Climate change, biodiversity conservation, and the role of protected areas: An Australian perspective

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Abstract. The reality of human-forced rapid climate change presents an unprecedented challenge to the conservation of biodiversity in Australia. In this paper we consider the role of Australia's current protected area network in mitigating biodiversity loss across the continent. We do this by first examining the evolutionary history of Australia's extant fauna and flora and, specifically, the reasons why species have persisted through major changes in climate during repeated glacial cycles, and through the massive climatic changes that occurred during the Miocene and Pliocene climate change events. We then review the current major threats to Australian native species, including inappropriate fire regimes, feral mammalian predators and herbivores, invasive plants, and habitat loss, fragmentation and degradation by land use activities (especially commercial logging, water impoundment and diversion, agricultural expansion, and the intensification of pastoralism). We argue that these current threats are interfering with the natural responses to climate change that native species have relied upon in the past, thereby undermining their resilience in the face of current, human-forced climate change.

We predict that the current approach to conservation planning based on accumulating small amounts of protected lands across the continent, using a set of arbitrary conservation 'targets', will not be effective in mitigating the impacts of human-forced climate change on Australia's biodiversity. We argue that an Australia-wide conservation strategy is needed that incorporates a larger adaptation agenda- one that recognizes the importance of protecting and restoring those natural processes and responses that have enabled species to persist through past environmental change. The following key elements are a crucial component of an effective conservation plan: identifying and protecting important climate refugia (both ecological and evolutionary); conserving the large-scale migration and connectivity corridors that operate at continent scales (including regional networks of habitat patches and habitat 'stepping stones'); maintaining viable populations of all extant species to maximize intra-species genetic diversity and thus options for local adaptation; reducing all current threatening processes at the landscape scale across the continent; and protecting and restoring key large scale ecological processes (especially hydro-ecology and ecological fire regimes). Finally, underpinning climatic adaptation responses must be a thorough understanding of the special role Australia's extensive intact landscapes will play in the future protection of Australia's native biodiversity.

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INTRODUCTION

Australia's landscapes have been evolving for around 60 million years in isolation from other continents. In this time the continent has drifted from higher latitudes towards the equator as the global oceans have gradually cooled, resulting in extensive new sub-tropical environments (Nix 1982). Unlike much of the higher latitudes in the Northern Hemisphere, Australia was only marginally affected by glacial events over the last few million years. A combination of relative climatic 'stability' in parts (Hopper and Gioia 2004) and geographic isolation, during which new habitats have appeared, have contributed to the continent's high level of species (and generic) richness and endemism. Australia is one of only 17 mega-diverse countries that collectively support about 70% of the world's species of plant and animals (Mittermeier *et al.* 1997). While it was settled by humans about 45000 years ago (Kershaw *et al.* 2006) it had not experienced agriculture and pastoralism until the arrival and rapid spread of European settlement over the past 200 years.

Because the major threatening processes to biodiversity are the result of recent change in land use, Australia is one of the few developed countries that remains a leading contributor to the current human-induced global mass extinction event (Wilson 1993; Lovejoy and Hannah 2005). Close to half of all mammal extinctions in the last two hundred years have occurred in Australia (Johnson 2006), while three bird species, four frog species and 61 species of flowering plant have become extinct since European settlement (Australian Bureau of Statistics 2006).

Australia's biodiversity crisis is also evident by the number of native species that have seriously declined in range and abundance since 1788 (the time of European settlement). Approximately 13% of all Australia's known vertebrate species are now listed in Australia's official national Environment Protection and Biodiversity Conservation Act, as either 'threatened' or 'vulnerable' (Table 1) and between 1995 and 2005, the number of terrestrial bird and mammals assessed as extinct, endangered or vulnerable on this list rose by 41% (Australian Bureau of Statistics 2006). These are numbers for concern but a recent regional analysis paints an even direr picture. When the conservation status of all Australian terrestrial vertebrate species listed in one of the IUCN threat classes under (i) state legislation and (ii) non-legislative authoritative assessments (such as national action plans) is tabulated, nearly 45% of all Australia's vertebrate species are in some form of serious decline in one or more parts of their range (Table 1).

