

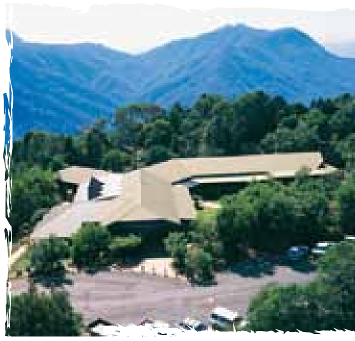


Connectivity conservation and the Great Eastern Ranges corridor

Prepared by Brendan Mackey, James Watson and Graeme L Worboys of ANU Enterprises Pty Ltd

An independent report to the Interstate Agency Working Group (Alps to Atherton Connectivity Conservation Working Group) convened under the Environment Heritage and Protection Council/Natural Resource Management Ministerial Council

National Library of Australia Cataloguing-in-Publication entry

Bibliography.

Includes index.

ISBN 978 1 74232 216 2

1. Environmental policy – Australia 2. Environmental science – Australia 3. Connectivity conservation – Australia 4. Environmental management – Australia I. Australia. NSW Department of Environment, Climate Change and Water

Citation

Mackey B, Watson J and Worboys GL of ANU Enterprises Pty Ltd 2010, *Connectivity conservation and the Great Eastern Ranges corrido*r, an independent report to the Interstate Agency Working Group (Alps to Atherton Connectivity Conservation Working Group) convened under the Environment Heritage and Protection Council/Natural Resource Management Ministerial Council.

Acknowledgments
The report has been independently peer reviewed and the authors have taken into account comments of the reviewers.

Cover photos: main photo – M. Van Ewijk; top to bottom – D. Perryman, DECCW, DECCW.

Published by:
Department of Environment, Climate Change and Water NSW
59–61 Goulburn Street, Sydney
PO Box A290
Sydney South 1232
Ph: (02) 9995 5000 (switchboard)
Ph: 131 555 (information & publications requests)
Fax: (02) 9995 5999
TTY: (02) 9211 4723
Email: info@environment.nsw.gov.au
Web: www.environment.nsw.gov.au/ger/index.htm

DECCW 2010/59
March 2010
Printed on environmentally sustainable stock

Contents

List of tables and figures

Figures

Tables

Preface

There has been increasing interest over recent years in the concept of connectivity at a continental scale, particularly as a response to improving the resilience of our biodiversity and ecosystems to the anticipated impacts of climate change. In 2006, the Environment Heritage and Protection Council (EPHC) considered the issue of a possible continental-scale corridor extending along Australia's great eastern ranges from Victoria through NSW to Atherton in Queensland.

The EPHC established an Interstate Agency Working Group (Alps to Atherton Connectivity Conservation Working Group) comprising the following members:

- New South Wales – Ian Pulsford (Convenor), Department of Environment, Climate Change and Water
- Commonwealth – Dr Charlie Zammitt, Department of Environment Water Heritage and the Arts
- Queensland – Anita Haenfler, Department of Environment and Resource Management
- Australian Capital Territory – Sharon Lane, Department of Municipal Services and Environment
- Victoria – Nina Cullen, Department of Sustainability and Environment, and Phil Peggler, Parks Victoria.

The Interstate Agency Working Group agreed that there was a need for a 'proof of concept' report outlining the scientific principles that underpin the concept of a continental-scale connectivity conservation approach to Australia's great eastern ranges. It was also agreed that the report should be undertaken by an independent internationally recognised Australian scientist.

Following a decision of the EPHC in April 2008, the Interstate Agency Working Group now reports to the Natural Resource Management Ministerial Council (NRMMC).

Terms of reference for independent report

This report's main aim is to review the scientific basis for the connectivity conservation approach that underpins the proposal for Australia's first continental-scale connectivity conservation corridor from the Australian Alps to the Atherton Tablelands and beyond. The report was commissioned by the Department of Environment, Climate Change and Water NSW on behalf on the Interstate Agency Working Group in October 2007 with specific terms of reference. These are listed in '1 Introduction' on page 5 of this report.

Executive summary

Background

In 2006, the Environment Heritage and Protection Council (EPHC) first considered the idea of a possible continental-scale conservation corridor extending along Australia's great eastern ranges from Victoria through NSW to Atherton in Queensland.

The EPHC established an Interstate Agency Working Group to progress the concept. The Working Group agreed that there was a need for a 'proof of concept' report outlining the scientific principles that underpin the concept of continental-scale connectivity conservation, such as the concept proposed for the great eastern ranges.

Professor Brendan Mackey, Dr James Watson and Dr Graeme Worboys of ANU Enterprises Pty Ltd were commissioned to write this report, now entitled *Connectivity conservation and the Great Eastern Ranges corridor.* The report's terms of reference included:

- clarifying the scientific basis for the concept of connectivity conservation
- examining the capacity of continental-scale connectivity conservation to maintain or enhance landscape resilience given threatening processes including climate change
- identifying the kinds of species and ecosystem services that would most benefit from connectivity conservation and their contribution to landscape resilience
- developing generalised connectivity conservation principles and design criteria.

Key conclusions and recommendations

- Connectivity conservation is based around the concept of 'landscape corridors' that maintain or establish multi-directional and multi-scale connections over entire landscapes and can encompass up to thousands of square kilometres. Connectivity conservation extends the concepts of biodiversity and biological corridors to the landscape scale. Elements of a landscape corridor include dispersal corridors (such as corridor networks and habitat corridors) and ecological corridors (which focus on landscape permeability for ecosystem processes).
- The review concluded that there is strong scientific basis for connectivity conservation based on theoretical and empirical findings in Australia and internationally. Connectivity conservation builds upon the existing foundations of conservation science, which include:
  - biological theory concerning the genetics, dynamics and viability of populations
  - the equilibrium theory of island biogeography and metapopulation theory
  - macroecology (the emergent statistical properties of ecological data sets)
  - knowledge of historic, environmental and evolutionary biogeography.

  Connectivity conservation is a logical extension of these foundations which is necessary given the scale of the current biodiversity extinction crisis and the potential synergistic impacts of climate change.
- A revised conservation science consensus is beginning to emerge in response to the limitations of conservation efforts to date and the enormity of the challenge. The term 'connectivity conservation' is now being widely used to capture this emerging scientific consensus among researchers and practitioners. A connectivity conservation approach recognises that:
  - conservation management is needed on the lands around formal protected areas to, among other things, buffer them from threatening processes originating off-reserve and to care for biodiversity assets found on other land tenures
  - on land that has been heavily cleared and fragmented, there is a need for large-scale ecological restoration and rehabilitation so that protected areas do not remain isolated islands and 'extinction vortices'
  - in largely intact areas, the option remains to maintain ecological integrity *in toto* through a combination of formal protected areas and complementary off-reserve conservation management areas

  - systematic conservation planning must factor in the conservation requirements of large-scale, spatially dependent, ecological and evolutionary processes essential for the long-term persistence of biodiversity; among other things, these processes help sustain and regenerate wildlife habitat.

- Case studies from the Bega Valley, north-eastern NSW and central Queensland help illustrate the conservation challenges facing much of the great eastern ranges (GER) corridor. There are significant areas of intact native vegetation, but extensive habitat clearing, fragmentation and degradation have also occurred. Many of the more biologically productive landscapes have been cleared for, or are subject to, ongoing land-use activities. Habitat fragmentation and degradation are therefore ubiquitous outside the protected area network. Population numbers of many mammal species have been dramatically reduced since European settlement, and significant regional extirpations have also occurred, resulting in impoverished community assemblages and loss of associated ecosystem functions.
- The best response to the threats of habitat loss and degradation is to retain natural lands in an undisturbed condition. The second most important response is to retain strategic interconnections to make habitat remnants both bigger and less isolated. However, habitat rehabilitation strategies still need to consider conservation management in the broader landscape matrix. Management of the land surrounding remnant habitat patches can also be critical for some threatened species in the fragmented landscapes of eastern Australia, for a number of reasons. It can contain habitat and resources for species with specific needs or large territories that cannot otherwise be found in the remnant patches. In addition, it can be a movement conduit for some species, thus reducing the negative effects of habitat isolation. When the matrix is not managed to meet the needs of species it can become simply too hostile for native species to survive and these landscapes experience higher extinction rates in habitat fragments than in more appropriately managed landscapes.
- Australia's native species have used various life history strategies and responses to persist through past climate change events such as local adaptation, long distance dispersal and range contraction to refuges. However, the problem is that climate change overlays a suite of other serious human-caused threatening processes – especially habitat loss, fragmentation and degradation; the introduction of feral animals and invasive plants; and changed fire and hydrological regimes. These threatening processes are interfering with the natural adaptation processes that enabled species to persist through previous climate change events. Ecologically interconnected and intact natural lands maximise the opportunities for species to positively respond to climate change. The GER corridor provides an opportunity for coordinated, large-scale responses to the challenges of climate change.
- Appropriate conservation management can lead to the GER corridor making a significant contribution to Australia's national carbon accounts by protecting forest and other ecosystem carbon stocks and avoiding depletion of these stocks from emissions associated with land use activities, allowing forests and other ecosystems with depleted carbon stocks to regrow to reach their carbon-carrying capacity, and by further increasing the stock of carbon stored in the GER corridor ecosystems by promoting permanent native revegetation.
- The mountainous and upland areas of the GER corridor contain headwaters that capture the most reliable rainfall in eastern Australia. The ongoing quality and supply of water are fundamental to the human health and economic development of Melbourne, Sydney, Brisbane and all coastal towns and cities between Eden and Cairns. GER corridor connectivity conservation planning can therefore contribute to ensuring the healthy functioning of Australia's most important water catchments. The type and condition of the vegetation cover are major factors influencing catchment hydrology and the quality and flow of water.
- The following principles characterise the connectivity conservation approach:
  - connectivity conservation initiatives focus on geographically extensive areas that are at least supra-regional in scale, and can extend to continental and intercontinental scales
  - the landscape matrix serves a number of critical functions
  - projects aimed at buffering and de-islanding should give priority to first securing extant native habitat

- ecological connectivity and biological permeability can be facilitated in the landscape matrix through promoting conservation management
  - achieving conservation outcomes across the landscape matrix involves active management
  - connectivity conservation initiatives invariably involve achieving conservation outcomes in an integrated way across a range of land tenures
  - financing of connectivity conservation initiatives may be achieved from a diversity of sources in addition to conventional budget allocations
  - increasingly, the climate change imperative is becoming a prime motivating factor for connectivity conservation initiatives which are seen as long-term strategic approaches to biodiversity conservation.

- Systematic conservation planning undertaken for the GER corridor should incorporate the following conservation goals:
  a) maintaining viable populations of all extant species and natural infra-species genetic diversity and thus options for local adaptation
  b) identifying and protecting relic and other types of refuges
  c) accounting for the special role of extensive intact lands in the future protection of Australia's biodiversity
  d) maintaining or restoring large-scale ecological and evolutionary phenomena, flows and processes
  e) strategic monitoring throughout the GER corridor to demonstrate the effectiveness of connectivity conservation management and to identify trends in threatening processes.

- Connectivity conservation provides a conceptual framework for breaking free from minimalist thinking that risks locking protected areas into an ever-tightening extinction vortex. Nonetheless, at any given point in time, difficult choices must be made regarding the most efficient investment of available resources for conservation efforts. In the case of GER, the spatial priorities in and around the connectivity area will vary from time to time depending on, among other things, the availability of resources, changing threats, and the likely benefits and costs of alternative investment options. Connectivity conservation and its effective management provide an opportunity for a fresh look at land use and the long-term needs of biodiversity conservation.

1 Introduction

The great eastern ranges corridor (hereafter, the GER corridor) – which extends from the mountains of Victoria to the Atherton Tablelands in far north Queensland – is a large-scale conservation vision for eastern Australia. The GER corridor envisages the systematic protection and restoration of biodiversity assets and associated processes from the mountains of Victoria in southern Australia (near Melbourne) to the Atherton Tablelands of Queensland, and potentially extending further north up through the eastern section of the Cape York Peninsula (Figure 1).

As discussed below, creating an integrated continental-scale conservation initiative for the ranges and associated land systems of eastern Australia will bring multiple benefits for biodiversity conservation. We hope the GER corridor's bold scope will inspire all landowners and managers to contribute to conservation efforts in a coordinated way and help build a broader base of public support for biodiversity activities. We can also anticipate significant social benefits. From an economic perspective, the GER corridor will contribute to the health and livelihoods of Australians through facilitating the wise management of ecosystems and the services they provide, in particular carbon sequestration and regulation of water supplies. The NSW Government's Alps to Atherton corridor proposal was keenly received by all Environment Ministers at the November 2006 meeting of the Environment Protection and Heritage Council. Ministers agreed to cooperate and to establish an interstate agency working group to further develop the concept and investigate how it might be implemented.

The general location of the GER corridor is shown in Figure 1. Its geography is defined relative to the two major physiographic features that run in parallel for more than 2,800 kilometres north–south along most of the eastern continental edge, namely, the Great Dividing Range and the Great Escarpment of Eastern Australia. Both of these features provide the 'spine' for identifying landscapes that fall within the scope of the GER corridor. Appendix 1 gives a more detailed account of the regions that are encompassed by the GER corridor, and associated issues.

This report's main aim is to review the scientific basis for the connectivity conservation approach that underpins the GER corridor. The report was commissioned by the Department of Environment, Climate Change and Water NSW (DECCW) on behalf of the Interstate Agency Working Group (Commonwealth, Queensland, Victoria, ACT and NSW) in October 2007 with the following specific terms of reference:

1 Clarify the scientific basis for the concept of connectivity conservation; (a) Clarify the alignment between connectivity conservation and other forms of biodiversity conservation, including through the protected areas estate and through complimentary conservation on private lands.

2 Summarise the findings of research, including those for the eastern Australian biophysical environment, examining the capacity of continental-scale connectivity conservation to maintain or enhance landscape resilience through ecosystem function and services over the long term; (a) As far as is practicable, take into account the resilience of Australian species, the impacts of past human activities and human-induced impacts, including land use intensification and climate change.

3 As far as is practicable, identify the kinds of species and ecosystem services that would most benefit from connectivity conservation and their contribution to landscape resilience.

4 Develop generalised connectivity conservation principles and design criteria, taking account of the various biophysical characteristics of eastern Australia from the western foot slopes of the great eastern ranges to the east coast; (a) Include criteria addressing inclusion of areas within corridors that are cleared or include non-remnant ecosystems.

5 As far as is practicable, outline the economic, social and cultural benefits of continental-scale connectivity conservation of the great eastern ranges.

Sections 2 to 5 that follow are structured to address each of these five terms of reference.

Figure 1: **The proposed great eastern ranges corridor (the GER corridor), extending more than 2,800 kilometres from the Australian Alps near Melbourne to the Atherton Tablelands near Cairns and beyond in far north Queensland.**

Note: the GER corridor encompasses most of Australia's mainland forest biome and hence forest-dependent flora and fauna.

2 The scientific basis

2.1 Background

The Earth is currently experiencing the sixth massive extinction event of its evolutionary history and the first for 65 million years (Wilson 1992, 2002). This new geological era, now known as the Anthropocene, is unique in terms of the speed and breadth of extinctions and because the cause is the actions of just one species: *Homo sapiens sapiens* (Houghton 1994; Cardillo et al 2004). The current rate of species extinction is estimated to be 1000 times greater than it would be under the influence of natural disturbances (MEAB 2005). The International Union for Conservation of Nature 2007 Red List, an annual report on the conservation status of the world's species, shows that one in four mammals, one in eight birds, and one in three amphibians are now in danger of extinction (IUCN 2007a).

Unfortunately, the conservation status of Australia's biodiversity tracks the global situation. Close to half of all mammal extinctions that occurred on the planet in the last 200 years have occurred in Australia (Johnson 2006; Johnson et al 2007), and three bird species, four frog species and 61 species of flowering plant have become extinct since European settlement (ABS 2006). Australia's biodiversity crisis is also evident due to the number of native species that have seriously declined in range and abundance since European settlement. Approximately 13% of all Australia's known vertebrate species have been listed in Australia's national *Environment Protection and Biodiversity Conservation Act 1999* as either 'threatened' or 'vulnerable', and the number of terrestrial bird and mammals assessed as extinct, endangered or vulnerable on this list rose by 41% in the last decade (ABS 2006).

The known species extinctions that Australia has experienced since European settlement have been largely in the arid/semi-arid climatic biome. However, significant loss of biodiversity has also occurred in the forest and woodland biomes in terms of local extirpations of populations and community assemblages, and degradation of ecosystem functionality. This local loss of biodiversity is partly recognised by the species and ecosystems that are formally recognised as threatened by each State, as distinct from being listed nationally as threatened with global extinction. However, the extent to which local extirpations of populations correspond with the loss of (a) infra-species genetic diversity or (b) co-evolved (and hence genetically based) species interactions is largely unknown.

Land-use change has been identified as the root cause of biodiversity loss (Sala et al 2000). The human population has increased six-fold since the 1800s, and Earth has been transformed to accommodate human habitation and meet rising consumption (Ehlrich and Ehlrich 2002; Ehlrich 2003). A human footprint is now detectable across 83% of the land area of the world (excluding Antarctica) (Sanderson et al 2002) and an attempt to map large (defined as greater than 4000 square kilometres), undeveloped wild areas (lands dominated by natural processes) globally estimated that such areas constitute only 16% of the land on Earth outside the polar regions (McCloskey and Spalding 1989). Where predominantly natural land on Earth does remain, it is often in fragmented patches and rarely contains the biodiversity that existed in the region before fragmentation (Laurance and Bierregaard 1997; Mittermeier et al 2003).

The destruction, degradation and fragmentation of natural habitats associated with agriculture and urbanisation has been the main direct threat to species and cause of extinction (Wilcove et al 1998; Lindenmayer and Franklin 2002). Habitat fragmentation is arguably the most insidious of these threats, as the process can occur through what are considered 'minor' human activities (such as building roads) and often results in time lags before extinction occurs, resulting in a false sense of security (Whittaker et al 2005; Lindenmayer and Fischer 2006). Fragmentation of habitat reduces the total amount of habitat available and simultaneously isolates the remaining habitat. This prevents movement of organisms and disrupts ecological processes in previously connected landscapes (Whittaker 1998; Bennett 2003). The remaining habitat fragments are often too small or isolated to maintain viable populations of species. There are examples throughout the world of demographic, environmental and genetic forces, whether random or deterministic, acting in concert to create a 'vortex' of extinction in fragmented, isolated populations (Gilpin and Soulé 1986; Bierregaard et al 2001).

An alarming aspect of the current biodiversity crisis is that the effects of human-caused climate change on species and ecosystems are only recently being felt. There is now irrefutable scientific evidence that emissions of greenhouse gases through human actions are causing an ongoing rise in the average planetary temperature (IPCC 2006, 2007a, b, c). Of great concern is the fact that Earth is entering the high end of scientific projections for global climate change. An Australian Bureau of Agricultural and Resource Economics report, commissioned by the Commonwealth Government for the APEC conference, proposed that we will most likely enter an 'enhanced technology' scenario that would result in global greenhouse gas emissions rising about 60% above 1990 levels by 2050 (ABARE 2007). The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) indicates that such an increase in emissions would result in a rise in long-term average global temperature of between 3.2 and 4.9 ºC above pre-industrial levels (IPCC 2006).

