degree of threat from the current and projected large population increase with approximately 50 000 people per annum migrating into South East Queensland and 575 000 new dwellings proposed by 2026 (OUM 2005).

This priority bioregional map for consolidating the National Reserve System is currently being reviewed by WWF in liaison with each of the States and Territories. Only limited change in relative priorities has occurred since that time.

Within the lesser priority bioregions there are nevertheless some subregions and many ecosystems that are poorly conserved. These should continue to be a priority for further represented in the National Reserve System e.g. ecosystems associated with coastal lowlands of the Wet Tropics. However, from a national perspective it is desirable to identify those large parts of Australia where the conservation estate does not adequately conserve biodiversity.

Most of the highest priority bioregions for consolidating the National Reserve System shown in Fig. 1, fall either in whole or part, within the semi-arid zone of Australia. Exceptions occur in some arid parts and in wetter areas including the Tasmanian Northern Midlands, Avon Wheatbelt, Daly Basin, the

Brigalow Belt (though partly semi-arid), Nandewar, New South Wales South Western Slopes and the Victorian Volcanic Plain. This semi-arid rangeland zone contains the more intensively settled pastoral lands bordering on cropping lands.

In considering potential impacts of climate change, socio-economic factors surrounding current land use and settlement patterns should also be considered. An economic analysis at the enterprise scale of the profitability Australia's pastoral zone shows that large parts experience very poor economic returns (Fig. 2). Australian Bureau of Agriculture Resource Economics (ABARE) statistics and other data for the late 1990s suggest the relative profitability in comparison with other rangeland regions would not have changed since that time.

In constructing Fig. 2, the Darling Riverine Plains bioregion has been excluded from the original data as it is now subject to much intensive irrigated agriculture. Also, the marginal bioregions of the Desert Uplands and Cape York Peninsula which originally had been assessed within other more productive areas have been separately identified. These marginal and submarginal areas showed negative business enterprise profitability (including capital appreciation), negative business profit per square kilometre and negative net returns to public revenue. It should be appreciated however, that within these large areas there are productive grazing lands with some profitable enterprises that rise above the average.

In many parts, particularly where pastoralism is intensive, poor economic returns contribute to land degradation as landowners try to maintain their business operations without the flexibility of being able to move stock, adopt safe carrying capacities and other sustainable grazing practices.

Furthermore, many areas such as the Mulga Lands, southern Desert Uplands and parts of the Western Division of New South Wales, are structurally unsound in terms of small property size as a result of closer settlement policies for over a century. For example, the average size of properties in Queensland's Mulga Lands is just over 20 000 ha compared with over 200 000 ha in the adjacent and more productive, though highly variable Channel Country.

Even productive regions such as Queensland's Mitchell Grass Downs are subdivided into properties of just over 20 000 ha where profitability and land condition may quickly deteriorate under adverse conditions compared with the larger properties exceeding 500 000 ha on the Barkly Tableland. It is interesting that one of the original reasons for governments not allowing closer settlement of the more arid areas included climatic variability, which with climate change will now become the defining factor for the semi-arid lands.

Climate Change

Climate change is predicted to significantly increase temperature particularly in the arid and semi-arid parts of Australia and cause greater extremes of natural variation and influence seasonality. Though predictions of regional differences in rainfall pattern vary, the trend in rainfall recorded by the Bureau of Meteorology from 1900 to 2006, show a significant decline in rainfall in large parts of eastern Australia and south west Western Australia (Bureau of Meteorology 2007).

For every 1°C increase in temperature, up to 8% increase in the evaporation is projected over much of Australia thus further affecting water balance. Global warming is expected to enhance the drying associated with El Niño events contributing further to drought conditions (CSIRO 2001).

Notwithstanding the possibility of some CO_2 enrichment of plant growth, it is considered that the socio-economic factors particularly associated with increased drought and its impact on marginal land uses will far outweigh such effects. Expected expansion of woody weeds such as Prickly Acacia (*Acacia nilotica*) (Kriticos *et al.* 2003) from CO_2 enrichment will further impact on property sustainability. Anecdotal evidence indicates a relatively recent, extensive expansion of Mimosa (*Acacia franesiana*) on overgrazed lands on the Darling Riverine Plains in north western New South Wales though the impact of climate change is unknown.