This statistic points to the need for regional declines and extirpations to be acknowledged. Currently, these "secret extinctions" often fall below the conservation assessment radar and are not formally recognized at national and international levels of reporting. The potential erosion of intra-species genetic diversity from regional losses is of conservation concern because, among other things, it may reduce the ability of Australia's fauna and flora to respond to future challenges. Given current land cover status and environmental trends (Australian State of the Environment 2006), Australia's biodiversity will be affected in the coming decades by the same suite of global drivers operating on other continents including changes in land use, climate,

Animal class	Freshwater fish	Frogs	Reptiles	Birds	Mammals
The total number of species in each vertebrate animal class for continental Australia	230	214	633	675	378
Species listed under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999; bracketed values indicate % of listed species in each animal class	27 (12%)	26 (12%)	45 (7%)	70 (10%)	99 (26%)
Number of species given any IUCN threat class (except 'least concern') accumulated over all jurisdictions plus non-legislative assessments; bracketed values indicate % of listed species in each animal class.	97 (42%)	92 (43%)	262 (41%)	269 (41%)	214 (57%)

Table 1. A comparison of the difference in the conservation status of Australian terrestrial vertebrate animal species between (a) the Australian Environment Protection and Biodiversity Conservation Act and (b) state and territory legislation plus authoritative national assessments. Adapted from Mackey (2006) and unpublished material. In compiling these statistics consideration was given to vagrants, species that naturally have only marginal distributions in a given jurisdiction, and the arbitrariness of some jurisdictional boundaries.

atmospheric carbon dioxide concentrations, invasive species, and ecosystem dynamics (Sala *et al*. 2000). Note however, that while most trends suggest increasing stress for species and ecosystems, positive responses to climate change are also possible and apparent (Nemani *et al*. 2003).

In order to generate discussion and debate among scientists and policy makers, we here provide an assessment of what is needed to promote the survival of Australia's biodiversity given the prospects for the onset of human-forced, rapid climate change. We first review the interactions between natural climate change and biodiversity in Australia and outline reasons why species have persisted through past climate change events. We then provide an account of the current threatening processes that are leading to wide-scale biodiversity decline in Australia and the breakdown of important natural processes. We then review the current national reserve system to consider its adequacy in conserving Australia's biodiversity into the foreseeable future. In our conclusion we identify a number of strategies we believe are crucial for the development of an effective continental conservation plan. Our focus is primarily on species rather than ecosystems as the units of biodiversity. Some attention is given here to genetic diversity issues, but clearly, further research is needed on the ecosystem dimension of biodiversity-climate change interactions, including the influence of species on the functioning of ecosystem processes (Hooper *et al*. 2005).

THE RELATIONSHIP BETWEEN CLIMATE CHANGE AND AUSTRALIA'S EXTANT BIODIVERSITY

Analysis of fossil records and molecular data has shown that Australia's native plant and animal species are of ancient lineage (leaving aside relatively recent immigrants such as dingoes, *Canis lupus dingo*). The last great vertebrate animal speciation event appears to have been during the Pliocene/early Pleistocene drying and cooling event some 4-1 million years ago, as exemplified by the explosion of song birds and appearance and radiation of rodents on the Australian continent (Norman *et al*. 2007). Most extant marsupial mammal species are derived from groups that appear in the mid- to late- Miocene, some 20 million years ago (Archer and Hand 2006; Osborne and Christidis 2002). Australia's plant species are of similar or more ancient lineage, with the origin of many being traced back to when Australia was part of the super-continent Gondwanaland, over 100 million years ago (Barker and Greenslade 1982; White 1998). Exceptions are the alpine and desert floras which both speciated and recruited in the Pliocene with the advent of cold or extensive dry climates (Barlow 1986; Hill 1994; Hope 1994). These changes have also involved gradual species loss and range restrictions, particularly for rainforest taxa. For example, the *Brassospora* group of *Nothofagus* and gymnosperms such as *Dacridium* and *Dacrycarpus* and their associated faunas disappeared from southern Victoria in the mid-Pliocene and their loss is attributed to increased summer radiation load (Sniderman *et al*. 2007).