It is inevitable that a rapidly changing global climate will place increased stress on Earth's biodiversity. Recent studies claim that current and future global climate change will be the primary driver of species extinctions in the near future (Sala et al 2000; Lovejoy 2005; Thuiller et al 2005). There is evidence that human-forced global warming is already having an impact on species (Parmesan et al 1999; Parmesan and Yohe 2003; Root 2003; Thuiller et al 2006). Given the uncertainty about the precise nature of climate change at a regional scale, it is becoming clear that species' responses to climate change are likely to vary enormously, depending on the species' geography, tolerance to extremes, ecological versatility, and genetic adaptability (Hill et al 2002; Thomas et al 2004; Midgley and Thuiller 2005). At a minimum, it can be anticipated that shifts in latitudinal and altitudinal species distributions will lead to species-level changes in phenology, behaviour, morphology and physiology (Walther et al 2002; Walther 2004). There will be repercussions for biotic interactions, including, among others, host-pathogen dynamics (Pounds and Crump 1994; Pounds et al 2006). Changes at the community level can therefore be anticipated in assemblage structure (Ehlrich and Ehlrich 2002; Parmesan and Yohe 2003; Peterson 2003).

Climate change, including rapid climate change, is part of the story of life on Earth and a range of natural adaptation processes has enabled many species to persist through multiple cycles of warming and cooling, especially through the Pleistocene era (Dechaine and Martin 2005, 2006; Mackey 2007; Mackey et al 2008a). Unfortunately, it can be anticipated that the threatening processes underpinning current biodiversity will interfere with the natural adaptive processes that have enabled many species to persist through past climate changes (Opdam and Wascher 2004). For example, habitat loss and fragmentation increase the vulnerability of species by reducing overall population size. Furthermore, the life history characteristics of many invasive plants and feral animals may be better suited to the new conditions resulting from climate change. Consequently, predictions of the consequences of such interactions are calamitous, with one report suggesting that approximately 20–30% of plant and animal species assessed so far are likely to be at increased risk of extinction if increases in global average temperature exceed 1.5 to 2.5 ºC, and that such average increases are now almost inevitable (Thomas et al 2004; see also discussion in Steffen et al 2009).

2.2 Conventional conservation thinking

The conservation of biodiversity is now a mainstream social concern supported by all major political parties, with supporting legislation, policy and publicly funded programs at all levels of government. However, it is also recognised that too few resources are invested in conservation programs, given the magnitude and urgency of the biodiversity extinction crisis (Sanderson et al 2006). The Convention on Biological Diversity (CBD) ratified by Australia in 1993 was a significant response by the international community for dealing with the continuing loss of biodiversity. It is a multi-tiered approach to biodiversity conservation, with Article 8 of the Convention specifically requiring each signatory party to pursue *in situ* conservation by establishing a national system of protected areas. Establishing protected areas is a necessary strategy for biodiversity conservation, as by definition no other land-use category has the same potential to stem the impact of inappropriate human activities (Ricketts et al 1999; Lindenmayer and Franklin 2002; Soulé et al 2004; Worboys et al 2005).While it is the CBD's principal tool for the conservation of biodiversity, the CBD program of work for protected areas (Dudley et al 2005) recognises there are limitations to protected areas and more needs to be done.

Although there are more than 110,000 protected areas (around 11.5% of terrestrial Earth) (UNEP-WCMC 2009), it is recognised that the size and number of conservation reserves do not provide sufficient protection for global biodiversity (Rodrigues et al 2004a; 2004b). In addition, the establishment of comprehensive and representative reserve systems worldwide is unfinished, and it is one of the key targets of the CBD program of work for protected areas (Dudley et al 2005). A common historical legacy throughout the world is that most protected areas have not been explicitly designed for the long-term protection of biodiversity, though there are notable exceptions such as the Land Conservation Council of Victoria process of reserve selection (Worboys et al 2005). Instead, many reserves have been created in response to aesthetic or recreational values and without explicit reference to the needs of species and ecosystems. In addition, most of the biologically productive landscapes in high Human Development Index countries (UNDP 2005) have been converted to agricultural and other uses, and are privately owned (Mittermeier et al 2003; Recher 2004). The species inhabiting these productive areas are often extremely under-represented in the protected area system, and there is little opportunity to create adequate reserves for them (Lindenmayer 2007).

Despite significant advances in systematic conservation planning (Possingham et al 2006), a ‘reductionist world view’ generally frames the over-arching conservation goals these tools are calibrated against. Conservation planning therefore often, albeit unwittingly, falls into a ‘minimalist trap’ (*sensu* Sanderson et al 2006) as the conservation targets that are set are not necessarily based on a robust scientific understanding of what is needed for the long-term conservation of biodiversity (Soulé and Sanjayan 1998; Rodrigues and Gaston 2001; Pressey et al 2003, 2004; Brooks et al 2004; Svancara et al 2005). Conservation programs based on inadequate conservation targets can create a false sense of security about the conservation status of a region’s biodiversity.

Halting and reversing the biodiversity extinction crisis requires a shift away from conventional minimalist conservation approaches (Groom and Grubb 2002; Sanderson et al 2006). Rather, explicit priority must be given to the long-term needs of species and ecosystems. At the species level, we now have a better understanding of requirements to promote both the viability and ecological effectiveness of populations (Soulé et al 2003). At the ecosystem level, the concept of system resilience has found currency among conservation planners and managers (Walker and Salt 2006). In its simplest interpretation, ‘resilience’ is the ability of a system to absorb external perturbations without changing into a fundamentally different state (Holling 1994, 1996). A necessary requirement for ecosystem persistence is for there to be sufficient resilience within the system to absorb or adapt to the external drivers of change. Genetic diversity and species richness give ecosystems resilience by increasing the likelihood that a population is present that is best suited to the changed conditions and can continue contributing to critical ecological functions (Naeem 1998; Johnson 2000). Human land-use impacts can reduce ecosystem resilience and result in dramatic shifts to less species-rich and lower productivity states (Hooper et al 2005).

The mix of system responses from multiple human impacts can be complex and difficult to predict. Human disturbances can be both direct, such as habitat loss and fragmentation, and indirect, including the various flow-on effects from human-forced climate change (Folke et al 2004). Climate change presents a new suite of considerations that must now be factored into systematic conservation planning. The conservation requirements of spatially related evolutionary as well as ecological processes must be considered (Moritz 2002; Cowling and Pressey 2003; Soulé et al 2004; Mackey et al 2007). From an evolutionary perspective, conservation planning must consider, among other things, phylogenetic lineages and concentrations of historically isolated populations, as well as contemporary genetic flows between meta-populations (Faith 1992; Davis et al 2007; Forest et al 2007; Mace and Purvis 2008).

In a recent analysis, the amount of habitat loss exceeds the amount protected by a ratio of 10 to 1 in more than 140 of 810 global ecoregions studied (Hoekstra et al 2005). Most of these protected areas exist as islands in an altered or fragmented landscape, fulfilling the theoretical expectations of MacArthur and Wilson’s (1967) equilibrium theory of island biogeography. Long-term monitoring has shown that some of the best known and relatively large protected areas are failing to maintain minimum viable populations, especially of large animals, over the long term (Khan 1995; Newmark 1995; Recher 2004). Yellowstone National Park, for example, the largest national park in the contiguous United States of America, is too small to support viable populations of large carnivores in the long term (Newmark 1987).

Park managers and conservationist scientists have also realised that reliance on site-based strategies alone (i.e. a small number of protected areas under various management schemes) results in conservation reserves being vulnerable in the landscape, given the scale of threats to their long-term survival (Allen and Starr 1982; Worboys et al 2005). Modified landscapes surrounding reserves can in various ways critically affect biodiversity conservation within the reserve (Whittaker et al 2005; Watson et al 2005; Lindenmayer and Fischer 2006). Threats from adjacent lands can include invasive species, poaching, pollution, and altered disturbance regimes such as flood and fire (Worboys et al 2005; Worboys 2007). Lands adjacent to reserves can contain habitat resources needed by species inhabiting protected areas. Adjacent lands can also be a conduit for dispersal (Watson et al 2005). In many cases, the natural ecological processes required to maintain biodiversity operate at a larger scale than the reserve itself (Soulé et al 2006). Therefore, more consideration must be given to the contribution to biodiversity conservation of the land beyond, around and between formal reserves. This is what is meant when reference is made to the need to enhance the 'connectivity' of protected areas. Such 'connectivity' is a critical factor when assessing the 'adequacy' criterion for a comprehensive, adequate and representative national reserve system.

2.3 Connectivity conservation thinking

Concern with the spatial dimension, including the relationship between scale and pattern, and the biodiversity values of the broader landscape matrix has always informed conservation biology. Whittaker et al (2005) suggested that the theoretical underpinnings of conservation biology draw on four sources. First is the development and evaluation of biological theory spanning population, biological and genetic processes, and concerns with minimum viable populations, genetic erosion from small populations, competitive influence of invasive species, and behavioural ecology; i.e. processes in which biogeography is not usually prominent. Second is the theory concerning processes at the local-landscape scale, including MacArthur and Wilson's (1967) equilibrium theory of island biogeography, the derivative Single Large or Several Small reserves (SLOSS) debate (Diamond 1975), metapopulation theory (Hanski and Gaggiotti 2004), and nestedness (reviewed by Whittaker 1998) – i.e. themes that bridge ecology and biogeography. Third are applications on a yet coarser scale, in part concerned with mapping and modelling biogeographic patterns and in part invoking historic biogeographic theories concerned with the distribution and explanation of geographic patterns in diversity; these reach back to the origins of modern biogeography (e.g. the work of Wallace 1859) and encompass the exploration of specific processes such as the peninsula effect (Means and Simberloff 1987). Fourth is macroecology (Brown 1995), which involves analysis of emergent statistical properties of ecological data sets and can address both ecological traits (growth rates, propagule size, breeding system, body size) and biogeographic traits (range size, region of origin).

However, a revised conservation science consensus is beginning to emerge in response to the limitations of conservation efforts to date and the enormity of the challenge, given the scale of the current biodiversity extinction crisis and the potential synergistic impacts of climate change (Welch 2005). The term 'connectivity conservation' is now being widely used to capture this emerging scientific consensus among conservation researchers and practitioners.

The IUCN World Commission on Protected Areas (WCPA), the key global expert body on protected areas, in supporting the concept of 'connectivity conservation', argues it is a socially inclusive approach that sees all sectors in a society contributing to a strategic conservation effort benefiting both people and nature. The WCPA further argues that:

> The maintenance and restoration of ecosystem integrity requires landscape-scale conservation. This can be achieved through systems of core protected areas that are functionally linked and buffered in ways that maintain ecosystem processes and allow species to survive and move, thus ensuring that populations are viable and that ecosystems and people are able to adapt to land transformation and climate change. We call this proactive, holistic, and long-term approach connectivity conservation. (IUCN WCPA 2006)

Among other things, a connectivity conservation approach recognises that:

- conservation management is needed in the lands around formal protected areas to buffer them from threatening processes originating off-reserve
- on land that has been heavily cleared and fragmented, there is a need for large-scale ecological restoration and rehabilitation so that protected areas do not remain isolated islands and 'extinction vortices'
- in areas with high wilderness quality (*sensu* Lesslie et al 1988; Mackey et al 1998), the option remains to maintain ecological integrity *in toto* through a combination of formal protected areas and complementary off-reserve conservation management
- systematic conservation planning must factor in the conservation requirements of large-scale, spatially dependent, ecological and evolutionary processes essential for the long-term persistence of biodiversity.

These landscape contexts are illustrated in Figure 2. Connectivity conservation provides a framework for developing a comprehensive, whole-of-landscape approach to biodiversity conservation at all levels – genetic, species and ecosystem. Although grounded in conservation science, connectivity conservation also has social implications because its implementation requires a collaborative approach with a broad spectrum of landowners and managers. However, we have not analysed these social considerations in this report.

Figure 2: The gradient in habitat condition found across the GER corridor represented by three classes of habitat condition – intact, fragmented and cleared.

Photos: Ian Pulsford

Three points along this gradient are illustrated:

- left: intact habitat, where the native vegetation remains intact over extensive areas (even though other threats to biodiversity, such as foxes, exist)
- centre: degraded habitat, where native vegetation persists, but in a degraded and fragmented form
- right: largely cleared habitat, found throughout Australia's intensive agricultural zone. Around 56% of Australia is subject to grazing leases; this habitat is, or is potentially, exposed to habitat degradation. Only about 26% of native vegetation has not been cleared for agriculture or is not subject to commercial grazing leases.

Different conservation strategies are needed in each of these three situations, but in each case conservation management is required irrespective of land tenure in order to protect biodiversity on and off reserves.

2.4 An expanded understanding of 'connectivity'

Within both the scientific and broader conservation community, confusion has arisen on the meaning of the 'connectivity' part of 'connectivity conservation'. The common understanding of connectivity refers to a relatively narrow strip of native vegetation between two remnant habitat patches in a largely cleared landscape. However, in a 'connectivity conservation' context, the word encompasses but is not limited to this conventional usage.

'Disconnectivity' refers to impediments to the natural movement of organisms or the flow of processes. In the absence of human perturbations, there is a degree of both connectivity and disconnectivity due to natural barriers of various kinds. However, one of the consequences of habitat loss and fragmentation is a breakdown in connectivity of many spatially dependent, physical, biological, ecological and evolutionary processes. Connectivity conservation seeks to protect and conserve intact connections and strategically rehabilitate disrupted connections. However, the concept of connectivity conservation must also be informed by how natural barriers are part of the make-up of spatially dependent processes.

Ecologists have identified two primary components of connectivity (Bennett 2003; Tischendorf and Fahrig 2000). The first, known as 'structural connectivity' or 'landscape connectivity' (Lindenmayer and Fischer 2006), refers to the spatial arrangement of different types of habitats or habitat patches in the landscape and is measured by analysing landscape pattern without any explicit reference to the movement of organisms or the flux of processes. Various spatial statistics have been devised to measure the degree to which a landscape is fragmented and to describe the spatial configuration of vegetation patches (McGarigal et al 2002). The second, known as 'functional connectivity', refers to changes in spatially dependent biological, ecological and evolutionary processes. Functional connectivity can be considered in terms of (a) 'habitat connectivity' – the connectedness between patches of suitable habitat for an individual species – and (b) 'ecological connectivity' – the connectedness of ecological processes across multiple scales (Crooks and Sanjayan 2006; Lindenmayer and Fischer 2006). Examples of the latter include trophic interactions, disturbance regimes and hydroecological flows (Soulé et al 2004).

A useful definition of connectivity that attempts to combine both structural and functional aspects was provided by With et al (1997):

> ... connectivity is the functional relationship among habitat patches, owing to the spatial contagion of habitat and the movement responses of organisms to landscape structure.

However, this definition is limited as it does not refer to the flux of things other than organisms, including the environmental flows and regimes that sustain habitat resources or that comprise selective forces to which species must be adapted in order to persist in a landscape. Nor does this definition make reference to the connectivity needed for spatially dependent evolutionary processes. The conservation of biodiversity requires that attention be given to evolutionary processes in terms of both (a) genetic change in populations that represents local adaptations to changing environmental conditions ('microevolution') and (b) longer term directional genetic change in a population leading to divergence and speciation ('macroevolution') (Frankel and Soulé 1981; Thompson 2005; Giennapp et al 2007; Mace and Purvis 2008).

The need to consider connectivity in relation to spatially dependent evolutionary processes is emphasised with the potential synergies between climate change and habitat loss. Microevolution is a continuous process as every generation presents new genetic material on which natural selection can act, potentially giving preference to traits that fit better with respect to changing environmental conditions, such as rapid climate change (Davies et al 2007). However, the capacity of a species for local adaptation depends on, among other things, the extent of within-species genetic diversity and the geographic structure of the species' distribution (Myers and Knoll 2001). Evolution is a relatively slow process for animals and plants with a long generational time, but it can occur relatively rapidly for organisms with a more rapid turnover such as bacteria and many invertebrates.

In summary, the 'connectivity' part of connectivity conservation refers to various kinds of connections including:

- the structural configuration of habitats or habitat patches in a landscape mosaic
- the permeability of a landscape mosaic for dispersal and movement of a specific species
- the presence or absence of barriers or impediments to the natural flux of water, nutrients, or fire experienced in a landscape
- landscape permeability with respect to meta-population dynamics
- gene flows associated with micro and macroevolutionary processes.

2.5 Scale and connectivity

Another critical factor that is brought to the foreground by connectivity conservation is the question of scale. The various ecological and evolutionary processes referred to above operate at difference spatial and temporal scales. This fact has been long recognised (Allen and Starr 1982) but only more recently factored into conservation thinking (Soulé et al 2004). The scales at which a selection of ecological and evolutionary processes occurs is illustrated in Figure 3. Many significant processes operate at trans-bioregional scales, encompassing biome level, and continental and biogeographic realm (Udvardy 1975) scales. Systematic conservation planning therefore needs to identify strategies and prescriptions at multiple scales, and identify processes that impact on and 'connect' locations beyond any single landscape, bioregion or State boundary. This is true even for fine-scaled processes operating at more local scales such as pollination, nutrient flux and the maintenance of ecologically functional populations in a landscape. Attention to fine-scaled processes might be required if they are affected by processes operating at larger (bioregional, biome and continental) scales (Sanderson et al 2006).

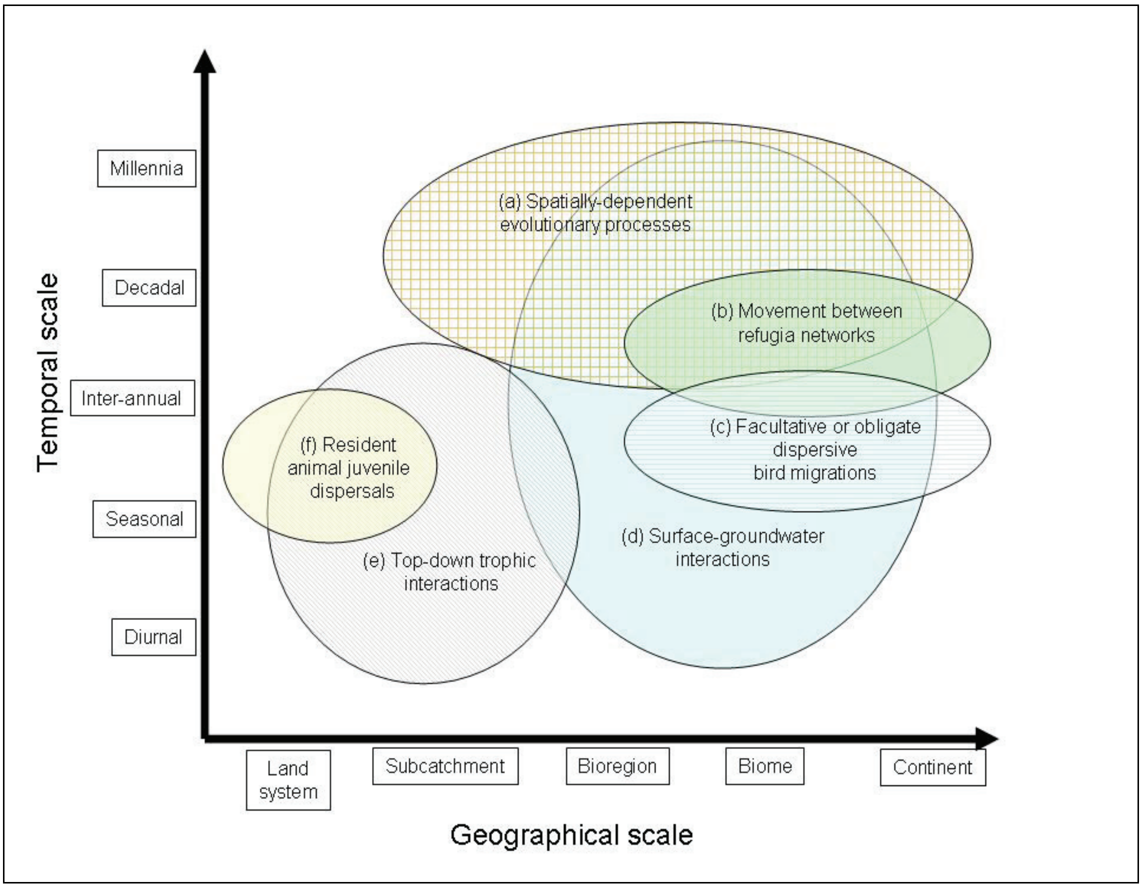

Figure 3: The geographical and temporal scales at which a selection of significant ecological and evolutionary processes occur.