Changes in climate leading to increasing drought conditions will have considerable impact on the pastoral zone with impacts magnified in many of the marginal rangelands areas (Figs 3, 4). These impacts will include the loss of refugia as well as loss of the ecological patterning of the landscape (Ludwig & Tongway 1995), direct changes to water and nutrient availability, degradation of ground cover and soils and in some cases, changed fire regimes. It has also been argued by Chilcott *et al.* (2002) that enhanced seasonal climate variability and extremes under climate change will interact with current poor management of Queensland's native pastures and amplify the risks of resource degradation.

A direct relationship between loss of mammal species since European settlement and landscape stress and rainfall (productivity) has been shown (Fig. 5) (McKenzie & Burbidge 2002). The contributing stress effects of both landscape degradation and predation have since been further defined (McKenzie *et al.* 2007). In addition, changes in the bioclimatic envelope for species from climate change are predicted to cause a significant contraction of Western Australia mammals (Pouliquen-Young & Newman 1999). McKenzie *et al.* (2006) suggest conservation action could be most effective at the wetter edges of semi-arid and arid species ranges. However, this zone aligns with the more intensively utilised bioregions described above where intensive pastoralism is already pervasive.

Garnett *et al.* (2002) compared bioregional differences between the two *Bird Atlas* surveys and also reported that many bird species are sensitive to declining landscape health with grassland, woodland and ground-nesting guilds particularly affected.

More than half, 14 out of 26, of the bioregions within the marginal rangeland zones identified in Fig. 2 are priority bioregions for consolidating the National Reserve System. This means that there is an urgent priority to consolidate the National Reserve System across the semi-arid and arid lands of Australia due to the interaction of climate change with other threatening processes and current land use. The establishment of protected areas in this zone would enable direct management of other interacting threats with climate change including the removal of grazing pressure. Failure to manage such threats, particularly in the closer settled semi-arid lands, will not only lead to species loss but ecosystem collapse.

Refugia

The conservation of refugia will be increasingly significant for the maintenance of biodiversity under a changing climate. Other criteria such as maximising environmental gradients in protected area design and the establishment of greater connectivity of protected areas will also be important.

However, caution is raised in designing corridors to ensure that they are viable for identified species, that associated management requirements are assessed and that their effectiveness is considered in relation to implementing other bioregional conservation actions. Howden *et al.* (2004) have suggested that the rate of climate change is likely to exceed the dispersal rate of all but the most mobile species, which casts uncertainty over the effectiveness of corridors for many species.

Connectivity conservation is discussed elsewhere in this volume.

The three types of refugia as described by Morton *et al.* (1995) are defined as follows:

- Evolutionary refugia, being areas where most of the original geographic range becomes uninhabitable because of climate change with resulting high frequencies of endemic species;
- Ecological refugia, being areas where species or suites of species persist for short periods such as less than one generation, or perhaps just a few, because large parts of their preferred habitat becomes uninhabitable due to unsuitable climatic or ecological conditions;
- European-induced refugia, where species have retreated because of factors associated with environmental change set in train by European settlement and where threatened species often occur.

Understanding the nature of refugia can assist in prioritising their protection and the development of suitable management regimes. Examples of protected area proposals describing each type of refugia are given below: such examples indicate that direct action can be taken now in building resilience and adaptive capacity for climate change into the National Reserve System.

Evolutionary refugia

Examples of protected area proposals containing evolutionary refugia include the Mt Abbot-Bogie River park proposal near Bowen where the Brigalow Belt North bioregion extends to the coastline (WWF 2003). The dry Bowen-Townsville corridor is a major biological barrier between the moist zones of the Central Mackay Coast and the Wet Tropics bioregions. This dry corridor occurs because of a lack of near coastal ranges to intercept rainfall. It contains three isolated mountains Mt Spec and Mt Elliott which are already protected as National Parks and a small precipitous mountain, Mt Abbot (1056 m).

The invertebrate fauna of Mt Abbot is particularly significant (Monteith & Joyce 1999; O'Keefe & Monteith 2000) with species from both sides of the biological barrier being preserved side-by-side. Many species are at their extreme southern or northern limits of their distribution indicating an ancient refugial situation where the rainforests to the north and south pulsed to and fro through this dry corridor. One species of beetle, *Clidicus abbotensis*, is the only occurrence in Australia and represents an extension in range of 3500km from Java and Borneo. In addition, 493 vascular plant species representing 344 genera and 113 families have been collected (Bean 1994). This proposal extends down to the Bogie River thus preserving a wide environmental gradient and enabling the conservation of ecosystems that have long since been cleared in the southern dry corridor to the coast about Rockhampton.