Evidence from marine sediments and polar ice cores has revealed the severe climatic oscillations that have occurred over the last 500,000 years (Petit *et al*. 1999). About every 120,000 years, average planetary conditions have oscillated between long glacial periods with low levels of atmospheric CO2, low temperatures and dryness to shorter inter-glacial 'highs' that experienced high levels of atmospheric CO2, higher temperatures and wetness. These glacial-interglacial oscillations revealed in the marine and ice core records are considered to be driven by long term periodic 'wobbles' in the Earth's orbit which changes the balance of solar energy reaching each hemisphere (Muller *et al*. 1997). The transition from glacial to interglacial is speeded up by positive feedbacks from ice melt and oceanic discharge of greenhouse gases (Hansen *et al*. 2007). The ice core record also shows that the transition out of glacial troughs may have been extremely rapid; arguably involving as much as 5°C warming in 20 years (Taylor 1999). There has been a trend to greater variation in moisture within the past 400,000 years with associated changes in fire behaviour (Lynch *et al*. 2007). Although in Australia warm interglacials were formerly associated with higher summer rainfall as evidenced by full interior lakes, the process seems to have failed in our present interglacial, the Holocene (Magee *et al*. 2005). Miller *et al*. (2005) suggest human impact as a possible cause coupled to the extinction of the largest mammals and birds around 45000 years ago. Brook *et al*. (2007) and Burney and Flannery (2005) note a severe and continuing effect of humans on the biota after arrival. In any case, while the causal factors involved in these specific events may remain debated, we can reliably conclude that all native species extant when Europeans first occupied the continent 220 years ago had persisted through all these long term trends and oscillations in temperature, CO2 concentration and wetness.

A number of adaptive responses or strategies can be proposed to explain how species persisted on the continent through past climate and other environmental changes.

1. **MICRO-EVOLUTION**. Evolution is heritable genetic change within populations. It is commonly understood to refer to only long term directional genetic change leading to speciation, that is, the evolution of new species. However, also evident is the evolution of new, fitter traits that represent local adaptations to changing conditions, including climate change, that are not necessarily directional and lead to speciation. There is increasing evidence that micro-evolution is far more rapid, common and widespread than previously recognized (Thompson 2005) and is now occurring in response to rapid climate change (Bradshaw and Holzapfel 2006).
2. **PHENOTYPIC PLASTICITY**. The phenotype is the physical expression in an organism of its genome. Phenotypic plasticity refers to the range of genetically controlled permissible responses with respect to a species' morphological, physiological, behavioural or life history strategies and traits (Nussey *et al*. 2005). An example of phenotypic plasticity is the ability of a plant to change its growth form from a 'tree' to a 'shrub' in response to reduced water availability. Phenotypic plasticity differs from micro-evolution in that the adaptive response is found within the existing genome and is not the result of new, heritable genetic change in the population.
3. **DISPERSAL**. The dispersal of juveniles and seasonal migrations are common ecological activities. However, dispersal – in the sense of long distance movement – to locations that meet a species physiological niche and habitat resource requirements is a common adaptive life history strategy in many species, especially birds (Gilmore *et al*. 2007). In Australia, this is a necessary adaptive response for many species given the great variability in year-to-year rainfall and associated fluctuations in plant growth and the supply of food resources (Berry *et al*. 2007).
4. **REFUGIA AND RANGE REDUCTIONS**. Species can also persist by range reduction to micro-habitats that retain the necessary niche and habitat requirements; so called refugia (Mayr 2001; Lovejoy and Hannah 2004). Locations can function as refugia as a result of species responses to long term or short term environmental change. In Australia, refugia have been documented in the arid zone (long-term climate change related refugia; Morton *et al*. 1995), in temperate forests (fire refugia with respect to fire intervals of decades to centuries; Mackey *et al*. 2002), and monsoonal Northern Australia (annual seasonal refugia; Woinarski *et al*. 2007). The recognition of locations or networks of locations as refugia also invokes issues of spatial scale. For example, Soderquist and MacNally (2000) identified the role of mesic gullies embedded within dominantly drier forested landscapes. Remnant patches in a fragmented landscape can also function as refugia from which organisms can disperse to re-populate habitat as it regenerates following broad scale ecological restoration efforts.
5. **WIDE FUNDAMENTAL NICHE**. It is also possible for species to persist simply because they have evolved very wide fundamental (that is, physiological) niche requirements (*sensu* Hutchinson 1957) and are able to survive, compete and reproduce under a broad range of climatic conditions. For example, many of Australia's forest and woodland birds occur in temperate, subtropical and tropical climatic zones, with the common determinate being vegetation-related habitat resources rather than fundamental niche response to temperate regimes (Keast 1985).