Such processes include:

(a) spatially dependent evolutionary processes which can result in genetic changes in populations reflecting allopatric or ecological selection pressures

(b) movement between refugia networks such as when waterbirds utilise ephemeral wetland habitats

(c) many bird species being highly dispersive, moving over great distances either seasonally or facultatively in response to unreliable food resources

(d) surface–groundwater interactions which are a vital component of hydroecological relations in many parts of Australia (e.g. the Great Artesian Basin is continental in extent and its discharge supports significant wildlife in arid Australia, but the water it provides can take thousands of years to cycle from recharge to discharge)

(e) top-down trophic interactions – meta-populations of dingoes influence fox and cat numbers over entire landscapes

(f) common biological events such as the localised dispersal of juvenile animals from sites whose carrying capacity has been reached – such multiple-scaled processes are explicitly recognised by connectivity conservation planning.

Large-scale ecological processes are of two kinds. The first refers to large-scale movements of organisms, and the second to large-scale environmental flows and disturbance regimes. An example of large-scale biological movement is 'dispersive species'. In addition to a high level of endemism, Australia's biodiversity is distinctive in the special life history strategies that have evolved in response to its particular climatic environments, especially the high year-to-year and spatial variability in rainfall and associated primary productivity. Given this dynamic habitat template, it is not surprising that around 50% of Australia's birds are highly dispersive and can travel large distances to obtain the necessary habitat resources or to optimise physiological niche requirements (Gilmore et al 2007). An example of the second kind (large-scale environmental flows) is hydrological flows and their interactions with vegetation ecosystems (hence 'hydroecology' – Soulé et al 2006). Both surface water catchment boundaries and groundwater recharge/discharge zones transcend protected areas and bioregional boundaries and demand a whole-of-landscape approach to their maintenance and for the persistence of the flora and fauna they sustain over broad areas. In addition to hydroecology, 'fire regimes' is another multi-scaled phenomenon that influences the evolution and ecology of Australian species (Gill 1981).

The significance of spatially dependent evolutionary processes and the dispersal requirements of species is increasingly being studied (e.g. Driscoll 1998; Burdon and Thrall 1999) but to date has not had a great impact on conservation planning. The advent of modern molecular-based methods of analysis is beginning to reveal the genetic structure of populations and the genetic basis of the geographic mosaic of communities they form across their range, along with increasing insights into phylogentic histories and modes of speciation (Kirchman and Franklin 2007; Norman et al 2007).

Evolution is defined as inheritable genetic change in a population, and thus it is the population that is the 'unit' that evolves (Mayr 2001). As noted above, evolution is a continuous process spanning many scales, but it is useful to distinguish 'micro' from 'macro' evolution, with the former referring to ongoing incremental changes in a population's genetic make-up (in particular, that which represents adaptive traits) and the latter referring to long-term directional changes in, and divergence of, populations, leading to speciation.

As discussed by Burdon and Thrall (1999), most biological systems are characterised by the uneven distribution of individuals into a series of populations that show varying degrees of connectedness; that is, they constitute meta-populations. Thus, all ecological and evolutionary processes have a strong spatial component that must be factored into conservation assessments. Of particular conservation interest is the fact that most species comprise populations that are genetically differentiated (Thompson 2005). Loss of this genetic diversity through local extirpations represents cryptic extinctions that to date have escaped environmental impact assessment: despite significant regional declines and genetic erosion a species may still not be listed as threatened. Also ignored is the loss of local assemblages. Species generally form communities with different species across their range, thereby creating a geographic mosaic of community assemblages that both reflects and influences ecological and co-evolutionary species interactions (Thompson 2005).

The potential for micro-evolution is facilitated by maintaining the genetic variability within species and ensuring viable populations are maintained across a species' entire range. Landscape permeability can be important for enabling the meta-population's dynamics that enhance infra-species genetic diversity and maintain co-evolved interactions. It is also a requisite for range expansion, which can be a key stage in evolutionary differentiation and speciation (Avise 2000). However, the scale at which these various evolutionary processes need to be considered varies with the size and life history of the target species.

Protecting natural ecological and evolutionary connectivity across all relevant spatial and temporal scales can make a significant contribution to mitigating extinction vortices (Crooks and Sanjayan 2006; Lindenmayer and Fischer 2006). In essence, this means preventing habitat loss, fragmentation and the degradation of natural lands in the first place, and the active management of natural connectivity so that threats are minimised and the resilience of species maximised. Connectivity conservation highlights the need for thinking beyond isolated conservation enclaves or islands to a 'whole-of-landscape' vision of large areas of interconnected natural lands (and seas). The land that must be managed is invariably held under various tenures and jurisdictions. Internationally, multiple nations may also be involved, demanding a cooperative, transboundary approach. Connectivity conservation recognises the need to maintain and restore across multiple scales key ecological and evolutionary phenomena, flows and processes that are critical in shaping and supporting the long-term conservation of biodiversity. Conservation connectivity initiatives involve systematic conservation effort across the landscape matrix on supra-regional to continental scales.

2.6 Corridors and connectivity

Any discussion of connectivity invariably leads to consideration of 'corridors'. As with 'connectivity', there is a diverse range of meanings used by conservation researchers and practitioners (Chester and Hilty 2009). As noted by Anderson and Jenkins (2006), at the most basic level, **linear corridors** (which establish or maintain relatively straight-line connections between larger habitat blocks and extend over distances of up to tens of kilometres) can be distinguished from **landscape corridors** (that maintain or establish multidirectional connections over entire landscapes and can encompass up to thousands of square kilometres). **Linear corridors** will usually be one of the structural elements in a **landscape corridor** initiative.

Anderson and Jenkins (2006) also identified the following ways in which the term 'corridor' is used in conservation:

- **biodiversity corridors** (also called **biological corridors**) – large-scale landscape linkages covering hundreds to thousands of square kilometres – the term is therefore synonymous with **landscape corridor**
- **corridor networks** – systems of corridors running in multiple directions
- **dispersal corridors** – corridors that promote the movements or migrations of specific species or groups of species; synonyms include **movement corridors** and **wildlife corridors**
- **ecological corridors** – corridors that maintain or restore ecological services on which biodiversity conservation depends (this term is unfortunately alternatively used as a synonym for 'biodiversity corridor')
- **habitat corridors** – linear strips of native habitat linking two larger blocks of the same habitat. Presumably, the purpose of **corridor networks** and **habitat corridors** is complementary to those of **dispersal corridors** and **ecological corridors**.

In summary:

(a) landscape corridors (and their synonyms, **biodiversity** or **biological corridors**) describe the principal geographical component of a connectivity conservation initiative

(b) elements of a landscape corridor include **dispersal corridors** (such as **corridor networks** and **habitat corridors**) and **ecological corridors** (which focus on landscape permeability for ecosystem processes).

Bennett and Mulongoy (2006) made the useful distinction between:

- **linear corridors** such as a hedgerow, forest strip or river
- **stepping stones** or arrays of small patches of habitat that individuals use during movement for shelter, feeding and resting
- **interlinked landscape matrices**, which comprise various forms that allow individuals to survive during movement between habitat patches.

Again, these three types of corridor are possible structural elements of a landscape corridor.

A complementary categorisation of corridors was provided by Bennett (2003), based on their origin:

- **disturbance habitat corridors** – including roads, railway lines, cleared utility lines, and other linear disturbances
- **natural habitat corridors** – including streams and riparian zones typically following topographic or environmental contours
- **planted habitat corridors** – including farm plantations, windbreaks and shelterbelts, hedgerows and urban greenbelts established by humans
- **remnant habitat corridors** – including roadside woodlands ('beauty strips'), linear stretches of unlogged forest within clearcuts, and undisturbed habitats between protected areas
- **regenerated habitat corridors** – formerly cleared or disturbed linear strips where vegetation has regrown, such as 'fencerows' and 'hedges'.

Hilty et al (2006) drew the distinction between:

- unplanned corridors, which are landscape elements that enhance connectivity but exist for other reasons, and
- planned corridors, which are established for both biological connectivity and other reasons (e.g. greenways, riparian zone buffers).

These additional categorisations of corridors are useful because they highlight the diversity of landscape structural elements that can function as either **dispersal corridors** or **ecological corridors** in a landscape corridor.

'Biolinks' is another connectivity/corridor related term. It came into use in Victoria during the 1990s and has been applied more recently to describe large-scale connectivity conservation activities. Mansergh and Cheal (2007) defined 'biolinks' as a national ecological infrastructure that forms part of an adaptive response to climate change and includes all land tenures. As such, the term can be considered synonymous with a landscape corridor initiative such as the GER corridor.

2.7 Critiques of landscape corridor initiatives

There has been a longstanding debate about the efficacy of connectivity conservation initiatives that has generally hinged on the meaning and use of 'corridors' in a restoration and rehabilitation context (Simberloff et al 1992; Bennett 2003, 2004; Crooks and Sanjayan 2006; Hilty et al 2006; Lindenmayer and Fischer 2006). The debate has focused on three issues:

- whether sufficient scientific evidence is available to demonstrate the potential conservation benefits of corridors
- whether the potential negative effects of corridors outweigh any conservation values (e.g. through enhancing fire or invasive species)
- whether corridors are a cost-effective option in comparison with other ways of utilising scarce conservation resources.

Corridor restoration and rehabilitation is one of many conservation methods. As argued by Bennett (2003), the controversy and debate surrounding corridors has been narrowly focused on regenerating habitat corridors, largely ignoring other types of movement and connections, including the use of 'stepping stones' (Fischer and Lindenmayer 2005; Haddad and Tewsbury 2005), migratory stopovers, habitat mosaics and the permeability of the intervening matrix (With et al 1997; Watson et al 2005) (Figure 4).

When considering the efficacy of connectivity, Bennett (2003) suggested two key questions:

- Are populations, communities and natural ecological processes more likely to be maintained in landscapes that comprise interconnected systems of habitats than in landscapes where the remaining natural habitat patches occur as dispersed, ecologically-isolated fragments?
- What is the most effective pattern of habitat patches in a disturbed landscape to ensure ecological connectivity for species, communities and ecological processes?

Few ecologists would argue with the first question, because there is little debate that movements of animals and plants and the flow of wind, water, materials and biota between habitats is a key characteristic in the functioning of natural ecosystems (Forman 1995; Wiens 1995). Of more practical interest is how best to address the second question.

Overall, much of the current discussion about the efficacy of corridor restoration seems to be less about the advantages and disadvantages as a specific conservation tool, than it is about the challenges associated with purchasing, designing, constructing, restoring and maintaining corridors. Of particular concern are the high resource and opportunity costs involved. As Crooks and Sanjayan (2006) argue, perhaps the most pertinent question facing conservation biologists, land-use planners and resource managers today is not 'Why do we need natural levels of connectivity?', but rather, 'How should connectivity be restored in areas that have experienced significant biodiversity loss and fragmentation, for what target species or ecological process, and at what scale?' Hilty et al (2006) reinforce this point, arguing that those factors that can cause corridor projects to fail or fall short are not reasons to abandon connectivity conservation initiatives. Rather, they should be used as a checklist to take into account when designing, establishing and managing a corridor. Relevant elements of such a checklist include:

- the physical structure of corridors should minimise edge effects such as increased levels of predation and parasitism
- corridors should be established to minimise competition with exotic and native invasive species
- corridors should not lead to the dilution of locally adapted genes
- corridors should not allow local populations to be overwhelmed by immigrants
- where populations are small and lack immunity, corridors should not allow for the spread of infectious diseases
- the opportunity costs associated with establishing and maintaining corridors must be evaluated (for example, would it be more effective to enlarge core areas to achieve adequate biodiversity conservation?)
- because corridors will often be placed in areas of high economic value, the political costs of establishing and maintaining corridors, including an appraisal of the costs of not maintaining corridors, will need to be assessed.

Corridor restoration and rehabilitation is one, albeit significant, component of a **c**onnectivity conservation initiative. Other elements include:

- protecting the extant natural connectivity of large intact areas
- instigating complementary conservation management in the landscape matrix within which protected areas are embedded.

Connectivity conservation is therefore about much more than paddock-scale corridors linking two patches of remnant native vegetation in an intensive agricultural zone, though this may well be an element within a broader landscape corridor project.

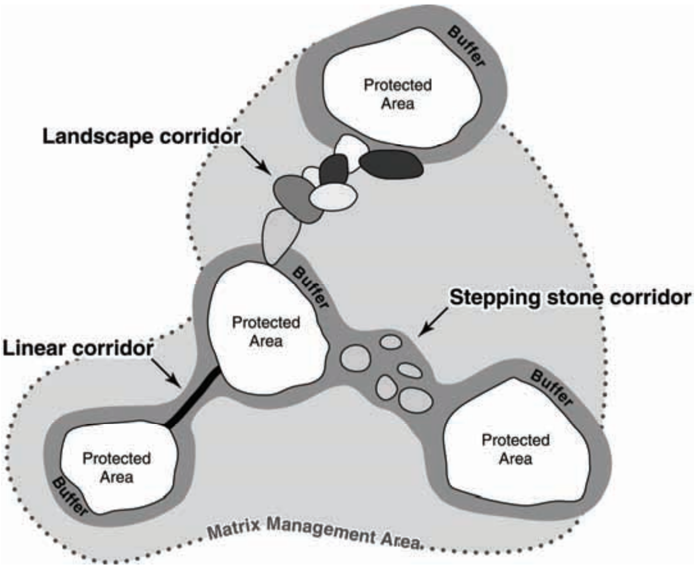

Figure 4: Some of the conceptual elements that comprise connectivity conservation spatial planning: core protected areas, the landscape-wide matrix management area, native vegetation that serves as 'stepping stones' and linear corridors of native habitat (adapted from Bennett 2004)

3 Connectivity conservation and the Great Eastern Ranges corridor

In this section, we consider more specifically the scientific arguments and evidence in support of applying a connectivity conservation approach to the GER corridor. In section 3.1 we briefly review some of the region's biodiversity assets, natural values and relevant associated ecological and evolutionary processes. In section 3.2 we define 'landscape resilience' in order to explicitly address the second term of reference for this report. Section 3.3 briefly reviews three case studies in NSW and Queensland that have examined landscape resilience and related connectivity conservation issues. In section 3.4 we consider four threatening processes of particular relevance to the GER corridor. Section 3.5 discusses ways in which connectivity conservation can help mitigate threatening processes, and maintain and restore landscape resilience in the GER corridor.

3.1 Overview of the GER corridor biodiversity assets

The land that falls under the scope of the GER corridor is among the most biodiverse in the continent. The landscape ecosystems encompassed by the GER corridor contain important water catchments and rich bio-cultural heritage, and provide outstanding recreational resources near major urban centres. Spanning a latitudinal band of 28 degrees over 2,800 kilometres, the GER corridor contains significant areas of tropical, subtropical and temperate forest and woodland ecosystems. These zones are more precisely described in terms of thermal regimes, and understanding their relationship to the evolution and biogeography of plants is necessary background for understanding the potential impact of climate change on Australian vegetation.

Nix (1982) suggested there are three primary thermal regimes to which plants are adapted. These regimes equate with mean annual temperatures of:

- >24 ºC (megatherm)
- >14 ºC and <20 ºC (mesotherm)
- <12 ºC (microtherm).

Nix argued that these thermal regimes and associated biota have persisted on the Australian continent throughout the last 60 million years. As discussed by Hill (1994), climates were not uniform across Australia during the Middle Eocene, and the local topography in the Oligocene and the Early Miocene influenced the climate and plant communities in south-eastern Australia. Increasing seasonality in both temperature extremes and rainfall and, to a lesser extent, marked changes in other aspects of the thermal regime, were the primary driving forces of biotic change within Australia during the early to mid Tertiary. The paleorecord reveals that in the Oligocene (23.8–33.7 million years ago (mya)), temperatures were cooler than in the Eocene (33.7–54.8 mya) and lineages such as *Nothofagus* became increasingly important, with leaf characteristics suggesting a humid microthermal climate. Middle Miocene (5.3–23.8 mya) flora lacked some key Oligocene plants, suggesting increasing seasonality and temperature extremes. Sub-alpine woodlands emerged around this time and there was an expansion of microthermal climates in south-east Australia. By the late Miocene, seasonal dryness was well established.

The three World Heritage areas found in the GER corridor reflect the continent's evolutionary history in response to global climate change, the long period of isolation since breaking clear of Antarctica (and Gondwanaland) some 60 mya, and adaptations to Australia's unique landscape conditions, such as the dominance of deeply weathered and infertile substrates. Consequently, the region contains ancient species of Gondwanic origin such as the Wollemi Pine (*Wollemia nobilis*), and there are many centres of endemism for both plants and animals. These influences have helped shape the biodiversity and natural history of the region's three World Heritage areas (Wet Tropics, Central Eastern Rainforest Reserves and Greater Blue Mountains), and the three Ramsar-listed wetlands (Blue Lake, Ginini Flats and Little Llangothlin Nature Reserve).

The GER corridor includes 14 (or 16.5%) of Australia's 85 bioregions, and the catchments of 63 of Australia's easterly and southerly river basins (NLWRA 2002) (Table 1). Bioregions and subregions within its area include:

- the highest concentrations of bird species in Australia: in south-east Queensland (with 429 species) and north-eastern NSW (with 428 species) (NLWRA 2002)
- the richest concentration of Australia's mammal species (NLWRA 2002)
- one of the two greatest concentrations of *Eucalyptus* and *Acacia* species in Australia (the other being south-west Western Australia) (NLWRA 2002)
- one of the three most important centres of endemicity for eucalypts and acacias, the other two being Western Australia's Kimberley and south-west Western Australia (NLWRA 2002) (Table 2).

The GER forms a significant part of the area being considered for listing as the 35th Conservation International global high biodiversity hotspot.

Table 1: Indicative biodiversity status of the GER corridor bioregions and subregions
(Source: NLWRA 2002)

	Birds (700-plus species in Australia)	**Mammals (331 species in Australia)**	**Eucalypts and acacias (1090 taxa of *Eucalyptus* and 1095 taxa of *Acacia* in Australia)**
	Abundance by bioregion (no. of species) Minimum = 100–150 Maximum = 301–350	Abundance by bioregion (no. of species) Minimum = 25–35 Maximum = 66–86	Abundance by bioregion (no. of combined species) Minimum = 1–80 Maximum = 251–500
ACT	251–300	55–65	251–500
NSW	251–300 and 301–350	46–55 and 66–86	151–250 and 251–500
Qld	301–350	56–65 and 66–86	81–150; 151–250; 251–500
Victoria	251–300	56–65	251–500
GER corridor	'The bioregions with the highest number of bird species occur along the length of Eastern Australia.' (NLWRA 2002 p. 70)	'The mesic regions of northern and eastern Australia had the faunas with the highest number of species.' (NLWRA 2002 p. 86)	'Moderately species-rich bioregions occur … [in] the subtropical humid and temperate sub-coastal areas of eastern Australia.' (NLWRA 2002 p. 102) 'When species numbers and the numbers of endemic species are considered, an endemicity index can be calculated. The majority of the [GER corridor] has a high endemicity index reading.' (NLWRA 2002 p.106)

The combination found in the GER corridor of climatic zones (Figures 5 and 6), elevation gradients, substrate types and landforms, together with the long length of time the continent has been isolated, has produced a rich biological diversity at all levels: genetic, species and ecosystem. The GER corridor encompasses high-rainfall catchments that generate a surplus of water, with rainfall exceeding evaporation on an annual basis. The net positive water balance results in high and reliable rates of net primary productivity (NPP) and thus the largest standing stocks of biomass. Consequently, the GER corridor contains the majority of Australia's extant rainforest (Figure 7) and *Eucalyptus* forest (Figure 8) and hence the majority of Australia's forest-dependent flora and fauna.