Another significant park proposal containing important evolutionary refugia is Aramac Springs. This proposal straddles the Desert Uplands and Mitchell Grass Downs bioregions with an environmental gradient extending from the ironbark woodlands on the tertiary plateau of the Desert Uplands to the Mitchell Grass Downs grasslands. This proposal contains 45 artesian springs occurring in size from four m^2 to 400 m^2 and containing three critically endangered endemic fish species, six endangered snail species and a number of other endemic crustaceans: amphipod, shrimp, and ostracodes. There is only one other arid zone spring in the world (in Mexico) that exhibits an equivalent radiation in endemic hydrobiids (Wagner undated). This area is particularly threatened from grazing, feral animals (pigs and mosquito fish), weeds, changed hydrology and poaching. Many of these threats such as overgrazing, woody weed invasion will be aggravated by climate change.

Ecological refugia

One significant example of a major park proposal containing ecological refugia is Bulloo Lakes. This significant wetland at the terminus of the Bulloo River on the Queensland and New South Wales Border is part of the network of arid wetlands that sustain avifauna across the continent. In this example, connectivity conservation involves the protection of habitats that are hundreds of kilometres apart with the Bulloo and Paroo wetlands on Currawinya National Park being a critical refuge when the Lake Eyre system is dry (Jaensch pers. comm.). The Bulloo wetlands at times support large numbers of species with aggregations of waterbirds in excess of 30 000 recorded (Jaensch 1998). This arid area is vulnerable to overgrazing and changed hydrology. Roshier *et al.* (2001) have also expressed concern that climate change that results in a drying or reduced frequency of large flood events, exacerbated by extraction of water for agriculture, could be catastrophic for waterbirds which use a mosaic of wetland habitats at broad spatial scales.

European- induced refugia

A coastal example of European induced refugia includes the park proposal over Warps Holding near Ingham on the lowlands the Wet Tropics bioregion. This area is a major refuge for the Herbert River population of the endangered Mahogany Glider, *Petaurus gracilis*. The proposal is surrounded on three sides by sugar cane farms with few remnants of habitat remaining elsewhere on the lowlands. Significantly, this proposal links westward through natural forest to the coastal ranges and the Wet Tropics World Heritage Area to provide an important corridor for other species (Mahogany Gliders occur below an altitudinal limit). Protection of this area is critical to the survival of the Mahogany Glider which is increasingly threatened by fragmentation of habitat and other threats in an intensively managed landscape.

National Refugia Identification Program

Further systematic identification and classification of refugia should be supported at a national scale. Ideally, the identification of significant refugia should be part of the development of systematic bioregional strategies for each bioregion to integrate reserves into the broad landscape mosaic (Sattler 2006). Such strategies should form a key input into regional planning and natural resource management processes. However, in the absence of systematic bioregional strategies being developed across each bioregion of Australia, the identification of key refugia as a separate national program to assist in the development of the protected area estate both on public and private lands is needed.

This action would help implement Strategy 5. 2 of the *National Biodiversity and Climate Change Action Plan 2004-200 7* (NRMMC 2004):

> "Reviewing reserve acquisitions to strengthen the capacity of the reserve system to act as refuges for vulnerable terrestrial species and integrate reserve planning and management with broader landscape protected area networks to allow the movement of species across bioclimatic gradients"

Carbon market incentives for protected areas

With carbon trading proposed nationally for Australia, significant opportunities exist for biodiversity conservation to be jointly planned for as part of proposals for the biosequestration of carbon. Proposals for carbon biosequestration should not be developed without the opportunity being afforded to plan for biodiversity. Given the pressures on biodiversity generally from climate change, the combining of both biodiversity and greenhouse objectives represent a significant opportunity for financing expanded nature conservation.

Opportunities for combining greenhouse and biodiversity objectives range from the addition of a diverse species mixes with forest plantation establishment as well as the protection of corridors within plantation design, to the planning of the reservation and management of protected areas.