Given the above, can we now assume that Australia's flora and fauna are pre-conditioned to survive global warming impacts and that most species will be able to persist through the human-forced rapid climate change we are now experiencing?

The current rapid 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) with additional effects from particulates and increased albedo (planetary *albedo* is the proportion of solar radiation reflected back into space). It is projected to impose climates not previously experienced in the Pliocene-Pleistocene and could result in entirely new mixes of environmental regimes. These new conditions may impose selective forces for which a species does not possess a suitable genetically programmed adaptive response. Under this scenario, even taxa with a wide fundamental niche may be stressed (adaptation mechanism 4 described above). Nor can there be any guarantee that micro-evolution will generate a solution (adaptation mechanism 1). Second, and probably more importantly, the current rapid climate change coincides with over two centuries of habitat loss and degradation since European settlement of the Australian continent. Intensive land use for forestry, mining and the development of human settlements, along with the extensive use of 54% of the continent for pastoralism has changed vegetation cover dramatically. Since European settlement around 50% of all woodland and forest ecosystems have been cleared and in some productive bioregions 95% of all natural vegetation has been modified or destroyed (NLWRA 2001; Australian Bureau of Statistics 2006).

The combined grazing pressure of domestic and feral livestock has also dramatically changed understorey plant species composition and phenology, increased run-off and proneness to erosion and resulted in the trampling of the tunnels and nests of ground-dwelling animals, throughout Australia (McKenzie and Burbidge 2002; Woinarski *et al*. 2007). Australia's fire regimes have been profoundly changed by loss of pre-European indigenous fire regimes with serious repercussions for fire-sensitive species and ecosystems (Bowman 2000). The invasions of weeds and feral animals over the past two centuries have also heavily contributed to the decline and extinction of many Australian flora and fauna. Two exotic generalist predators (Cat, Felix *domesticus*, and Fox, *Vulpes*

vulpes) have made major contributions to all mammal and bird extinctions that occurred in Australia since European settlement (Dickman 1996; Johnson 2006) while the introduction of the Cane Toad (*Bufo marinus*) has decimated the amphibian and reptile populations in the north of Australia (Woinarski *et al*. 2007). There are now more than 2500 non-native plant species established in Australia (Australian State of the Environment 2006), with the total proportion of feral plants to all plant diversity being 12% (Olson *et al*. 2006). The presence of many of these species is changing the ecological functioning of some native ecosystems (Woinarski *et al*. 2007).

It is beyond this paper to review all of the threatening processes that are currently causing species decline in Australia but it is important to note that there are a myriad of threats leading to both global extinctions and regional losses of Australia's biodiversity. As noted above, regional extirpations represent the loss of local populations of a species and the associated erosion of infra-species genetic diversity is of evolutionary significance (Mayr 2001; Mackey 2006). Regional losses reduce prospects for many Australian species to persist in the face of rapid climate change through either micro-evolution or phenotypic plasticity (adaption mechanisms 1 and 2 described above; also see Mansergh and Cheal 2007). Human-forced climate change has altered species distributions on regional scales in Australia and will continure to do so. It is predicted that by the middle of the next century range shifts due to climate change will commonly span tens of kilometers (Kapelle *et al*. 1999). Paleoecological evidence and future modeling efforts suggests that these range migrations will be individualistic, involving the movement of individual species, not communities (Hannah *et al*. 2007). However, evidence for the significance of co-evolutionary processes is also continuing to emerge (Thompson 2005), and will undoubtedly lead to further surprises being revealed about the complex nature of species responses to climate change, such as the extent to which successful migrations require the accompaniment of co-evolved mutualists or even antagonists. In any case, habitat loss, degradation and fragmentation across Australia means species will find it more difficult to find suitable locations to which they can migrate or take refuge (adaptation mechanisms 3 and 4; Soulé 1990).

In summary, human activities are not only causing climate to rapidly change but over the past two centuries they have interfered with natural processes that would otherwise result in ecosystem processes optimally (*sensu Odum* 1995) re-organising to changing climatic and associated environmental conditions. 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, while in the past, the full complement of natural adaptation mechanisms were potentially available to a species, this is no longer the case.