The GER corridor contains diverse ecosystem types in addition to its core representation of Australia's forest biome. This diversity reflects the reduction in NPP and the evolution of special plant characteristics associated with cooler (microthermal) climates (e.g. alpine meadows), nutrient poor substrates (e.g. coastal heath), landforms (e.g. wetlands) and combinations of these (e.g. temperate grasslands). Running off the spine of the GER corridor inland are open woodlands, reflecting rapidly decreasing rainfall. In the most easterly areas, there is a diversity of coastal ecosystems, including mangroves. The escarpment and mountain areas of high relief contain gorges, limestone caves and other specialised habitat locations. Only a small portion of the lands encompassed by the GER corridor were affected by the Pleistocene glaciations; they therefore have provided a continuous expanse of habitat, dominated by, but not restricted to, the forest biome, within which species have been able to move, in terms of both latitude and altitude, in response to the natural climatic change that eastern Australia has experienced over geological time (White 1986, 1994).

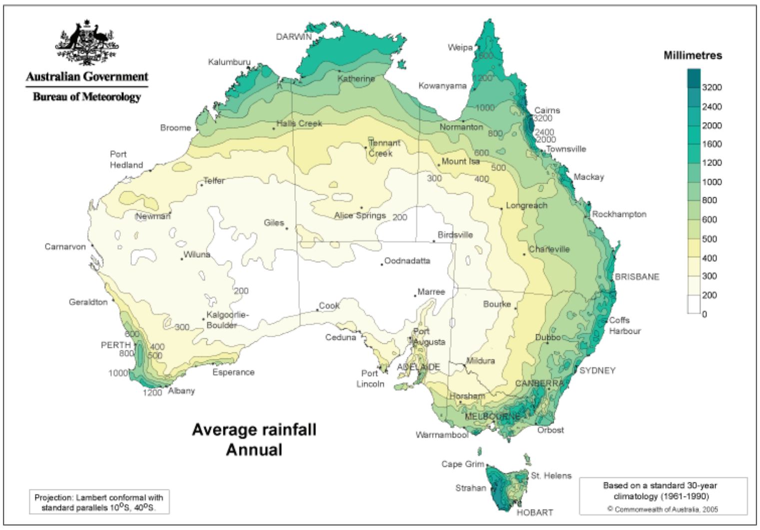

Figure 5: Long-term annual rainfall for Australia.

Source: Bureau of Meteorology online climate services; www.bom.gov.au/climate/

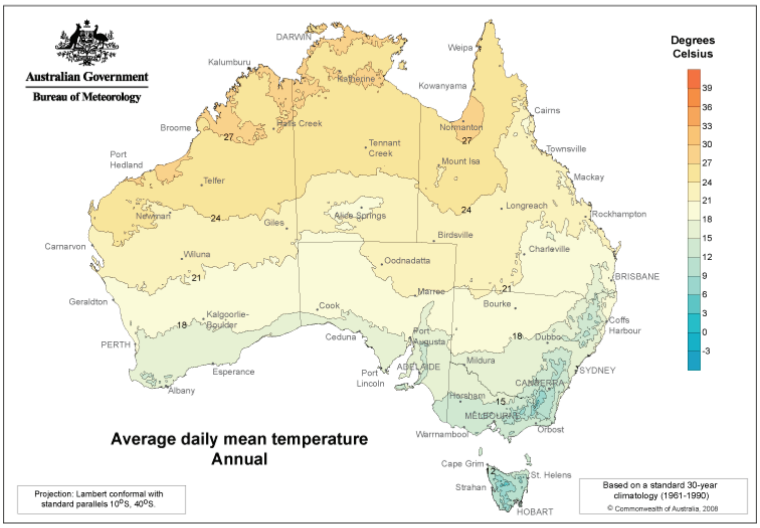

Figure 6: Long-term mean annual daily temperature for Australia.

Source: Bureau of Meteorology online climate services; www.bom.gov.au/climate/

Figure 7: Distribution of rainforest in Australia.

Source: National Heritage Trust 2001, *Australia's native vegetation – a summary of the National Land and Water Resources Audit's Australian Native Vegetation Assessment 2001*, visit www.environment.gov.au/atlas.

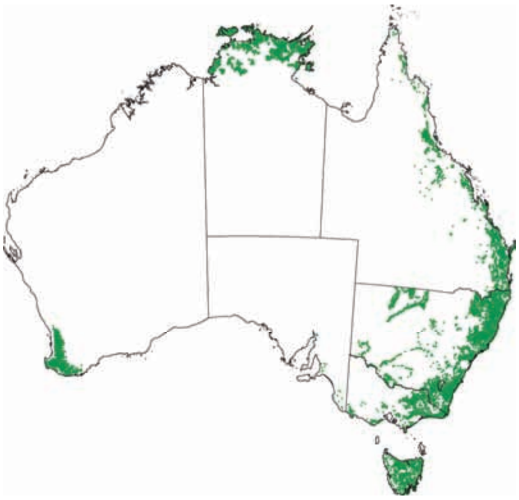

Figure 8: Distribution of open *Eucalyptus* forest in Australia.

Source: National Heritage Trust 2001, *Australia's native vegetation – a summary of the National Land and Water Resources Audit's Australian Native Vegetation Assessment 2001*, visit www.environment.gov.au/atlas.

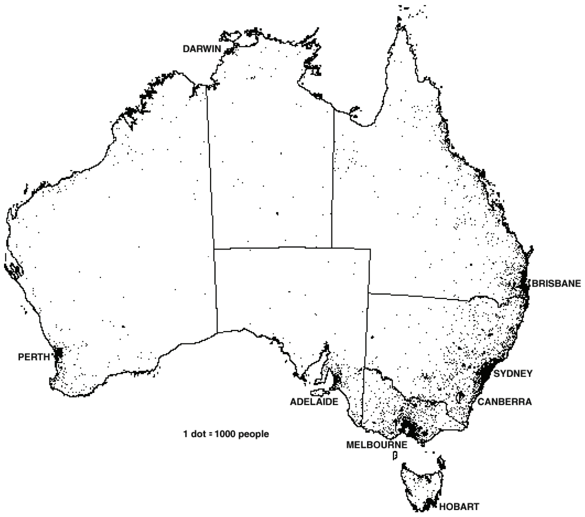

Figure 9: Distribution of Australian population centres 2004–05.

Source: *A picture of the nation: the statistician's report on the 2006 census* (ABS cat. no. 2070.0). ABS data used with permission from the Australian Bureau of Statistics.

Scattered throughout the GER corridor are substantial areas of fertile volcanic and alluvial soils which, together with high and reliable rainfall regimes, produce biologically productive land. Consequently, southern and central parts of eastern Australia, in particular, have been extensively cleared for agriculture and many remaining areas are grazed. The coastal region also supports an increasing human population (Figure 9), with large urban areas centred around the capital cities of Melbourne, Sydney and Brisbane. There is also an increasingly continuous peri-urban zone that is rapidly expanding, including areas such as Wollongong–Sydney–Newcastle strip, the Byron Bay–Gold Coast–Brisbane–Sunshine Coast strip and, further to the north, the Cairns area. The GER corridor also includes a diversity of land-use activities and land covers, many of which are based on the environmental services that flow from the extensive areas of natural ecosystems (see Table 2).

3.2 Defining landscape resilience

The terms of reference call for consideration of the contribution of ‘continental-scale connectivity conservation to maintain or enhance landscape resilience through ecosystem function and services over the long term’. However, ‘landscape resilience’ is not a standard operational term. Logically, it is related to, among other things, the concepts of ‘ecological integrity’ and ‘ecosystem health’. These terms also lack a single, accepted scientific definition. Given this, for current purposes we have adopted the following definitions of landscape resilience and related terms.

‘Resilience’ was defined by Hollings (1973) as the capacity of a system to absorb perturbations without ‘flipping’ into a different state, though additional interpretations have since been proposed. A commonsense understanding yields a similar definition: when resilience is breached the system is destroyed – that is, it ceases to function as a system. Ecosystems can be destroyed, but they can also be reconstituted as a different kind of system. Given this reality, the Hollings definition acknowledges that when resilience is breached a system can be replaced by another system – that is, the capacity to form a system is not always destroyed. Resilience can arise through a system simply resisting or repealing an external perturbation. System resilience can also result from an ecosystem absorbing external perturbations through internal reorganisation of its structure, composition or process rates, or dissipation of unusable energy, or both. In ecosystems, resilience can also be derived from the evolution of new traits among the component species, or the immigration of new species that are better adapted to the changed conditions (see discussion in Thompson et al 2009).

Table 2: Bioregions, sites of significance, river basins and catchments in the GER corridor

	No. of bioregions (some are shared) (NLWRA 2002)	GER corridor sites of international significance	No. of easterly and southerly flowing river basins (NLWRA 2002)	GER corridor catchments: significant capital city water supply impoundments
ACT	2	1 Ramsar wetland	N/A	Canberra: Cotter, Bendora, Corin, Googong
NSW	5	2 World Heritage sites (1 shared with Qld) 2 Ramsar wetlands 1 biosphere reserve	20	Sydney: Burragorang, Avon, Cordeaux, Cataract, Tallowa
Qld	8	2 World Heritage sites (1 shared with NSW)	35	Brisbane–Gold Coast - Wivenhoe, Somerset, North Pine, Hinze
Victoria	4		8	Melbourne: Thompson, Upper Yarra, Sugarloaf, Cardinia

	No. of bioregions (some are shared) (NLWRA 2002)	GER corridor sites of international significance	No. of easterly and southerly flowing river basins (NLWRA 2002)	GER corridor catchments: significant capital city water supply impoundments
GER corridor	14	3 World Heritage sites 3 Ramsar wetlands 1 biosphere reserve	63	16-plus major impoundments for 4 capital cities, plus impoundments for towns and cities along the entire east coast of Australia

Natural ecosystems have autopoietic (self-creative) capacities to organise, regenerate, reproduce, sustain, adapt, develop and evolve (Westra et al 2000). Humans can intervene in these systems in ways that undermine their autopoietic capacities. For example, humans can harvest fibre from forest ecosystems at rates and in ways that exceed the forest's capacity to regenerate the biomass, disrupt nutrient cycling, and render the landscape incapable of growing trees, in which case ecosystem resilience has been breached and the system 'flips' into another state – the forest is replaced, for example, with degraded shrub-grassland (Nepstad 1999). At the extreme end of human intervention, land is cleared of its evolved ecosystems and replaced with a land cover that is maintained by continual inputs of human capital, technology and labour. In between, there is a gradient of human interventions, impacts and resilience.

In the context of connectivity conservation and the GER corridor, the focus is primarily on terrestrial (and aquatic) biodiversity and thus landscape ecosystems. The state of landscape resilience can be objectively assessed by using measurements of ecosystem integrity (also called ecological or biological integrity) – assuming that resilience is a function of system integrity. As defined by the Oxford Dictionary, 'integrity' is 'the condition of having no part or element taken away or wanting; undivided or unbroken state; material wholeness, completeness, entirety'. From a conservation science perspective, 'wholeness' and 'completeness' can refer to:

(a) the genetic, taxonomic and functional composition of an ecosystem

(b) the functionality of ecological and evolutionary processes

(c) the health of the resident individual organisms and populations.

All are relative to a baseline.

James Karr pioneered the creation of objective and quantitative multi-metric indices of biological integrity (IBIs) (Karr 1981). These indices measure the extent to which a biota deviates from a state of integrity by using metrics calibrated from a baseline condition. IBI metrics evaluate species richness, indicator species (stress intolerant and tolerant), relative abundance of trophic guilds and other ecological groups, presence of alien species, or the incidence of hybridisation, disease and anomalies such as lesions, tumours or physiognomic abnormalities (Karr 1991). IBIs were originally developed for streams and rivers to implement requirements under the US *Clean Waters Act*, but they have also been developed and applied to terrestrial systems.

A synonym for biological integrity is 'ecosystem functionality'. An approach to assessing this has been applied in NSW environmental impact assessments based on five criteria (Bega Valley Shire Council 2001):

- **landscape integrity**, which refers to whether an ecosystem falls into a heavily modified landscape
- **extent of habitat fragmentation**, which refers to the comparative size of current patch size relative to historical conditions
- the **proportion of native species present** in an area's fauna and flora
- **current habitat complexity**, which refers to the micro-habitat of an ecosystem, relative to historical conditions
- **presence or absence of key functional groups**.

The NSW approach therefore captures landscape-level changes in habitat loss and fragmentation, invasive species, vegetation condition and species loss.

Various approaches have been developed in Australia to measure vegetation condition. The Vegetation Assets, States and Transitions (VAST) framework was developed by the Bureau of Rural Science, Australian Government Department of Agriculture, Fisheries and Forestry. VAST classifies vegetation by the degree of human modification as one of seven states (Thackway and Lesslie 2006):

- naturally bare
- residual
- modified
- transformed
- replaced – adventive
- replaced – managed
- removed.

For the classification, a benchmark is identified for each vegetation association based on structure, composition and current regenerative capacity. These benchmarks reflect the best understanding of pre-European conditions. For each site or patch, the relative change in condition from this benchmark is then assessed. Parkes et al (2003) documented the 'habitat hectares' approach to assessing the quality of native vegetation. Components of their index include vegetation physiognomy and critical aspects of viability (e.g. degree of regeneration, impact of weeds), and spatial considerations (e.g. area, distribution and connectivity of remnant vegetation in the broader landscape).

As noted above, the resilience of landscape ecosystems is also related to the composition of resident and visiting species. One reason why the extent of local extirpations and the introduction of alien species are included in biological integrity metrics is because of the relationship between species composition and ecosystem function. In a major review, Hooper et al (2005) concluded that:

- certain combinations of species are complementary in their patterns of resource use and can increase average rates of productivity and nutrient retention
- susceptibility to invasion by exotic species is strongly influenced by species composition and, under similar environmental conditions, generally decreases with increasing species richness
- having a range of species that respond differently to different environmental perturbation can stabilise ecosystem process rates in response to disturbance and variation in abiotic conditions.

Heemsbergen et al (2004) showed experimentally that biodiversity effects on soil processes can be explained as follows:

- species traits determine their functional role
- communities with the same species numbers but different species compositions have very different effects on soil ecosystem processes
- facultative interaction between functionally dissimilar species is the explanation for an increased rate of soil ecosystem processes.

3.3 Case study perspectives on landscape resilience

In this section we briefly consider three case studies in NSW and Queensland that have examined landscape resilience and related connectivity conservation issues.

Case study 1

In a historical review of the ecological impacts of post-European settlement in the Bega district, NSW, Lunney and Leary (1988) concluded that:

> Most native mammal populations of the Bega district are now confined to the forests on the hilly, least arable country with low-nutrient soils. It is not surprising that most species are currently uncommon or rare. The accumulated evidence demonstrates that European settlement resulted in a decline of all

> native mammal populations, and the [local] extinction of at least six species of mammals: the eastern quoll *Dasyurus viverrinus*; a rat kangaroo, probably *Bettongia gaimardi*; two 'pademelons', *Macropus parma* and *Thylogale thetis*; the wallaroo *Macropus robustus* and the brush-tailed phascogale *Phascogale tapoatafa*. Four other species of mammals – the koala *Phascolarctos cinereus*, the southern brown bandicoot *Isoodon obesulus*, the spotted-tailed quoll *Dasyurus maculatus*, and the little red flying-fox *Pteropus scapulatus* – have become rare and are threatened with extinction in the Bega district.

Most of the regional losses and declines of mammal species documented by Lunney and Leary for the Bega district were the result of habitat loss and introduced species (in particular, hares, rabbits, and foxes). Lunney and Leary also noted that:

> … any initiatives which resulted in reclamation of parts of the valley, such as marginal farmland, for conversion to original forest, would benefit many species. Most importantly, an imaginative wildlife management programme…could do much to halt the loss of original habitat…

The Bega district story has been replicated in general terms up and down eastern Australia.

Case study 2

Pressey et al (2002) examined the effectiveness of protected areas in north-eastern NSW, a region occupying about 7.6 million hectares and one of the most biologically rich parts of the continent. Before European settlement, the region was mostly covered by forest and woodland. However, some 44% of the native vegetation has now been cleared. Their results showed that the portion of the region's biodiversity most in need of protection from vegetation clearing remained poorly protected, and that the least protected forest types tended to be those with the highest vulnerability to ongoing clearing. They concluded that effective conservation efforts should be extended beyond public land, that forest types and species on the region's private land continue to languish with little effective protection, and that effective use of limited conservation resources requires decisions about conservation priorities on private land to be made strategically.

Case study 3

The third example is from Hannah et al (2007), who examined impacts of clearing, fragmentation and disturbance on bird fauna of eucalypt grassy woodlands in the Brigalow Belt North and southern Desert Uplands biogeographical regions of Queensland. These regions have been subject to extensive broadscale clearing and pastoral intensification. Hannah et al measured bird assemblages in cleared, fragmented and uncleared woodland sites against various measures of ecological integrity, including:

- habitat fragment size
- condition (as measured by stocking levels, extent of buffel grass, incidence of fire and extent of fallen logs)
- underlying environmental variation
- an index of the shortfall in species composition (a quantitative measure of the divergence in bird fauna from an assumed pre-clearing baseline)
- the abundance of two miner (honeyeater) species known to dominate degraded habitat to the exclusion of other species.

Their results showed that a very high proportion of woodland bird assemblages is lost with clearing, and that the site-level bird richness of pastures is only about 40% of woodlands. Other results from this study revealed that bird species richness increased significantly with fragment size (e.g. woodland fragments of 10 hectares would support about half of the bird species richness of woodlands of 100 hectares) and decreased with increasing abundance of miners. A major conclusion from this study was that vegetation regrowth following clearing supports a non-inconsequential bird fauna and that these areas may resemble intact habitat assemblages in one or two decades. Consequently, they argued there are substantial biodiversity benefits from protecting regrowth and that careful encouragement of regrowth may provide one mechanism for regional-scale rehabilitation and the maintenance of connectivity.

Lessons to be learnt from the case studies

The stories of Bega Valley, north-eastern NSW and central Queensland help illustrate the conservation challenges facing much of the GER corridor. There are significant areas of intact native vegetation, but extensive habitat clearing, fragmentation and degradation have also occurred, the proportion of which varies from bioregion to bioregion, with some regions having suffered extensive habitat loss. Many of the more biologically productive landscapes have been cleared for agriculture or are subject to ongoing land-use activities, including commercial grazing and logging. Habitat fragmentation and degradation are therefore ubiquitous outside the protected area network, particularly on private land. As the result of a bias in protected areas towards steeper and less fertile land systems, and of over-clearing of more productive ecosystem types, population numbers of many mammal species have been dramatically reduced since European settlement, and many species have been forced outside their adaptive peak environments into sub-optimal habitats. Significant regional extirpations have also occurred, resulting in impoverished community assemblages and loss of associated ecosystem functions.

The loss of ecosystem function associated with loss of biological diversity is attracting increasing scientific interest and is of growing conservation concern (Doherty et al 2000; Hooper et al 2005). However, with respect to the landscape ecosystems within the GER corridor, we remain largely in a state of ecological ignorance. The loss from the Bega district fauna of the rat kangaroo or bettong (now found only in Tasmania) *Bettongia gaimardi* is a case in point. It is an example of likely, but only poorly studied, ancient and pervasive mutualistic symbioses between mammals, eucalypts and fungi. Bettong feed on ectomycorrhizal fungal sporocarps ('truffles'). Ectomycorrhizae (EM) fungi commonly form mushroom fruiting bodies and are usually associated with large woody plant species, especially in temperate zones (Bruns et al 2002). Many Australian eucalypt species support EM fungi, which act to facilitate nutrient cycling (Glen et al 2002). It is likely, given their eating habits, that bettong spread fungi and therefore facilitated eucalypt–EM fungi symbioses. The bettong has been found to contribute to other important ecological functions in Australian ecosystems (Noble et al 2007). However, the fact is we simply do not know the consequences of the loss of bettongs for the ecological integrity and resilience of landscape ecosystems in the Bega district.