Many protected areas proposals today contain areas of cleared or degraded ecosystems within the boundaries of the property to be acquired or covenanted to secure key biodiversity attributes. The revegetation of those cleared area could earn carbon dollars to help pay for acquisition and management, as well as restoring connectivity and buffering for the intact natural areas.

In parts of northern Australia, considerable natural regeneration or regrowth potential exists due to a much more recent clearing history than in the southern states. The management of regrowth towards natural climax communities is a much more cost effective operation than replanting schemes. Furthermore, regrowth could sequester significant amounts of carbon in moist environments as well as bioregions such as Brigalow Belt South and Brigalow Belt North as Brigalow has remarkable regenerative capacity.

In drier areas such as the Mulga Lands and Desert Uplands bioregions, the potential sequestration of carbon per hectare is much lower, however large areas create a significant multiplier. In these rangelands, considerable soil degradation has occurred in parts and restoration may facilitate the sequestration of considerable amounts of soil carbon together with the regeneration of ground and shrub layers under the existing woodland canopy.

Elsewhere in northern Australia, Ash *et al.* (1995) have shown a 42% difference in soil organic carbon in plots dominated by annual species indicative of poor range condition compared with plots dominated with perennial grass species. They calculate the conversion of deteriorated rangelands in northern Australia to a desirable sustained condition over a 30 year period would result in an average annual carbon sink equivalent to 6. 5% of the Australian total net emissions in 1990, a significant amount.

It is essential in the first instance, for carbon restoration through the management of regrowth and reinstatement of soil carbon to be accredited with appropriate verification, as well as tree planting, in the design of carbon trading criteria for Australia.

The opportunity then exists to broker the protection of areas of high nature conservation value to achieve both carbon and biodiversity objectives. Such arrangements could include obtaining a financial contribution for carbon credits towards the acquisition and management of the protected area or encouraging business to acquire such proposals and allow the management of areas for biodiversity as well as carbon objectives. This could have additional corporate appeal in terms of displaying a commitment to broader environment protection.

An example of one such suitable area includes a property near Blackwater in central Queensland within Brigalow Belt North. This properly contains the only other population of the endangered Bridled nailtail wallaby, *Onychogalea fraenata*, to that protected on Taunton National Park as well as poorly conserved Brigalow ecosystems. Part of the property has been cleared and regrowth potential could be assessed. Acquisition of this property would achieve significant biodiversity and protected area objectives as well as securing a significant area for carbon sequestration. The protection of regrowth has also been called for as an important component in the maintenance of connectivity of natural vegetation in planning for climate change (Krockenberger *et al.* 2003).

Another more extensive example of a park proposal that could meet both carbon as well as biodiversity objectives includes a large property of over 200 000 hectares in the Desert Uplands around Lake Buchanan, a nationally significant wetland. Erosion and degradation of soils on this properly has occurred over a long history of heavy domestic grazing pressure. Potential exists to sequester soil carbon and above ground carbon by destocking and restorative management.

Conclusion

Understanding the interaction of climate change with other threatening processes and socio- economic pressures is important to identify where accelerated loss of biodiversity may occur across Australia. Consideration of these factors will allow strategic consolidation of the protected area system to stem the loss of biodiversity through the direct management of interacting threats.

Most of the highest priority bioregions for the National Reserve System are within the semi-arid lands of Australia. Many of these rangeland areas are particular stressed due to their marginal economic status and further degradation from overgrazing and constrained pastoral management opportunities in conjunction with climate change will cause increasing loss of biodiversity.

The systematic identification and classification of refugia at a national scale, ideally as part of systematic bioregional conservation strategies, is required as a key criterion in protected area planning and development of suitable management regimes.

A greatly expanded protected area program is needed, particularly in threatened priority bioregions, to conserve Australia's unrepresented biodiversity, for the protection of refugia and to integrate reserves into the broader landscape matrix. Such investment will assist in protected areas adopting the dual role of preserving species vulnerable to climate change in the short-term and facilitating the adaptation of biodiversity to climate change over a longer period.

The promotion of biodiversity objectives as part of carbon sequestration proposals associated with proposed carbon trading should be a key requirement for industry. Significant potential exists to restore large areas of habitat, assist in the acquisition of protected areas and to foster biodiversity as part of carbon sink creation.

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