WILL AUSTRALIA'S NATIONAL RESERVE SYSTEM BUFFER EXTINCTIONS FROM RAPID CLIMATE CHANGE ?

The National Reserve System (NRS) is Australia's premier investment in nature conservation. The system includes public reserves, protected areas on private lands and Indigenous Protected Areas. Currently 11.6% of terrestrial Australia is in IUCN category I-VI reserves (Sattler and Taylor 2008). This is comparable with recommended international targets but the reserve system has not been designed to maximize or even optimize the conservation of biodiversity. Instead, many reserves in Australia have been established for their aesthetic or recreational value and established from land residual to the needs of agriculture, forestry and settlement (Lindenmayer 2007).

In recent years there have been laudable efforts by the Federal and State governments to systematically improve Australia's protected area system, in particular, by promulgating a more systematic approach to the identification and establishment of new reserves for the NRS based on the criteria of comprehensiveness, adequacy and representativeness (Commonwealth of Australia (CAR) 1996; 2005). However, there are a number of reasons why this plan (even if fully implemented) will be unable to "extinction-proof" Australia's biodiversity in the face of extant and imminent threatening processes.

First, only 67% of ecosystems that occur in Australia are represented in the NRS and many of these are small and poorly connected to other natural areas (NLWRA 2002).

Second, the thresholds identified for meeting the CAR criteria reflect an arbitrarily minimalist view on the social, economic and political feasibility of achieving effective, albeit bold, conservation goals. For example, ecosystem surrogates (generally defined in terms of broad classes of native vegetation) are considered 'adequately' conserved when 15% of their pre-European settlement extent are in a protected area. Yet there is no evidence in the scientific literature for the efficacy of this threshold (Commonwealth of Australia 2005), and an ecologically effective target could well be beyond double this figure (Tear *et al*. 2005).

Third, the planning does not take into account the needs of dispersive species whose long term survival depends on protecting the ongoing productivity of 'source' resource areas in multiple and varying locations (Woinarski *et al*. 1992; Soulé *et al*. 2004; Gilmore *et al*. 2007). The habitat resources needed by these species are not necessarily found in or do not persist reliably within the same landscape, and are distributed across land tenures.

Fourth, the NRS does not take into account large-scale ecological processes important for the conservation of biodiversity, either because they constitute evolutionary selective forces to which species are adapted (i.e. fire and hydrological regimes), or because they sustain and replenish the habitat on which animals depend (e.g. hydro-ecology) (Soulé *et al*. 2004; Mackey *et al*. 2007).

We conclude that the National Reserve System is neither large enough, nor will be large enough even if the NRS 15% target is met, nor is it being designed to meet the challenges to biodiversity conservation from climate change. Indeed, the inadequacies of the NRS are evident even before considering the potential impact of rapid climate change (Mackey 2007). Give this, how can the effectiveness of NRS planning be improved in the face of rapid climate change and other threats?

SIGNIFICANTLY EXPANDING THE CURRENT NATIONAL RESERVE SYSTEM AND ASSIGNING PRIORITY TO PROTECTING LARGE, INTACT LANDSCAPES

Systematic planning tools should used be used to identify new reserves designed to meet specific conservation goals (Bruner *et al*. 2001; Pressey and Cowling 2001). A primary goal needs to be the maintenance of viable populations of all extant species across natural ranges in order to maximize intra-species genetic diversity and thus allow options for local adaptation and phenotypic plasticity. This requires replicating habitats in the reserve system so as to protect multiple source populations across the environmental gradients occupied by the species.

Another important goal of an effective continental wide plan for the reserve system will be the identification and protection of refugia, including micro-habitats supporting relictual species (Morton *et al*. 1995; Pressey *et al*. 2007). Past climate change has resulted in some species experiencing dramatic range reductions and these now only occur in networks of scattered locations that retain suitable conditions at a micro-scale. Refugia may prove critical in assisting certain species to persist through future rapid climate change as they provide a degree of additional resilience (*sensu* Holling 1996). In Australia, refugia are often wetter locations and/or with diverse topography (e.g. groundwater discharge points, run-on areas, escarpments) that may well help buffer a drier future climate, as has been projected for many parts of the continent (CSIRO 2007). While some of Australia's protected areas contain recognized refugia, many locations that function as refugia are not under any form of protection (Mackey *et al*. 2002). The prospect for rapid climate change accentuates the need for including refugia in the goals of systematic conservation planning for an expanded Australian NRS.