These three case studies also serve to illustrate the kinds of past and ongoing land-use activities that are stressing the biodiversity of the GER corridor. A recent analysis showed that the NSW section of the GER corridor includes 59% of the State's vulnerable and endangered fauna species and 64 % of its endangered and vulnerable flora (of which 78% are vulnerable*)* species listed under the NSW *Threatened Species Conservation Act 1995* (M. Pennay pers comm 2007). As elsewhere, these statistics largely reflect the direct and indirect impacts of human activities, and in particular habitat loss and fragmentation (NLWRA 2002). A recent analysis (Mackey et al 2008a) has shown that when the conservation status is tabulated for all Australian terrestrial vertebrate species listed in one of the IUCN threat classes (IUCN 2007a) under (i) State legislation and (ii) non-legislative authoritative assessments such as national action plans, nearly 45% of all Australia's vertebrate species are in some form of serious decline in one or more parts of their range. These 'secret extinctions' usually fall below the conservation assessment radar.

3.4 Threatening processes

In this section we consider the role a connectivity conservation approach can play in promoting the resilience of species and landscape ecosystems in the GER corridor in terms of four major threatening processes. These processes have been identified as particularly significant by various reviews (Saunders et al 1996; NLWRA 2002; SoE 2006). The four threatening processes are climate change, habitat loss and fragmentation, altered fire and hydrological regimes and introduced species. We first consider each of these processes and then provide a synopsis of how connectivity conservation can help as part of a comprehensive threat mitigation and adaptation strategy.

Climate change

Australia's native plant and animal species are largely of ancient lineage, leaving aside relatively recent immigrants such as dingoes (*Canis lupus dingo*). The last great vertebrate animal speciation was during the Pliocene/early Pleistocene drying and cooling event some 4 to 1 million years ago, leading to an explosion in the number of species of song birds and the migration and subsequent radiation of rodents on the Australian continent (Rowe et al 2008; Worboys et al 2005; 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 (Osborne and Christidis 2002; Archer and Hand 2006). Australia's plant species are also of ancient lineage, with the origin of many traced back to Gondwanaland over 100 million years ago (Barker and Greenslade 1982; White 1986, 1994). Alpine and desert floras are of a more recent origin following speciation and recruitment in the Pliocene with the advent of cold or extensive dry climates (Barlow 1981; Hill 1994; Hope 1994).

Past global environmental change also involved species loss and range restrictions, particularly for rainforest taxa. For example, the *Brassospora* group of *Nothofagus* and gymnosperms such as *Dacrydium* 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; Mackey et al 2008a). Nonetheless, all the species extant when Europeans arrived in Australia had persisted for millions to tens of millions of years, including during the multiple glacial cycles of the last 500,000 years. Antarctic ice core records have revealed that every 100,000 years or so the global climate swings between cool–dry and warm–wet conditions, with resultant sea level falls and rises (Petit et al 1999).

Mackey et al (2008a) identified five adaptive responses or strategies to explain how species persisted on the continent through past climate and other environmental changes. These responses are the key to understanding how connectivity conservation can promote the persistence of species, the maintenance of ecosystem functions, and landscape integrity, in the face of future climate change.

1 **Local adaptation through microevolution**. With every generation comes new genetic material that may produce traits that, as revealed and promulgated by natural selection, make an organism better adapted to new conditions. There is increasing evidence that local adaptations are far more rapid, common and widespread than previously recognised and are now occurring in response to the climate change we are currently experiencing (Thompson 2005; 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 microevolution in that the adaptive response is found within the existing genome and is not the result of new, heritable genetic change in the population. It is likely that many Australian plants persisted through past climate change because of phenotypic plasticity in their physiognomy and phenology.

3 **Long-distance dispersal**. Dispersal of juveniles and seasonal migrations are common ecological activities. In addition, as noted above, 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. Indeed, given the extreme year-to-year variation in Australian rainfall and associated plant productivity, many Australian species may be pre-adapted to rapid climate change in this regard.

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 2005). 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).

5 **Wide fundamental niche and habitat generalist**. Species can also 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 responses to temperate regimes (Keast 1985). Also, an animal species can persist through being a habitat generalist that is able to obtain necessary food, shelter and nesting resources from a broad range of ecosystem types.

Given this, could we not reasonably assume that Australia's native species are well placed to respond to the global climate change now occurring? The problem is that the current rapid human-forced climate change overlays a suite of other serious human-caused threatening processes – especially habitat loss, fragmentation and degradation, the introduction of feral animals and invasive plants, and changed fire and hydrological regimes. These threatening processes are interfering with the natural adaptation processes that enabled species to persist through previous climate change events.

Human-caused climate change has altered, and will continue to alter, species distributions on regional and supra-regional scales in Australia. It is predicted that, by mid-next century, the equivalent of range shifts in biomes due to climate change will have begun to occur (Kapelle et al 1999; Hughes 2003; Howden et al 2003). Many native species have been found to occupy narrow climate envelopes. For example, one quarter of Australia's *Eucalyptus* species occur only over a range of 1 ºC average temperature and 20% average rainfall (Hughes et al 1996). It was argued (Brereton et al 1995) that for a scenario of 3 ºC local warming relative to 1990 temperatures, 15 of the 42 native fauna species from across Victoria would have their current climatic envelopes eliminated (envelope expansion was predicted for only one species). Another study has predicted that the distribution and occurrence of rainforest ecosystems in the north Queensland wet tropics will be altered by global warming, with the elimination of the climatic envelopes for 30 of the 65 species of endemic rainforest vertebrates (Williams et al 2003). Similar potential impacts were identified for the golden bowerbird, a bird endemic to ranges of north-eastern Australia (Hilbert et al 2004).

However, the reasons for such narrowly realised climatic envelopes are not clear because they can be due to:

- competitive exclusion, whereby species are restricted to a narrow subset of their potential (physiological) niche
- specialised edaphic requirements (i.e. associated with soil, substrate or topography)
- impediments to dispersal
- tight, genetically determined physiological niche thresholds.

Species will be in trouble if it is the last of these that proves to be the limiting factor. However, our scientific knowledge of ecology, ecophysiology and biogeography is insufficient to specify, for most species, the factors that determine their realised climatic envelope. It is therefore currently not possible to accurately predict species' responses to future climates.

Ignorance cuts both ways. Plants can be sensitive to small changes in average climate, because even small changes in averages can imply large changes in the frequency of extreme weather events that may be damaging to young plants. Furthermore, there will be significant ecological impacts from climate change indirectly through rapidly altered fire and hydrological regimes (Mackey et al 2002). One environment where the climate change impacts are less ambiguous is the Australian Alps, since, in evolutionary terms, cold climates are relatively new to the continent, having emerged only during the Pliocene. We can perhaps predict with more confidence that the narrow climatic envelopes found for many alpine species may represent physiological niches that will disappear even under modest global warming scenarios (Hennessy et al 2003).

Habitat loss and habitat fragmentation

Intensive land use is considered the greatest contributor to the loss of Australia's biodiversity over the past two centuries (SoE 2006; Lindenmayer 2007). The major spines of the GER corridor (the Great Divide and Great Escarpment) are adjacent to most of Australia's coastal population centres and its intensive agricultural zone. Consequently, parts of the GER corridor are in the midst of the most heavily cleared, fragmented and degraded landscapes in Australia, largely because of urbanisation and intensive agriculture (Figure 10). Since 1788 around 20% of all woodlands and forests have been cleared or thinned, primarily for crops, grazing and timber (ABS 2006). Forestry and mining have also had their impacts.

Figure 10: Regions where native vegetation clearing threatens ecosystems.

Extensive clearing and increased fragmentation of remnants are principal factors threatening ecosystems in eastern Australia. In northern Australia, horticulture and the introduction of improved pastures threaten ecosystems.

Source: Australian Natural Resources Atlas, Fast Facts 38 - vegetation clearing as a threat.

These broad statistics mask some important trends, because land clearance has been concentrated in certain ecosystems. For example, more than 95% of land clearing in Australia has occurred in 25 of Australia's 85 bioregions and in ecosystems that were found on the most fertile soils (NLWRA 2001; 2002). These regions now contain extremely high numbers of threatened species that exist as relict populations in fragmented landscapes (Garnett and Crowley 2000; Garnett et al 2002). More recently, human 'amenity migrants' (Moss 2006) and 'sea changers' are affecting natural habitats.

Habitat destruction directly destroys local populations of many native species and can easily lead to a species' local extirpation from a region. It almost inevitably leads to habitat fragmentation, by dissecting habitat into small and isolated pockets that, over time, cannot maintain populations of many species (Whittaker 1998; Miller and Cale 2000). Habitat loss and habitat fragmentation have led to catastrophic losses of eastern Australia's mammals (Bennett 1990; Holland and Bennett 2007); birds (Watson et al 2001, 2005), reptiles (Fischer and Lindenmayer 2005; Fischer et al 2005) and plants (Hobbs and Yates 2000).

The best response to such impacts is to retain natural lands in an undisturbed condition (Lindenmayer and Fischer 2006). The second most important response is to retain strategic interconnections to make habitat remnants both bigger and less isolated. However, habitat rehabilitation strategies still need to consider conservation management in the broader landscape matrix (Lindenmayer and Franklin 2002). Management of the land surrounding remnant habitat patches can also be critical for some threatened species in the fragmented landscapes of eastern Australia (Barrett et al 1994; Lindenmayer and Fischer 2006).

Management of the land surrounding remnant habitat patches is critical for a number of reasons. It can contain habitat resources for species with specific needs or large territories that cannot otherwise be found in the remnant patches. In south-eastern Australia, Lindenmayer et al (2002, 2003) and Fischer et al (2005) studied bird and lizard assemblages in native eucalypt patches located in an intensively managed matrix of introduced pine (*Pinus radiata*). They found that in this landscape many species were not restricted to native forest patches and some used the surrounding matrix extensively. In many cleared landscapes, where scattered trees are the only vegetation in the matrix, these trees have been found to be used by a majority of bat species (Law et al 1999; Lumsden and Bennett 2005) and many bird species (Fischer and Lindenmayer 2002;

Manning et al 2006) and they also provide useful resources for a range of reptiles (Fischer et al 2005). In addition to providing habitat and resources for some species, the surrounding matrix can be a movement conduit for some species, thus reducing the negative effects of habitat isolation. Date et al (1996) for example, found that frugivorous pigeons in northern NSW successfully moved among rainforest fragments and even utilised exotic fruits on the way. The reverse is also true. When the matrix is not managed to meet the needs of species it can become simply too hostile for native species to survive and these landscapes experience higher extinction rates in habitat fragments than in more appropriately managed landscapes (Lindenmayer and Franklin 2002).

Altered fire and hydrological regimes

Fire is a natural part of virtually all Australian landscapes and has an important influence on the biological productivity, composition, evolution and landscape patterning of ecosystems (Gill 1981; Mackey et al 2002). However, Australia's fire regimes (the spatial and temporal patterns of fires in a landscape) have been profoundly changed by modern land management. In systems fragmented by human activity, broad landscape processes have been disrupted, thus altering fire regimes (Hobbs 2000; Gill et al 2000). In the north of Australia there are now more large-scale, late dry season fires, and this has serious repercussions for fire-sensitive species and ecosystems (Woinarski et al 2007). Throughout the GER corridor, pre-European fire regimes have been altered in most landscapes as a result of both deliberate interventions aimed at protecting people and property, and inadvertently as the indirect result of land-use and land cover change.

There are significant conservation implications from ecologically inappropriate fire regimes in eastern Australia (such as too frequent fires, too few fires, an absence of hot fires and other perturbations). More species of native birds are threatened by altered fire regimes than by any other threatening process except land clearing (Woinarski 1999; Garnett and Crowley 2000). An example of a vulnerable species in eastern Australia that needs a highly focused fire management strategy is the eastern bristlebird (*Dasyornis brachypterus*). This species inhabits heathland; it has a highly restricted distribution, poor recolonisation abilities, and small populations that are sensitive to frequent fire (Baker 1997). It disperses poorly and appears to be vulnerable to the effects of large-scale fires that do not leave unburnt refugia (Pyke et al 1995; Baker 1997).

The impacts of disturbances by fire and associated effects on biota are complex. This is because in some landscapes the absence of fire creates problems such as a lack of regeneration of key species (Zackrisson 1977), whereas in other landscapes fires can be too frequent or too intense (Gill et al 1999). Owing to legal obligations and important social responsibilities, fire management in Australia is dominated by concern for human safety and property protection and less consideration is given to ecological fire regimes. Changes in fire regimes also affect the management of catchments regarding water supply.

The large-scale impoundment of water for human uses is another process that has had profound impacts on habitats in eastern Australia. Australia has 466 large dams with a crest height greater than 10 metres, and 196 (63%) of these are found within eastern mainland Australia. As noted by Kingsford (2000), these dams have changed aquatic vegetation, reduced vegetation health, reduced populations of waterbirds, native fish and invertebrates, and caused some floodplain wetlands to become permanent storage areas, so the naturally occurring plants and animals are replaced with species not tolerant of variable flooding regimes.

As noted above, hydroecology plays out over large scales. For example, estuarine food abundance for migrating birds may depend on hydrological catchment processes occurring hundreds of kilometres from the ocean (Tracey et al 2004). The negative impacts of inappropriate land-use activities – especially extensive clearing – on hydroecological processes are also well-documented in some areas of Australia (Cramer and Hobbs 2005). The environmental condition of the Great Barrier Reef, for example, is dependent in part on the water quality from at least 33 river basins (NLWRA 2002) that flow from the GER corridor. As impacts occur on many easterly and southerly flowing rivers, those second order (and above) streams that flow naturally from the GER corridor catchment watershed to the coast become even more significant. The environmental impacts of altered hydrological regimes are probably best documented in the Murray–Darling river basin. The costs of salinity in the basin have been estimated to total at least $305 million per year, and a number of environmentally significant terrestrial and wetland areas are at risk.

3.5 Introduced species

Invasions of weeds and feral animals over the past two centuries have contributed heavily to the decline and extinction of many of Australia's flora and fauna. The introduction of the two exotic generalist predators (the cat, *Felix domesticus,* and fox, *Vulpes vulpes*) has, in part, led to all mammal and bird extinctions that have occurred in Australia since European settlement (Johnson 2006). The introduction of the cane toad (*Bufo marinus*) has also decimated the snake and reptile populations in northern Australia (SoE 2006).

The invasion of other non-native species is also affecting Australia's biodiversity, with more than 2,500 non-native species now established in Australia (SoE 2006) and the total proportion of introduced plants to all plant diversity being 12% (Woinarski et al 2007). There are 20 recognised weed species of national significance causing significant environment damage, and all of these species have the potential to spread further (SoE 2006; Randall 2007). One example is *Lantana camara,* which is now naturalised on over 4 million hectares in Australia. Most species of willow (*Salix* spp.) are weeds of national significance and are considered to have only invaded 5% of their potential range in Australia.

3.6 Threat mitigation and landscape resilience

Given the brief review above of case studies and threatening processes, following are some specific ways in which a connectivity conservation approach can help to mitigate the impact of threatening processes and promote landscape resilience in the GER corridor.

Protected area buffering and de-islanding

Connectivity conservation highlights the need to:

- buffer the boundaries of existing protected areas
- ensure protected areas do not become or remain terrestrial biodiversity islands amidst a 'hostile ocean' – that is, a landscape matrix unsympathetic to biodiversity.

We can call the latter goal 'de-islanding' (or 'islanding prevention' if a protected area is not yet isolated). Although both these goals are well recognised, conservation connectivity elevates their significance as a prerequisite for the long-term conservation of biodiversity and demands that they be incorporated into systematic conservation planning.

Protected area buffering and de-islanding can be achieved through a range of mechanisms, including:

- expansion of the boundaries of existing protected areas
- designation of new protected areas
- covenants on private land
- special conservation conditions for leasehold land
- establishment of Indigenous Protected Areas
- payments for ecosystem services arising from habitat protection.

The mechanisms employed for buffering and de-islanding will vary across the GER corridor, depending on tenure, land-use history, existing planning overlays, available resources and community uptake of opportunities to contribute to the GER corridor vision and plan. Consistent with the recommendations of Sattler and Taylor (2008), projects aimed at buffering and de-islanding should give priority to first securing extant native habitat, and then restoring existing native regrowth vegetation. Revegetation on cleared land to restore landscape connectivity should be employed only as a last resort, when neither of the other two options is available.

Conservation on private, leasehold and Aboriginal land

Significant biodiversity assets occur outside conventional protected areas on private, leasehold and Aboriginal land. In addition to the contribution these lands can make to buffering and de-islanding protected areas, they are critical for achieving 'comprehensiveness' and 'representativeness' conservation targets. Simply put, there are many species, community assemblages and ecosystems that are not found on public land such as national parks, State forests or defence areas, or on unallocated Crown land. When viewed in isolation, the conservation significance of any given hectare of habitat on unprotected land can be dismissed as marginal ('there's always another hectare across the fence'). The GER corridor will provide the necessary context to help landowners and stewards understand and value the contributions of their small pieces of the biodiversity puzzle. At the same time, conservation managers will have the necessary context for identifying priorities within and between regions. We can no longer afford to ignore, or not give priority to, the biodiversity assets that lie outside the conventional conservation estate.

Maximising biodiversity asset accounting

The GER corridor has a vital role to play in helping to synthesise available data – providing a structured approach to filling in the knowledge gaps – and in applying this information to biodiversity conservation. We argue that the current biodiversity inventory available for systematic conservation planning in Australia and the GER corridor is inadequate (admittedly, this is the case for most bio-rich places in the world). We have reasonable information about the distribution of broad vegetation types and the life histories and autoecology (including habitat requirements) of most vertebrate animal species, vascular plant species, many non-vascular plants, and some invertebrates and fungi. However, it is what we know we do not know that is of concern, given that the basic input data for systematic conservation planning consist of spatial inventories of biodiversity assets. All planning models are constrained by the quality of the input data – a minimalist biodiversity account will produce a minimalist conservation plan. We urgently need to build maximal, rather than minimal, accounts of our biodiversity assets.

As discussed above, the ecological reality is that species with any kind of geographical range interact with different species across their distribution, forming distinctive community assemblages. Each of a species' populations therefore interacts with differing suites of (depending what kind of organism it is) antagonists (parasites; competitors for food, shelter and nesting resources; grazers; predators) and mutualists (symbionts; seed dispersers; pollinators). Furthermore, each population encounters different environmental conditions (e.g. drier and less fertile soil conditions, hotter and more frequent fires, greater variability in year-to-year rainfall), which also operate as selective forces on the evolution of plant and animal traits, including life history strategies and tactics, with natural selection promoting the persistence of organisms that can best exploit the extant conditions (Southwood et al 1983).

The increasing accounts of the genetic differentiation among the populations of many species reflect, at least in part, the complex and diverse biological and physical environmental conditions that a species interacts with and is adapted to – if it is to persist. Even populations that are genetically identical can, over time, become genetically differentiated owing to the differing selective pressures they face, in addition to random genetic drift. The extent to which populations become genetically differentiated also depends on the amount, rate and direction of gene flow between them. As noted by Thompson (2005) in relation to lands still dominated by natural processes:

> These are the landscapes in which we can still evaluate the genetic, populational and regional processes of coevolution that keep players in the evolutionary game for long periods of time … Each of them [long coevolved interactions] is a product of thousands or even millions of years of evolution and coevolution. These species have geographically structured genomes that have been honed sharply by natural selection across unforgiving landscapes, and their gene sequences carry crucial information on what works when coevolving with parasites, predators and mutualists in particular kinds of environments.

We have only just begun the task of mapping the geographic mosaic of community assemblages and their associated ecological, evolutionary, and coevolutionary local adaptations across the GER corridor.

The GER corridor provides the multi-scaled planning framework needed to ensure that the new vistas on biodiversity being revealed by studies of landscape genetics are synthesised and integrated into the biodiversity inventories that underpin systematic conservation planning.

Planning for ecosystem resilience and long-term persistence

Conservation planning must encompass the requirements of species and ecosystems in light of the largest-scale processes influencing system dynamics – whether those processes are physical, ecological, evolutionary or threatening. From hierarchy theory, we know that the conservation estate needs to be 'larger' than the largest-scaled phenomenon and, in particular, the largest-scaled external disturbance (Allen and Starr 1982). Global climate change and large unplanned fires, particularly in the forests of the GER corridor, are two obvious candidates for large-scale threatening processes that operate at supra-regional scales. However, the interactions between invasive plants, climate change and fire regimes must also be considered.

Ecologically interconnected and intact natural lands maximise the opportunities for species to positively respond to climate change by using the various adaptations noted in 'Climate change' in section 3.4. Such lands also provide greater 'landscape depth' to those natural forests of southern and eastern Australia that experience mega-fires. To maintain their biodiversity and promote the restoration of catchment integrity and habitats post-fire, these forests need a sufficiently large interconnected natural area to maintain a mosaic of burnt and unburnt lands at any given time (Mackey et al 2002).

The resilience of ecosystems to invasive plants is also a function of landscape integrity, as the spread of many weeds is facilitated by disturbances and land degradation. For more aggressive introduced species (both plant and animal), active control measures will be needed on a landscape-wide basis in the same way they will be required for protected areas. The GER corridor provides an opportunity for a coordinated, large-scale response to this problem.

Strengthening the National Reserve System

The National Reserve System (NRS) is Australia's premier investment in nature conservation. In 2005, 10.5% of terrestrial Australia was reserved as IUCN Category I–VI protected areas (CA 2005). Recent years have seen important efforts by the Commonwealth and State governments to improve Australia's protected area system. Specifically, this has been achieved by promulgating a more systematic approach to the identification and establishment of new reserves through the NRS on the basis of the criteria of comprehensiveness, adequacy and representativeness (CA 1997; Possingham et al 2006). The NRS forms the cornerstone of efforts to protect Australia's biodiversity in the face of extant and imminent threatening processes. However, even at the broad vegetation group level, only 67% of Australian ecosystems are represented by the NRS, and it is recognised that many reserves are far too small and are poorly connected to other natural areas (NLWRA 2002; Recher 2004). If we consider the maximal biodiversity asset accounting discussed above, achieving even modest representativeness targets will require complementary efforts. Further, even if national representativeness targets are reached at the broad ecosystem level, for many ecosystems this will be an insufficient area to ensure that biodiversity assets are adequately protected. The reality is that a threshold of 15% (CA 2005) is scientifically arbitrary and probably more strongly reflects presuppositions about what is socially and politically feasible (Recher 2004; Soulé et al 2006).

The GER corridor can play a complimentary role to the NRS by promoting conservation outcomes in the landscape matrix and attracting additional resources to broaden and deepen the representativeness and adequacy of the conservation estate. The GER corridor can further complement the NRS by considering the conservation requirements of species that present special conservation challenges. In particular, dispersive animals (non-obligate resident bird species and fish) may be ill-catered for by the NRS, as their long-term survival depends on protecting the ongoing productivity of source resource areas in multiple and varying locations. For regular migrants, this can require the maintenance of ecosystem types in different parts of the continent on which they are seasonally dependent (Woinarski et al 1992; Soulé et al 2004; Gilmore et al 2007). For such species, habitat resources are not necessarily found in, or do not persist, reliably within the same landscape and are distributed across land tenures.

The GER corridor can also complement the NRS by explicitly considering the various ecological and evolutionary processes that operate at scales larger than even the largest and most extensive of our terrestrial reserves (Figure 3). These large-scale ecological processes are important for the long-term conservation of biodiversity because they constitute evolutionary selective forces to which species are adapted (such as fire and hydrological regimes) or because they sustain and replenish the habitat on which animals depend (such as hydroecological processes) (Soulé et al 2004; Mackey et al 2007). As noted by various authors (Nix 2004; Recher 2004; Soulé et al 2006) the foundation of a national climate adaptation conservation strategy for Australia is to build on the NRS by recognising the need:

- for a whole-of-landscape approach to conservation at a scale that extends beyond conventional conservation policy and planning
- to ensure that protected areas are embedded and interconnected within complementary conservation management in the surrounding lands on all land tenures.

4 Benefits to species and ecosystem services

It is not possible within the confines of this report to present an exhaustive inventory and documentation of the benefits to species and ecosystems from connectivity conservation in the GER corridor. Nor it is possible to ascertain the full suite of ecological functions performed by these species and their contribution to landscape resilience and the maintenance of ecosystem services. Therefore, in response to term of reference no. 3, we simply present here some indicative species and ecosystem benefits likely to benefit from application of connectivity conservation principles to the GER corridor planning and management.

4.1 Indicative species

Along the GER corridor, many species have declined in both range and in abundance owing to processes associated with anthropogenic habitat fragmentation, habitat degradation and habitat loss due to various and often complex factors (Lindenmayer and Fisher 2006). Following are some indicative examples of how loss of habitat connectivity in the GER corridor has led to extirpation of species or species assemblages, or both, and thus where potential benefits can be derived from applying a connectivity conservation approach. Species, such as those noted below, that have undergone a decline in the GER because of habitat loss, degradation and fragmentation will benefit from connectivity conservation. This is because actions associated with restoration, land stewardship and formal habitat protection will increase the extent and ecological connectivity of habitat needed for these species to persist. These actions will also help remove direct threats (including exotic predators, logging, grazing and clearing of important habitat) from these landscapes.

Mammals

Fischer et al (2004) showed that the greater glider (*Petauroides volans*) needs trees of a particular age and abundant tree hollows in the montane ash forests of the Central Highlands of Victoria. Logging and land clearing remove these trees and have therefore caused a decline in this species. Pope et al (2004) found that the home range size of the greater glider decreased significantly with decreasing patch size and increased patch population density. Many rainforest mammals in northern Queensland are unable to use the new matrix in the remaining fragmented landscapes, and many of the remnant habitat patches are undergoing ‘relaxation’ as a consequence (Laurance 1991). Habitat fragmentation and degradation have also been shown to be important causes of increased movement by introduced predators (cats, foxes); this in turn has led to large declines in small marsupials and ground-dwelling birds in eastern Australia (May and Norton 1996).

Birds

Recher et al (1987) found that within linear strips of eucalyptus forest surrounded by an extensive radiata pine (*Pinus radiata*) plantation in eastern Australia, some species of birds and mammals have to move over large distances because they rely on dispersed food resources. This has led to overall decline in breeding success and the loss of some local populations of birds. Watson et al (2001, 2005) showed that in the temperate woodlands of the northern ACT, both remnant patch size and isolation and matrix ‘quality’ affect species assemblage at a regional scale. The more fragmented a landscape is and the more hostile the matrix surrounding these landscapes is, the fewer woodland-dependent birds persist in the landscape. The eastern yellow robin (*Eopsaltria australis*), which occurs in forest remnants of northern NSW, is declining in smaller remnants because of a loss in availability of food within the remnants (Zanette et al 2000).

Paton (2000) showed that, in southern Australia, honeyeaters are limited by food supply in summer and autumn; the effects of this are clearly exacerbated when these habitats have been altered. It has also been found that landscape alteration in the GER corridor can have profound impacts on competition for resources and can increase aggressive behaviour between taxa. The noisy miner (*Manorina melanocephala*) has increased dramatically since European settlement because of woodland and forest fragmentation and these birds’ aggressive behaviour has led to significantly reduced bird species richness in many woodland remnants; in particular, a reduction in insect- and nectar-feeding birds (Grey et al 1997; also see Section 3.3). There has also been some evidence that habitat fragmentation in the GER corridor is having an effect on the genetic make-up of species. For example, allee effects appear to be among the factors contributing to population declines of the speckled warbler (*Pyrrholaemus saggitatus*) (Gardner 2004).

Reptiles

Driscoll (2004) showed that reptiles have reduced species richness in landscapes in south-eastern Australia subject to land-cover modification. Hazell et al (2001, 2004) assessed the impacts of the degradation of aquatic ecosystems on amphibians in south-eastern Australia since European settlement. As a result of land clearing, overgrazing by domestic stock, and mining operations, deeply incised, fast-flowing streams now characterise areas that were formerly series of loosely connected 'chains of ponds'. As a result, some species, such as Bibron's toadlet (*Pseudophryne bibronii*), are now declining, as they lack the habitat resources needed to complete their breeding cycle. Summer et al (1999) showed that the density of prickly forest skink (*Gnypetoscincus queenslandiae*) was lower in rainforest fragments than in continuous areas of rainforest in eastern Australia (Queensland), and that adult skinks in fragments were significantly smaller than skinks in areas of continuous forest.

Dispersive species

Further comment is warranted on dispersive species. As noted above (Section 2.5), some 535 of Australia's vertebrate species (including 342 land and freshwater birds) are recorded as being dispersive (Gilmore et al 2007) and can travel long distances to obtain the habitat resources they need in response to climatic variability: seasonal, periodic and year-to-year. Such adaptations present unique conservation challenges, as the species often require resources not found within the formal protected area network (Soulé et al 2004; Woinarski et al 1992). There are many birds (such as quail, waterfowl, herons, kites, harriers, hawks, crakes, rails, button-quail, parrots, cuckoos, owls, a kingfisher, pardalotes, honeyeaters, chats, trillers, woods wallows and grassfinches) that breed and live in inland Australia and are subject to droughts. During such times, some may not breed, some may die, and others may disperse to find refuge areas, including habitat in the GER corridor, in order to survive (Menkhorst 2003).

Many birds found in the better-watered habitats of the GER corridor undertake north–south migrations; they include a number of species that breed in the high forests of the Great Dividing Range from western Victoria to north-east Queensland and move to lower latitudes in autumn–winter. These species include yellow-tailed black and gang-gang cockatoos; Australian king parrots; crimson rosellas; noisy pittas; Lewin's honeyeaters; flame, scarlet and rose robins; golden whistlers; grey fantails; pied currawongs; Torresian crows; regent and satin bowerbirds and Bassian thrushes (Menkhorst 2003).

Resident species

Many other species of the GER corridor are more specialised and are dependent on specific habitat types. However, as discussed above, the distribution and abundance of species and the composition of community assemblages are likely to be rearranged in response to climate change. As noted by Mansergh and Cheal (2007), moving to a more suitable location is only an option if suitable habitat is available that allows such movement (and if important mutualists co-locate). Although more research is needed, Mansergh and Cheal (2007) also cited empirical and experimental evidence to support their recommendation that maintaining the ecological integrity of habitats (by reducing the effects of human perturbations and protecting source populations and refugia) and ensuring ecological connectivity and biological permeability between habitats were likely to be more effective strategies than relying on active translocations. Interestingly, the long-term scientific field experiment conducted by Damschen and colleagues (2006, cited by Mansergh and Cheal) demonstrated statistically that corridors did increase native plant species richness and did not enhance the spread of exotics. A connectivity conservation approach implemented in the GER corridor will maximise opportunities for species to respond positively to climate change by providing a range of habitats and potential destinations for dispersive species.

4.2 Ecosystem services

The concept of 'ecosystem services' aims to express in economic terms the benefits humans derive from the free goods and services received from natural ecosystems. These can be measured in four classes, namely, 'supporting' (e.g. nutrient cycling), 'provisioning' (e.g. of freshwater), 'regulating' (e.g. regulation of flooding regimes) and 'cultural' (e.g. iconic and totemic species) (MEAB 2005). People and other species benefit directly from the functioning of ecological systems, including the supply of clean air and fresh water and the removal of waste products. Such ecosystem services are critical for life on Earth. Some analysts have quantified these ecosystem services in financial terms (Daily and Ellison 2002) and have placed an average global price tag of $US33 trillion a year on the provision of fundamental global ecosystem services (Costanza et al 1997). This is nearly twice the value of the global gross domestic national product of $US18 trillion. Some of the phenomena we value about biodiversity can be treated as economic services or even as commodities. In these cases a real or 'shadow' market price can be obtained.

However, there are many biodiversity values that cannot be quantified in economic terms and, in any case, the actual ecological roles of most species are unknown. The ecosystem services of most interest in Australia and of relevance to the GER corridor are the regulating service of carbon storage and the provisioning service of water supply. Both are of increasing economic interest because of climate change, but water has always been of concern as it is a limiting factor in most parts of the continent.

Carbon storage

It is very likely that, in the near future, carbon will have a market value. Irrespective of how international rules play out, there will be increasing economic opportunities under nationally mandated cape-and-trade transactions. Voluntary carbon transactions can also be expected to remain on the increase (Bayon et al 2007).

One necessary action to help solve the climate change problem is to prevent emissions from deforestation and forest degradation (reduced emissions from deforestation and degradation: REDD) (IPCC 2007a). Emissions from deforestation represent about 18% of annual global emissions – a share greater than that of the global transport sector (Nakicenovic 2000; IPCC 2006). Emissions from degradation of forests and other ecosystems have yet to be fully accounted for, but they are likely to be in the order of 10–15%. This would mean that emissions from land clearing and ecosystem degradation may account for more than 20% of the root cause of the climate change problem. Various mechanisms are now being considered for directing investments for funding activities that will result in REDD. Different rules and policies may be promulgated for REDD in developing versus developed countries. In any case, we should plan for 'wall-to-wall' carbon accounting in anticipation that the green carbon in natural forests and woodlands will very soon have a market value.

In 2006, agriculture produced around 16% of Australia's greenhouse gas emissions and forest land converted to crop and grassland provided a substantial contribution to the net emissions (AGO 2006; Mansergh and Cheal 2007). In contrast, in Victoria and Western Australia, agricultural lands converting to 'amenity landscapes' (Moss 2006) have helped to convert carbon source agricultural landscapes to re-afforested lands and net carbon sinks (Mansergh and Cheal 2007). However, accurate estimation of the green carbon currently and potentially stored in the GER corridor's terrestrial ecosystems is complicated by land-use history and, in particular, by logging and other land use activities in forests and woodlands that have reduced the current carbon stocks to below the natural carbon-carrying capacity (Mackey et al 2008b; Keith et al 2009, 2010). Therefore, further research is needed before the potential carbon value of the GER corridor ecosystems can be comprehensively quantified.

Nonetheless, research to date suggests that the GER corridor will help facilitate the retention and restoration of green carbon stocks in the most carbon-dense landscape in Australia (see Roxburgh et al 2006a; 2006b; Dean et al 2004; Mackey et al 2008b), and contribute significantly to management of Australia's carbon footprint and meeting its international climate change obligations. More specifically, appropriate conservation management could lead to the GER corridor making a significant contribution to Australia's national carbon accounts by (Keith et al 2009, 2010):

- protecting the stocks of carbon in forests and avoiding depletion of these stocks through emissions associated with forest logging, soil disturbance and regeneration burning
- allowing forests to reach towards their carbon-carrying capacity by cessation of the logging and other land use activities that remove, in particular, large, old trees that store most of the above-ground carbon and cause emissions of soil carbon stocks, thus restoring the forest's current carbon stocks
- further increasing the stock of carbon stored in the GER corridor ecosystems by promoting permanent native revegetation and restoration.

Water

Water supply is a critical issue for Australia and will be even more critical in the future. Climate change forecasts predict that parts of southern and eastern Australia will be substantially drier and hotter, and there is also a greater chance of more frequent large fires affecting certain catchments (IPCC 2007c). The mountainous and upland areas of the GER corridor contain headwaters that capture the most reliable rainfall in eastern Australia. The ongoing quality and supply of water are fundamental to the human health and economic development of Melbourne, Sydney, Brisbane and all coastal towns and cities between Eden and Cairns. The GER corridor catchment also feeds into the Murray–Darling Basin, and its waters flow to the Great Barrier Reef and nearby coastal systems that are important breeding grounds for fisheries.

GER corridor connectivity conservation planning can therefore contribute to ensuring the healthy functioning of Australia's most important water catchments. The type and condition of the vegetation cover are major factors influencing catchment hydrology and the quality and flow of water. Research on the *Eucalyptus regnans* forests that dominate the Victorian Central Highlands catchment (the source of Melbourne's water supply) has demonstrated a significant relationship between water yield in streams and the age of the forest. Following a stand-destroying disturbance, water flow from the catchments is reduced for the following 20–30 years, before gradually rising back, but pre-disturbance water yields are not expected to be reached for a further 100–150 years (Kuczera 1987). The reason for this relationship between disturbance, tree age and water flow is that young regenerating trees transpire more water than mature trees.

The interconnected Australian Alps protected areas (part of the GER corridor) are actively managed to conserve catchment and other values. They deliver long-term average water volume contributions of 5% to the Murray River system and 14% to the Murrumbidgee River system, and in dry conditions these contributions become more significant (Young 2004). For the Murray–Darling Basin irrigation areas, this water is estimated to be worth on average $245 million of the annual gross value of irrigated production (Young 2004). Connectivity conservation planning can help with the necessary whole-of-basin-scale ecosystem-based management that is now needed, particularly in response to climate change.

Various studies have also found that the presence of native vegetation can influence local rainfall in complex and unexpected ways and that land clearing can lead to a reduction in rainfall (Lyons et al 1993; Lyons 2002; Durieuxa et al 2003; Silberstein et al 2004; Gero and Pitman 2006; Preston and Jones 2006; Ray et al 2006). Native vegetation protection and rehabilitation are also important to other aspects of the hydrological cycle, including groundwater recharge, managing dryland salinity and maintaining riparian vegetation (Hairsine 1997).

Other ecosystem services

The GER corridor has outstanding landscapes for recreation and nature-based tourism. The area contains the largest and most accessible mountainous recreation areas in Australia and one of the longest walking tracks in the world – the 5,330-kilometre Bicentennial National Trail – which extends from Cooktown in Queensland to Healesville in Victoria. Many national parks in the area are readily accessible to 11 million Australians, being within a 4-hour drive of major cities. State Forests also provide complementary recreational and tourism opportunities. Nature-based tourism provides great benefit to eastern Australia's economy, human health and wellbeing.

The naturally vegetated lands of the GER corridor help protect soils and the many steep slopes associated with the Great Divide and the Great Escarpment lands. Maintaining intact and ecologically connected natural vegetation cover across catchments will help prevent further erosion in the face of the forecast increase in the frequency and severity of storm events in the future (IPCC 2007b), particularly in northern Australia. This ecosystem service will be especially important for minimising the loads of anthropogenic-driven sediment that easterly-flowing streams can potentially carry to the Great Barrier Reef. The reef is already being stressed by climate change-related water temperature increases (IPCC 2007b, c).

5 Connectivity conservation principles

On the basis of this review, the documented experiences of connectivity conservation practitioners and connectivity conservation management guidance (Worboys et al 2009), we have identified key connectivity principles and design criteria. As part of these considerations, we will also discuss some additional conservation goals that will need to be factored into strategic planning for the GER corridor.

5.1 Connectivity conservation principles

The following principles characterise the connectivity conservation (CC) approach.

1. CC initiatives focus on geographically extensive areas that are at least supra-regional in scale, and can extend to continental and intercontinental scales. The entire area of interest is called a 'landscape corridor', 'CC corridor' or 'CC area'. Other synonyms are 'biodiversity corridor' and 'biological corridor'. CC landscape corridors encompass the existing networks of protected areas (IUCN Categories I–VI), plus the intervening and surrounding lands – the so-called landscape matrix.