A revised set of conservation goals for an expanded NRS must also reflect a scientific understanding of the special role Australia's extensive intact landscapes will play in the future protection of Australia's native biodiversity (Soulé *et al.* 2004, Mackey *et al*. 2007). Large geographical regions of the Australian continent retain a continuous cover of native vegetation and therefore lack the massive habitat loss and fragmentation which are the principle drivers of biodiversity loss in many parts of the world (Fahrig 1997), and other regions within Australia (Glanznig 1995). This high level of natural connectedness improves the likelihood of survivorship of species by supporting large populations and a range of microhabitats. The ecosystems of extensive and intact lands will play a vital role in facilitating natural adaptation responses by species to human-forced climate change (Soulé and Terborgh 1999). In particular, mobile species will have more habitat options as they disperse to find suitable locations in response to rapidly changing climate.

Currently, large and intact landscapes are not recognized as a high priority for new reserves in Australia (Commonwealth of Australia 2005) because conservation investments are being directed to threatened species and ecosystems in land that has been highly disrupted by past land use. We argue the inverse, namely, that intact landscapes must become the highest priority for a continental-wide conservation plan. An example is the Kimberley region (in far north-west Australia) which is one of the few bioregions in Australia that retains its full complement of native mammal fauna (Woinarski *et al*. 2007) yet is not considered a priority under the NRS programme. Under the current approach, the Kimberley region will only become a priority after intensifying land use has caused significant habitat loss, fragmentation and degradation and vertebrate species have been severely reduced in numbers and range such that they are officially recognized as threatened. It is more cost effective to protect intact landscapes compared to restoring heavily degraded land, and there are more, higher quality options for reserves.

ENSURING ECOLOGICAL CONNECTIVITY IS MAINTAINED ACROSS THE CONTINENT

A further additional goal for an effective continental-wide conservation plan is maintaining and restoring large scale ecological phenomena, flows, and critical processes that sustain habitat resources, constitute selective forces to which species are adapted, or otherwise influence community composition. These 'connectivity' processes include: maintaining ecological functional populations of highly interactive species in the landscape (i.e. trophic regulators), understanding the habitat requirements of dispersive fauna; and maintaining natural fire and hydro-ecological regimes (Soulé *et al*. 2004; Mackey *et al*. 2007). Hydro-ecology warrants further comment, given that the distribution and availability of water is the principle environmental constraint, and thus determinant, of biology and ecology in Australia. Water availability determines rates of photosynthesis and biomass production, the 'fruits' of which propagate through the entire food chain (Berry *et al*. 2007). The vegetation cover in turn influences water infiltration, soil water storage, and catchment water budgets.

Figure1.
An example of one of Australia's intact landscapes: the Great Western Woodlands of southern Western Australia. Image courtesy of Charles Roche.

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 (Woinarski *et al*. 2007). Both surface water catchment boundaries and groundwater recharge/discharge zones transcend protected areas boundaries and, like other key landscape processes, demand a whole-of-landscape approach to their maintenance and for the persistence of the flora and fauna that they sustain over broad areas. Diversion of water resources for human use away from environmental flows changes natural hydro-ecological processes and has profound impacts on associated species and ecosystems (Kingsford 2000).

Maintaining the special habitat requirements of dispersive species will be particularly important in the face of rapid climate change. In addition to migrants, eruptives and nomads, many species are also facultative when conditions demand they migrate to find suitable conditions (Gilmore *et al*. 2007). As noted above, the habitat loss, fragmentation and degradation now present in Australia presents significant impediments and barriers to species that may need to disperse and find new habitats or refugia (Bennett *et al*. 1992; Mansergh and Cheal 2007). The current network of protected areas is geographically unconnected, 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 use unsympathetic to the movement of biodiversity.