2. The landscape matrix serves a number of critical functions, including:
   - buffering the boundaries of protected areas
   - maximising ecological connectivity and biological permeability between the protected areas (de-islanding)
   - protecting and restoring biodiversity assets not found within protected areas
   - maintaining large-scale ecological and evolutionary processes.

3. Projects aimed at buffering and de-islanding should give priority to first securing extant native habitat, and then to restoring existing native regrowth vegetation. Revegetation of cleared land to restore landscape connectivity should be employed only as a last resort when neither of the other two options is available.

4. Ecological connectivity and biological permeability can be facilitated in the landscape matrix through promoting conservation management in:
   - relatively small and linear wildlife corridors linking remnant habitat patches
   - more extensive (e.g. whole-of-catchment scale) habitat corridors
   - special habitat locations that serve as 'stepping stones' for particular species such as migratory birds
   - special habitat locations that function as refugia
   - networks of riparian zones and stock routes
   - remaining large scale naturally interconnected lands of high conservation value and strategic conservation importance.

5. Achieving conservation outcomes across the landscape matrix involves active management to:
   - minimise or eliminate human-caused threats including habitat destruction, introduced species and altered fire regimes
   - rehabilitate strategically important disturbed areas and ecosystems.

   Various instruments and mechanisms can be employed to promote conservation outcomes in the landscape matrix, including covenants, payments for ecosystem services and establishment of Indigenous Protected Areas and Private Protected Areas.

6. CC initiatives invariably involve achieving conservation outcomes in an integrated way across a range of land tenures – private property, community-owned property, leasehold, unallocated Crown land and various categories of government-managed land. Given this, CC initiatives must

find innovative and participatory ways of working with people and communities (Pretty and Smith 2004), based on, among other things:

- a shared vision and people working together voluntarily to achieve this vision
- an agreed strategic plan to help implement the vision
- innovative partnerships and cooperation between organisations and with individuals.

7 Financing of CC initiatives may be achieved from a diversity of sources in addition to conventional budget allocations from Commonwealth and state governments, including:

- philanthropic investments
- intra-government legal, policy and financial incentives
- payment for ecosystem services.

8 Increasingly, the climate change imperative is becoming a prime motivating factor for CC initiatives which are seen as long-term strategic approaches to biodiversity conservation. Furthermore, increasing recognition is being given to the economic and social benefits to individuals, property owners, communities and governments that stem from CC initiatives.

5.2 The GER connectivity corridor design and management

The above principles defining connectivity conservation initiatives have implications for the GER corridor design. Achieving conservation outcomes across the landscape matrix will require considerable voluntary contributions (especially on private, leasehold and Aboriginal land) and these voluntary contributions should be integrated to achieve a shared connectivity conservation vision including facilitating biodiversity conservation goals. Achieving an appropriate balance between scientifically-based conservation priorities, available resources and opportunities will require that the GER corridor initiative makes substantial and ongoing use of systematic conservation planning (Pressey and Cowling 2001). Given that resources for conservation investments are limited at any given point in time, a key task for planners will be to identify priorities for conservation investment from year to year and place to place. The comprehensive approach required for the GER corridor suggests the need for the ongoing development of sophisticated planning tools that enable the entire landscape to be evaluated and the optimum set of dedicated reserves, areas of connectivity and off-reserve management requirements to be identified (Soulé et al 2004). If these kinds of challenges can be properly formulated as a decision theory problem, decision theory algorithms can help solve the problem efficiently (Possingham et al 2001).

Significant advances have been made in developing planning tools to help identify networks of dedicated reserves that represent some kind of optima with respect to representation of biodiversity, their spatial configuration and the potential impact of removing land from other land uses, while at the same time minimising costs (Possingham and Wilson 2005). However, this type of planning has typically been applied at the bioregional scale and has not included conservation management of the broader landscape matrix. However, new approaches to large-scale planning are being developed and tested, including methods for incorporating targets for large-scale ecological and evolutionary processes (Klein et al 2009) and conservation management options (Murdoch et al 2007). Invariably, the GER corridor will present new technical problems for conservation planning tools that require further research and development.

Connectivity conservation planning will need to reflect the principle of subsidiarity which, as discussed above, implies that problems are solved at the appropriate scale and level of governance. Connectivity conservation does not mean that the only relevant scale is large scale. Rather, it implies a hierarchy of conservation plans where the goals and actions at each level are informed by those at the larger scale which in turn set the context for finer-scaled decision making. Managers describe these planning levels as strategic, tactical and operational planning (Worboys et al 2005).

As noted earlier in various sections, the connectivity conservation approach highlights the need for active conservation management to mitigate threats to biodiversity. Active conservation management contributes to the buffering and de-islanding of protected areas and the protection and restoration of ecological processes and important habitats in the landscape matrix. Connectivity conservation management needs to be explicitly incorporated into systematic conservation planning, along with targets for identifying new protected areas and priorities for promoting ecological connectivity and biological permeability. An essential part of planning for conservation management regimes is the need to factor in the diversity of social, natural and management settings that characterise the GER corridor.

A conceptual framework for managing connectivity conservation for large scale areas has been developed (Figure 11) (Worboys et al 2009). The conceptual framework identifies the central, pivotal role of a shared vision and five management functions. The first function establishes the situational contexts for people, nature and management for the connectivity area, and consistently provides updated information to managers reflecting changes happening in a dynamic real-world environment. Leadership is a critical function, and may be undertaken by many individuals and organisations across a connectivity area; and planning, implementing and evaluating are critical functions that are needed if the vision is to be achieved (Figure 11). Nine key tasks have been identified for connectivity conservation management in IUCN's book on this subject (Worboys et al 2009).

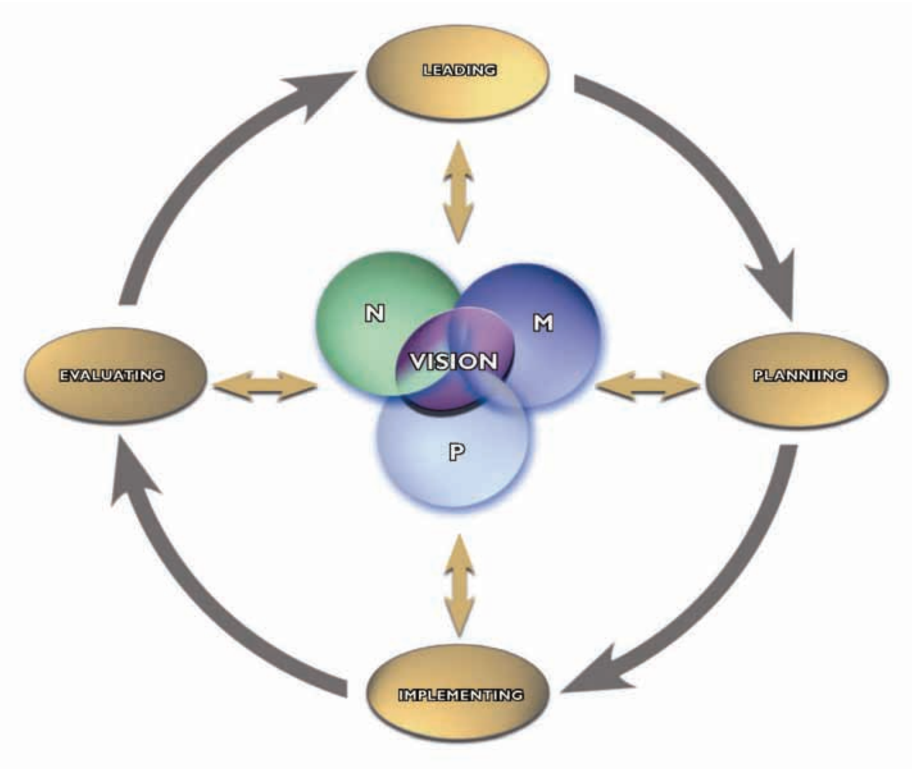

Figure 11: A conceptual framework for GER corridor connectivity conservation management. The framework illustrates the central role of the connectivity conservation vision and five functions of management. Establishing the context for people (P); nature (N); and management (M) and their interaction is a critical central function which helps inform other management functions. A process of connectivity management may be broadly recognised including the pivotal role of leadership at multiple levels; planning for management; implementation actions; and, the evaluation of actions taken and progress achieved in achieving the vision (Worboys et al 2009).

5.3 GER connectivity corridor conservation goals

GER corridor strategic conservation planning and management must be based on scientific knowledge about what is required to promote the long-term conservation of biodiversity. Therefore, systematic conservation planning undertaken for the GER corridor should incorporate the following conservation goals:

1 **Maintaining (i) viable populations of all extant species and (ii) natural infra-species genetic diversity and thus options for local adaptation.** Achieving these primary goals will

in turn require replicating habitats in the reserve system to protect multiple source populations across the environmental gradients occupied by the species (Pressey et al 2007).

2 **Identifying and protecting relictual and other types of refugia**. Past climate change has resulted in some species suffering dramatic range reductions and these species now only occur in networks of scattered locations that retain suitable conditions at a 'micro' scale. Ecological refugia may prove critical in assisting certain species to persist through future rapid climate change because they provide a degree of additional resilience. Although some of Australia's protected areas contain recognised evolutionary and ecological refugia, many locations that function as refugia are not under any form of protection (Mackey et al 2002; Sattler 2007).

3 **Accounting for the special role of extensive (large-scale) intact lands in the future protection of Australia's biodiversity**. The high level of natural connectedness found in large-scale intact lands improves the likelihood of survival of species by supporting large populations, a range of microhabitats, and the prospects that landscapes are permeable to the maximum range of plants and animals. 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; Soulé et al 2004; Mackey et al 2007).

4 **Maintaining or restoring large-scale ecological and evolutionary phenomena, flows and processes**. Protecting the special habitat requirements of dispersive species will be important in the face of rapid climate change (see sections 2.5 and 4.1); for example, by protecting and restoring known large-scale migration linkages that operate at regional and continent scales. If habitat connectivity has already been destroyed (as is the case for most of the temperate woodlands of southern Australia), it is important that some carefully selected large-scale linkages between existing nature reserves are rehabilitated as part of the GER corridor connectivity conservation framework, including (potentially) the development of some regional networks of habitat patches and habitat 'stepping stones' (Lindenmayer and Fischer 2006).

5 **Strategic monitoring throughout the GER corridor to demonstrate the effectiveness of connectivity conservation management and to identify trends in threatening processes.** Monitoring is needed to establish baseline values for selected GER corridor phenomena, measure change in condition and identify the severity of threats. Such research will be essential in order to implement adaptive management in the GER corridor (Figure 11).

6 Conclusions

An argument sometimes heard is that large-scale systematic conservation planning is unnecessary, and that one or other of the smaller scales of planning and management, such as the bioregional scale, will suffice. We have argued this is not the case and that a hierarchy of scales are required for systematic conservation planning and management. In addition, we have suggested that there is actually no conflict between a bioregional and a continental connectivity conservation approach to planning. A continental connectivity conservation approach builds on the same logic that is used to justify a bioregional approach (Sattler and Taylor 2008), but extends the concepts in space and time to better account for multi-scaled processes.

The extensive use made by Australian birds of large-scale migrations is a critically important ecological phenomenon for the GER connectivity corridor that demands a continental and supra-regional scale approach to conservation planning (Gilmore et al 2007). Climate change, hydroecology, ecological fire regimes, and spatially-dependent evolution, are four additional processes and phenomena that require a more geographically expansive framing if they are to be adequately accommodated by systematic conservation planning (Klein et al 2009). At the same time, a ‘big picture’ connectivity conservation perspective enables proper application of the principle of ‘subsidiarity’ – that a central authority should perform only those tasks that cannot be performed effectively at a more immediate or local level (ECI 2008), and vice versa.

In any case, we need to guard against locking into a single, predetermined representation and scale of bioregions. The Interim Biogeographic Regionalisation of Australia (IBRA) (Environment Australia 2000), like any regionalisation, is but one of many ways of validly classifying landscape patterns and processes. Multiple bioregionalisations can now be readily generated to answer specific questions depending on the selection of, amongst other things, aims, criteria and variables (Mackey et al 2008c). Such methods, along with improved approaches for analysing genetic data, and new remotely sensed data, provide opportunities for maximising our inventory of biodiversity assets.

Connectivity conservation and its effective management provide a conceptual framework for breaking free from minimalist thinking that risks locking protected areas into an ever-tightening extinction vortex. Nonetheless, at any given point in time, difficult choices must be made regarding the most efficient investment of available resources for conservation efforts. In the case of GER, the spatial priorities in and around the connectivity area will vary from year to year depending on, among other things, the availability of resources, changing threats, and the likely benefits and costs of alternative investment options. This dynamic is an integral part of connectivity management.

Connectivity conservation and its effective management provide an opportunity for a fresh look at land use in eastern Australia and the long-terms needs for biodiversity conservation. There are now many examples of connectivity conservation being implemented in various countries throughout the world (IUCN 2007b; Worboys et al 2009). Perhaps we can interpret the application of connectivity conservation principles in the GER corridor as indicating that the attitude of ‘taming the great south land’ (Lines 1991), which has been prevalent through much of our recent history, is now being replaced with one that reflects something more of a ‘working with nature’ mentality – on a landscape-wide, cross-tenure, multi-scale basis.

Acknowledgments

This publication was improved by critical suggestions from independent peer reviewers and comments from Anita Haenfler (Queensland Environmental Protection Agency), Nina Cullen (Department of Sustainability and Environment, Victoria), Sharon Lane (Department of Territory and Municipal Services, ACT), Dr Charlie Zammit (Australian Department of Environment, Water, Heritage and the Arts), and Ian Pulsford and Gary Howling (Department of Environment, Climate Change and Water NSW) and other staff within these agencies. The work documented here drew on some of the concepts developed through ARC Linkage grant LP0455163. Thanks also to Clive Hilliker (Fenner School of Environment and Society, Australian National University) for help with the figures.

References and further reading

ABARE (Australian Bureau of Agriculture and Resource Economics) 2007, *Australian security, clean technology development and climate change*, Commonwealth of Australia, Canberra.

ABS (Australia Bureau of Statistics) 2006, *Measures of Australia's progress*, Commonwealth of Australia, Canberra.

AGO 2006, *Reducing greenhouse gas emissions from Australian agriculture: The role of benchmarking in driving best management practice*, Australian Greenhouse Office, Department of the Environment and Heritage, ISBN 1 921120 84 3.

Allen TFH and Starr TB 1982, *Hierarchy: perspectives for ecological complexity*, University Chicago Press.

Anderson AB and Jenkins CN 2006, *Applying nature's design. Corridors as a strategy for biodiversity conservation*, Columbia University Press, New York.

Archer M and Hand SJ 2006, 'The Australian marsupial radiation', in Merrick J, Archer M, Hickey GM and Lee MSY (eds), *Evolution and biogeography of Australasian vertebrates*, Auscipub Pty Ltd, Sydney, pp 575–646.

Avise JC 2000, *Phylogeography: the history and formation of species,* Harvard University Press, Cambridge.

Baker J 1997, 'The decline, response to fire, status and management of the eastern bristlebird', *Pacific Conservation Biology* 3, pp 235–243.

Barker WR and Greenslade PJM 1982, *Evolution of the flora and fauna of arid Australia*, Peacock Publications, Adelaide.

Barlow BA 1981, 'The Australian flora: Its origin and evolution', in George AS (ed), *Flora of Australia*, Vol 1, AGPS, Canberra.

Barrett GW, Ford HA and Recher HF 1994, 'Conservation of woodland birds in a fragmented rural landscape', *Pacific Conservation Biology* 1, pp 245–256.

Bayon R, Hawn A and Hamilton K 2007, *Voluntary carbon markets: An international business guide to what they are and how they work*, Environmental Markets Insight Series, Earthscan, London.

Bega Valley Shire Council 2001, *State of the environment report – biodiversity,* available at www.begavalley.nsw.gov.au/environment/soe/Begavalley.

Bennett AF 1990, 'Land-use, forest fragmentation and the mammalian fauna at Naringal, south-western Victoria', *Australian Wildlife Research* 17, pp 325–347.

Bennett AF 2003, *Linkages in the landscape. The role of corridors and connectivity in wildlife conservation (second edition),* IUCN, The World Conservation Union, Gland.

Bennett G 2004, *Integrating biodiversity conservation and sustainable use. Lessons learned from ecological networks,* IUCN, The World Conservation Union, Gland.

Bennett G and Mulongloy KJ 2006. *Review of experience with ecological networks, corridors and buffer zones,* CBD Technical Series No 23, Secretariat of the Convention on Biological Diversity, Montreal.

Bierregaard RO, Gascon C, Lovejoy TE and Mesquita R 2001, *Lessons from Amazonia: the ecology and conservation of a fragmented forest,* Yale University Press, New Haven.

Bradshaw WE and Holzapfel CM 2006, 'Evolutionary response to rapid climate change', *Science* 312, pp 1477–1478.

Brereton R, Bennett S and Mansergh I 1995, 'Enhanced greenhouse climate-change and its potential effect on selected fauna of south-eastern Australia – a trend analysis', *Biological Conservation* 72, pp 339–354.

Brooks TM, Bakarr MI, Boucher T, Da Fonseca GAB, Hilton-Taylor C, Hoekstra JM, Moritz T, Olivier S, Parrish J, Pressey RL, Rodrigues ASL, Sechrest W, Stattersfield A, Strahm W and Stuart SN 2004, 'Coverage provided by the global protected-area system: Is it enough?', *BioScience* 54, pp 1081–1091.

Brown JH 1995, *Macroecology*, The University of Chicago Press, Chicago.

Bruns TD, Bidartondo MI and Taylor DL 2002, ‘Host specificity in ectomycorrhizal communities: What do the exceptions tell us?’, *Integrative and Comparative Biology* 42, pp 352–359.

Burdon JJ and Thrall PH 1999, ‘Spatial and temporal patterns in coevolving plant and pathogen associations’, *The American Naturalist*, Vol. 153, Supplement S15–S33.

CA (Commonwealth of Australia) 1997, *Nationally agreed criteria for the establishment of a comprehensive, adequate and representative system for forests in Australia*, Joint ANZECC/MCFFA National Forest Policy Statement Implementation Subcommittee. Canberra.

CA (Commonwealth of Australia) 2005, *Direction for the National Reserve System – a partnership approach*, Natural Resource Management Ministerial Council, Canberra.

Cardillo M, Purvis A, Sechrest W, Gittleman JL, Bielby J and Mace GM 2004, ‘Human population density and extinction risk in the world’s carnivores’, *PloS Biology* 2, pp 909–914.

Chester C and Hilty J 2009 (in prep), ‘Chapter 2.1 Connectivity conservation concepts – the natural setting’, in GL, Francis WL and Lockwood M, *Connectivity conservation management: a global guide,* Earthscan, London.

Costanza R, de Groot R, d’Arge R, Farber S, Grasso N, Hannon B, Limburg K, Naeem S, O’Neill J, Paruelo RG, Sutton P and Van Den Belt M 1997, ‘The value of the world’s ecosystem services and natural capital’, *Nature* 387, p 255.

Cowling RM and Pressey RL 2003, ‘Introduction to systematic conservation planning in the Cape Floristic Region’, *Biological Conservation* 112, pp 1–13.

Cramer VA and Hobbs RJ 2005, ‘Assessing the ecological risk from secondary salinity: A framework addressing questions of scale and threshold responses’, *Austral Ecology* 30, pp 537–545.

Crooks K and Sanjayan MA 2006, ‘Connectivity conservation: maintaining connections for nature’, in Crooks K and Sanjayan M (eds), *Connectivity Conservation*, Cambridge University Press, Cambridge.