Therefore, an important component of an overall conservation strategy is the protection and/or restoration of large-scale migration corridors that operate at regional and continent scales. Where habitat connectivity has already been largely disrupted through broad scale land clearing (such as in the temperate woodlands of south eastern Australia), it is imperative that large scale rehabilitation of land cover conditions and land use between existing nature reserves becomes an integral part of the conservation framework. These intervening lands need to become more conducive to biological permeability and associated ecological and evolutionary processes. In this context, restoration will include development of regional networks of habitat patches, habitat corridors and habitat 'stepping stones'. If migration corridors are not protected and/or restored across broad zones in the fragmented landscapes of Australia, the only other management option available for many species will be translocation with associated costs, risks and potential problems.

REDUCING THREATS IN THE LANDSCAPE ACROSS AUSTRALIA

Natural adaptive responses by species will be facilitated by reducing in the landscape the current threats to biodiversity. Necessary conservation actions include: halting and reversing land clearing as this will help prevent further loss and fragmentation of core habitats and migration corridors (Soulé *et al.* 2004); developing policies that lead to removal of unsustainable extractive land use activities (primarily livestock grazing and logging) (Woinarski *et al*. 2007; Lindenmayer 2007) thereby preventing further habitat degradation; halting further large scale impoundment and diversion of water (Mackey *et al*. 2007); controlling invasive weeds and animal pests (Woinarski *et al*. 2007); and implementing ecologically appropriate fire regimes (Soulé *et al*. 2004). Furthermore, rapid climate change may make many existing threats worse (e.g. exotic species invasions may be enhanced if native ecosystems come under stress) and plans must be in place to take this into account.

Some of the current threatening processes will be eliminated by creating additional protected areas, promoting biological permeability, and restoring ecological processes, in the surrounding landscape through more appropriate land management. However, some threats (like pests and weeds) must be managed both on and off reserves. Threat management has to be coordinated across land management agencies and land tenures at appropriate scales. A new, co-operative and integrated approach to planning is needed, in addition to current initiatives, so that the threatening processes that affect multiple bioregions are dealt with systematically and as effectively as possible (Worboys 2007). The concept of systematic conservation planning must therefore be expanded to include the problem of optimizing conservation management across land tenures in a coordinated way with any expansion of the reserve system.

Extending systematic conservation planning to private, Indigenous and freehold land will require innovative mechanisms that offer incentives to land owners and stewards, such as voluntary covenants and negotiated special leasehold conditions. Furthermore, the concept of economically valuing ecosystem services (such as regulation of water quality and supply) is now well recognized (Costanza *et al*. 1997). The likelihood that carbon will soon have a market price may well transform the economics of land management in Australia and provide new opportunities to fund the protection and restoration of native vegetation habitat (Mackey *et al*. 2008a).

CONCLUSIONS

Ultimately, it is the natural adaptation responses 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, in Australia, this potential adaptation capacity is being degraded and interrupted by the same forces driving the current biodiversity extinction crisis. The prevailing national strategy for biodiversity conservation hinges on (a) accumulating relatively small areas of additional protected lands across the continent, using a set of arbitrary conservation 'targets' and (b) the development of 'recovery plans' for a few priority threatened species. While necessary, we doubt these steps will be sufficient to effectively mitigate the impacts of human-forced climate change on Australia's biodiversity.

We argue that the foundation of an effective climate adaptation conservation strategy is the development of a whole-of-continent conservation plan. In such a plan, the protected area network will remain the cornerstone and central element. A greatly expanded protected area network is needed to ensure, among other things, all landscape ecosystems types are represented (see discussion in Mackey *et al*. 2008b), intra-species genetic diversity is maintained, refugia are protected, and populations of functionally significant species are of a size to be ecologically effective. Then, the challenge is to promote conservation management across all land tenures in ways that better buffer and link reserves, and protect and restore important habitat that resides in the broader landscape matrix. Systematic conservation planning must move beyond prioritizing additions to the national reserve system by adding to its tool kit mechanisms for off-reserve conservation management such as payments for ecosystems services, covenants on private land and changes to leasehold conditions. A national conservation plan must incorporate a "big picture" agenda that is holistic and recognizes the importance of protecting and restoring those natural processes and responses that have made species resilient to climate change in the past. In this context, the future use and management of currently intact lands warrants special consideration. Such investments will enhance the role protected areas play in helping biodiversity persist into an environmentally uncertain future.

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