Dailey GC and Ellison K 2002, *The new economy of nature: the quest to make conservation profitable*, Island Press, Washington.

Date EM, Recher HF, Ford HA and Stewart DA 1996, ‘The conservation and ecology of rainforest pigeons in northern New South Wales’, *Pacific Conservation Biology* 2, pp 299–308.

Davies AJ, Roberts JM and Hall-Spencer J 2007, ‘Preserving deep-sea natural heritage: Emerging issues in offshore conservation and management’, *Biological Conservation* 138, pp 299–312.

Davis LA, Roalson EH, Cornell KL, McClanahan KD and Webster MS 2006, ‘Genetic divergence and migration patterns in a North American passerine bird: implications for evolution and conservation’, *Molecular Ecology* 15, pp 2141–2152.

Dean C, Roxburgh S and Mackey BG 2004, ‘Forecasting landscape-level carbon sequestration using gridded, spatially adjusted tree growth’, *Forest Ecology and Management* 194, pp 109–129.

DeChaine EG and Martin AP 2005, ‘Marked genetic divergence among sky island populations of *Sedum lanceolatum* (Crassulaceae) in the Rocky Mountains’, *American Journal of Botany* 92, pp 477–486.

DeChaine EG and Martin AP 2006, ‘Using coalescent simulations to test the impact of quaternary climate cycles on divergence in an alpine plant–insect association’, *Evolution* 60, pp 1004–1013.

Diamond RF 1975, ‘The island dilemma: lessons of modern biogeographic studies for the design of nature reserves’, *Biological Conservation* 7, pp 129–146.

Doherty M, Kearns A, Barnett G, Sarre A, Hochuli D, Gibb H and Dickman C 2000, *The interaction between habitat conditions, ecosystem processes and terrestrial biodiversity – a review,* Australia: State of the Environment, Second Technical Paper Series (Biodiversity), Department of the Environment and Heritage, Canberra.

Driscoll DA 1998, ‘Genetic structure, metapopulation processes and evolution influence the conservation strategies for two endangered frog species’, *Biological Conservation* 83, pp 43–54.

Driscoll D 2004, ‘Extinction and outbreaks accompany fragmentation of a reptile community’, *Ecological Applications* 14, pp 220–240.

Dudley N, Mulongoy KJ, Cohen S, Stolton S, Barber CV and Gidda SB 2005, *Towards effective protected area systems. An action guide to implement the Convention on Biological Diversity Programme of Work on Protected Areas,* CBD Technical Series No 18, Secretariat of the Convention on Biological Diversity, Montreal.

Durieuxa L, Augusto L, Machadob T and Laurent H 2003, 'The impact of deforestation on cloud cover over the Amazon arc of deforestation', *Journal of Remote Sensing of Environment* 86, pp 132–140.

ECI (Earth Charter International) 2008, Principle 13f of *The Earth Charter*, Earth Charter International Secretariat, available at www.earthcharter.org.

Ehrlich PR 2003, 'The crowded greenhouse: Population, climate change, and creating a sustainable world', *Ecological Economics* 46, pp 512–513.

Ehrlich PR and Ehrlich AH 2002, 'Population, development, and human natures', *Environment and Development Economics* 7, pp 158–170.

Environment Australia 2000, *Revision of the Interim Biogeographic Regionalization of Australia (IBRA) and the development of version 5.1 – summary report*, Department of Environment and Heritage, Canberra.

Faith DP 1992, 'Conservation evaluation and phylogenetic diversity', *Biological Conservation* 61, pp 1–10.

Fischer J and Lindenmayer DB 2002, 'The conservation value of paddock trees for birds in a variegated landscape in southern New South Wales. I. Species composition and site occupancy patterns', *Biodiversity and Conservation* 11, pp 807–832.

Fischer J and Lindenmayer DB 2005, 'The sensitivity of lizards to elevation: A case study from south-eastern Australia', *Diversity and Distributions* 11, pp 225–233.

Fischer J, Lindenmayer DB and Fazey I 2004, 'Appreciating ecological complexity: habitat contours as a conceptual model', *Conservation Biology* 18, pp 1245–1253.

Fischer J, Lindenmayer DB, Barry S and Flowers E 2005, 'Lizard distribution patterns in the Tumut Fragmentation "Natural Experiment" in south-eastern Australia, *Biological Conservation* 123: pp 301–315.

Fischer J., Lindenmayer DB and Manning AD 2006, 'Biodiversity, ecosystem function, and resilience: ten guiding principles for commodity production landscapes', *Frontiers in Ecology and the Environment* 4, pp 80–86.

Folke C, Carpenter S, Walker B, Scheffer M, Elmqvist T, Gunderson L and Holling CS 2004, 'Regime shifts, resilience, and biodiversity in ecosystem management', *Annual Review of Ecology Evolution and Systematics* 35, pp 557–581.

Forest F, Grenyer R, Rouget M, Davies TJ, Cowling RM, Faith DP, Balmford A, Manning JC, Proches S, v. d. Bank M, Reeves G, Hedderson TAJ and Savolainen V 2007, 'Preserving the evolutionary potential of floras in biodiversity hotspots', *Nature* 445, pp 757–760.

Forman RT 1995, *Landscape mosaics*, Cambridge University Press, Cambridge.

Frankel OH and Soulé ME 1981, *Conservation and evolution*, Cambridge University Press, Cambridge.

Gardner JL 2004, 'Winter flocking behavior of speckled warblers and the allee effect', *Biological Conservation* 118, pp 195–204.

Garnett S and Crowley G 2000, *The action plan for Australian birds*, Environment Australia, Canberra.

Garnett S, Crowley G and Barrett G 2002, *Birds. Australian Terrestrial Biodiversity Assessment,* Commonwealth of Australia, Canberra.

Gero AF and Pitman AJ 2006, 'The impact of land cover change on a simulated storm event in the Sydney Basin', *Journal of Applied Meteorology and Climatology* 45, pp 283–300.

Gill AM 1981, 'Adaptive responses of Australian vascular plant species to fires', in Gill AM, Groves RH and Noble IR (eds), *Fire and the Australian Biota*, Australian Academy of Science, Canberra, pp 243–272.

Gill AM, Woinarksi JCZ and York A 1999, *Australia's biodiversity: Responses to fire*, Environment Australia, Canberra.

Gill M, Ryan PG, Moore PHR and Gibson M 2000, 'Fire regimes of World Heritage Kakadu National Park, Australia (2000)', *Austral Ecology* 25, pp 616–625.

Gilmore S, Mackey B and Berry S 2007, 'The extent of dispersive movement behaviour in Australian vertebrate animals, possible causes, and some implications for conservation', *Pacific Conservation Biology* 13, pp 93–103.

Gilpin ME and Soulé ME 1986, 'Minimum viable populations: processes of species extinction', in Soule ME (ed), *Conservation biology: The science of scarcity and diversity*, Sinauer, Sunderland, MA, pp 19–34.

Glen M, Tommerup IC, Bougher NL and O'Brien PA 2002, ‚Are Sebacinaeae common and widespread ectomycorrhizal associates of *Eucalyptus* species in Australian forests?', *Mycorrhiza Research* 12, pp 243–247.

Groom JD and Grubb TC 2002, 'Bird species associated with riparian woodland in fragmented, temperate-deciduous forest', *Conservation Biology* 16, pp 832–836.

Grey MJ, Clarke MF and Loyn RH 1997, 'Initial changes in the avian communities of remnant eucalypt woodlands following a reduction in the abundance of noisy miners, *Manorina melanocephala*', *Wildlife Research* 24, pp 631–648.

Haddad NM and Tewksbury JJ 2005, 'Low-quality habitat corridors as movement conduits for two butterfly species', *Ecological Applications* 15, pp 250–257.

Hairsine PB 1997, *Controlling sediment and nutrient movement within catchments*, Cooperative Research Centre for Catchment Hydrology, Monash University, Clayton.

Hannah D, Woinarski JCZ, Catterall CP, McCosker JC, Thurgate NY and Fensham RJ 2007, *Austral Ecology* 32, pp 261–276.

Hanski I and Gaggiotti EO 2004, *Metapopulation biology: past, present, and future*, Oxford University Press, New York.

Hazell D, Cunningham R, Lindenmayer DB, Mackey B and Osborne W 2001, 'Use of farm dams as frog habitat in an Australian agricultural landscape: factors affecting species richness and distribution', *Biological Conservation* 102, pp 155–169.

Hazell D, Hero J, Lindenmayer DB and Cunningham RB 2004, 'A comparison of constructed and natural habitat for frog conservation in an Australian agricultural landscape', *Biological Conservation* 119, pp 61–71.

Heemsbergen DA, Berg MP, Loreau M, van Hal JR, Faber JH and Verhoef HA 2004, 'Biodiversity effects on soil processes explained by interspecific functional dissimiliarity', *Science* 3016, pp 1019–1020.

Hennessy K, Whetton P, Smith I, Bathols J, Hutchinson M and Sharples J 2003, *The impact of climate change on snow conditions in mainland Australia*, CSIRO Atmospheric Research, Aspendale, Victoria.

Hilbert D, Bradford M, Parker T and Westcott DA 2004, 'Golden bowerbird (*Prionodura newtonia*) habitat in past, present and future climates: predicted extinction of a vertebrate in tropical highlands due to global warming', *Biological Conservation* 116**,** pp 367–377.

Hill JK, Thomas CD, Fox R, Telfer MG, Willis SG, Asher J and Huntley B 2002, 'Responses of butterflies to twentieth century climate warming: implications for future ranges', *Proceedings of the Royal Society B-Biological Sciences* 269, pp 2163–2171.

Hill RS 1994, *History of the Australian vegetation: Cretaceous to recent*, Cambridge University Press, Cambridge.

Hilty JA, Lidicker WZ and Merenlender AM 2006, *Corridor ecology: the science and practice of linking landscapes for biodiversity conservation,* Island Press, Washington.

Hobbs RJ 2000, 'Fire regimes and their effects in Australian temperate woodlands', in Bradstock RA, Williams JE and Gill (eds), *Flammable Australia, the fire regimes and biodiversity of a continent* (eds*,* Cambridge University Press, Melbourne, pp 305–326.

Hobbs RJ and Yates CJ 2000, *Temperate eucalypt woodlands in Australia: biology, conservation, management and restoration*, Surrey Beatty and Sons, NSW.

Hoekstra JM, Boucher TM, Ricketts TH and Roberts C 2005, 'Confronting a biome crisis: global disparities of habitat loss and protection', *Ecology Letters* 8, pp 23–29.

Holland GJ and Bennett AF 2007, ‘Occurrence of small mammals in a fragmented landscape: the role of vegetation heterogeneity’, *Wildlife Research* 34, pp 387–397.

Holling CS 1973, ‘Resilience and stability of ecological systems’, in *Annual Review of Ecology and Systematics* 4, pp 1–23.

Holling CS 1994, ‘Simplifying the complex – the paradigms of ecological function and structure’, *Futures* 26, pp 598–609.

Holling CS 1996, ‘Surprise for science, resilience for ecosystems, and incentives for people’, *Ecological Applications* 6, pp 733–735.

Hooper DU, Chapin FS, Ewel JJ, Hector A, Inchausti P, Lavorel S, Lawton JH, Lodge DM, Loreau M, Naeem S, Schmid B, Setälä H, Symstad AJ, Vandermeer J and Wardle DA 2005, ‘Effects of biodiversity on ecosystem functioning: a consensus of current knowledge’, *Ecological Monographs* 75, pp 3–35.

Hope GS 1994, ‘Quaternary vegetation’, in *History of Australian vegetation. Cretaceous to recent*, (ed Hill R), Cambridge University Press, Cambridge, pp 368–389.

Houghton RA 1994, ‘The worldwide extent of land-use change’, *BioScience* 44, pp 305–313.

Howden M, Hughes L and Dunlop M 2003, *Climate change impacts on biodiversity in Australia,* Outcomes of a workshop sponsored by the Biological Diversity Advisory Committee, 1–2 October 2002, Commonwealth of Australia, Canberra.

Hughes L 2003, ‘Climate change and Australia: Trends, projections and impacts’, *Austral Ecology* 28, pp 423–443.

Hughes L, Cawsey E and Westoby M 1996, ‘Climatic range sizes of *Eucalyptus* species in relation to future climate change’, *Global Ecology and Biogeography,* Letters 5, pp 23–29.

Hutchinson GE 1957, ‘Concluding remarks’, *Quantifying Biology* 22, pp 415–427.

IPCC (Intergovernmental Panel on Climate Change) 2006, *The Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge University Press, Cambridge.

IPCC (Intergovernmental Panel on Climate Change) 2007a, *The Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Synthesis Report, summary for policy makers November 2007*, available at www.ipcc.ch.

IPCC (Intergovernmental Panel on Climate Change) 2007b, *Climate Change 2007: The physical science basis summary for policymakers. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, available at www.ipcc.ch.

IPCC (Intergovernmental Panel on Climate Change) 2007c, *Climate Change 2007: Impacts, adaptation and vulnerability. Summary for policymakers. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, available at www.ipcc.ch.

IUCN (The International Union for Conservation of Nature) 2007a. *IUCN Red List of threatened species*, IUCN, Gland, Switzerland.

IUCN (The International Union for Conservation of Nature) 2007b, *Connectivity conservation: International experience in planning, establishment and management of biodiversity corridors*, IUCN, Gland, Switzerland.

IUCN WCPA (The International Union for Conservation of Nature World Commission on Protected Areas) 2007, ‘Papallacta Declaration’, *Mountain Forum Bulletin* VII(1), p 46.

Johnson KH 2000, ‘Trophic-dynamic considerations in relating species diversity to ecosystem resilience’, *Biological Reviews* 75, pp 347–376.

Johnson C 2006, *Australia's mammal extinctions*, Cambridge University Press, Cambridge.

Johnson CN, Isaac JL and Fisher DO 2007, ‘Rarity of a top predator triggers continent-wide collapse of mammal prey: dingoes and marsupials in Australia’, *Proceedings of the Royal Society* B 274, pp 241–246.

Kappelle M, Van Vuuren MMI and Baas P 1999, ‘Effects of climate change on biodiversity: a review and identification of key research issues’, *Biodiversity and Conservation* 8, pp 1383–1397.

Karr J 1981, ‘Assessment of biotic integrity using fish communities’, *Fisheries* 6, pp 21–27.

Karr J 1991, ‘Biological integrity: a long neglected aspect of water resources management’, *Ecological Applications* 1, pp 66–84.

Keast A 1985, ‘Bird community structure in southern forests and northern woodlands’, in *Birds of eucalypt forests and woodlands: ecology, conservation, management*, (eds Keast A, Recher HF, Ford H and Saunders D), Surrey Beatty, Sydney, pp 97–116.

Keith H, Mackey B, Berry S, Lindenmayer D, and Gibbons P 2010, ‘Estimating carbon carrying capacity in natural forest ecosystems across heterogeneous landscapes: addressing sources of error’, *Global Change Biology* (in press).

Keith K, Mackey B and Lindenmayer D 2009, ‘Re-evaluation of forest biomass carbon stocks and lessons from the world's most carbon-dense forests’, *PNAS* 106 (28), pp 11635–11640.

Khan JA 1995, ‘Conservation and management of Gir Lion Sanctuary and National Park, Gujarat, India’, *Biological Conservation* 73, pp 183–188.

Kingsford RT 2000, ‘Review: Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia’, *Austral Ecology* 25, pp 109–127.

Kirchman JJ and Franklin JD 2007, ‘Comparative phylogeography and genetic structure of Vanuatu birds: control region variation in a rail, a dove, and a passerine’, *Molecular Phylogenetics and Evolution* 43, pp 14–23.

Klein C, Wilson K, Watts M, Stein J, Berry S, Carwardine J, Stafford Smith, Mackey B and Possingham H 2009, ‘Incorporating ecological and evolutionary processes into continental scale conservation planning’, *Ecological Applications* 19, pp 206–217.

Kuczera G 1987, ‘Prediction of water yield reductions following a bushfire in ash-mixed species eucalypt forest’, *Journal of Hydrology* 94, pp 215–236.

Laurance WF and Bierregaard RO (eds) 1997, *Tropical forest remnants: Ecology, management and conservation of fragmented communities*, The University of Chicago Press, Chicago.

Laurance WF 1991 ‘Ecological correlates of extinction proneness in Australian tropical rain forest mammals*’, Conservation Biology* 5, pp 79–89.

Law B, Anderson SJ and Chidel M 1999, ‘Bat communities in a fragmented forest landscape on the south-west slopes of New South Wales’, *Biological Conservation* 88, pp 333–345.

Leslie RG, Mackey BG and Preece KM 1988, ‘A computer-based methodology for the survey of wilderness in Australia’, *Environmental Conservation* 15, pp 225–232.

Lindenmayer DB 2007, *On borrowed time: Australia’s environmental crisis and what we must do about it,* CSIRO Publishing, Camberwell NSW.

Lindenmayer DB, Cunningham RB, Donnelly CF, Nix H and Lindenmayer BD 2002, ‘Effects of forest fragmentation on bird assemblages in a novel landscape context’, *Ecological Monographs* 72, pp 1–18.

Lindenmayer DB and Fischer J 2006, *Habitat fragmentation and landscape change: an ecological and conservation synthesis*, Island Press, Washington.

Lindenmayer DB and Franklin JF 2002, *Conserving forest biodiversity: a comprehensive multiscale approach*, Island Press, Washington.

Lindenmayer DB, McIntyre S and Fischer J 2003, ‘Birds in eucalypt and pine forests: landscape alteration and its implications for research models of faunal habitat use’, *Biological Conservation* 110, pp 45–53.

Lines WJ 1991, *Taming the Great South Land*, Allen and Unwin, Sydney.

Lovejoy T 2005, ‘Conservation with a changing climate’ in Lovejoy T and Hannah L (eds), *Climate change and biodiversity*, Yale University Press, New Haven, Connecticut.

Lovejoy T and Hannah L (eds) 2005, *Climate change and biodiversity*, Yale University Press, New Haven.

Lunney D and Leary T 1988, ‘The impact on native mammals of land-use changes and exotic species in the Bega district, New South Wales, since settlement’, *Australian Journal of Ecology* 13, pp 67–92.

Lumsden LF and Bennett AF 2005, ‘Scattered trees in rural landscapes: foraging habitat for insectivorous bats in south-eastern Australia’, *Biological Conservation* 122, pp 205–222.

Lyons TJ 2002, ‘Clouds prefer native vegetation’, *Meteorology and Atmospheric Physic*s 80, pp 131–140.

Lyons TJ, Schwerdtfeger P, Hacker JM, Foster IJ, Smith RCG and Xinmei H 1993, 'Land–atmosphere interaction in a semiarid region: The bunny fence experiment', *Bulletin of the American Meteorological Society* 74, pp 1327–1333.

MacArthur RH and Wilson EO 1967, *The theory of island biogeography,* Princeton University Press, Princeton, USA.

Mace GM and Purvis A 2008, 'Evolutionary biology and practical conservation: bridging a widening gap', *Molecular Ecology* 17, pp 9–19.

Mackey BG 2007, 'Climate change, connectivity and biodiversity conservation', in *Protected areas: buffering nature against climate change* (eds Taylor M and Figgis P), WWF Australia, Sydney, pp 90–96.

Mackey BG, Lesslie R, Lindenmayer DH and Nix HA 1998, *The role of wilderness in nature conservation*, a report to The Australian and World Heritage Group Environment Australia. Australian Government, The Australian National University, available at http://fennerschool.anu.edu.au/publications/reports/cres/rolewild.pdf.

Mackey BG, Lindenmayer DB, Gill M, McCarthy M and Lindesay J 2002, *Wildlife, fire and future climate: a forest ecosystem analysis*, CSIRO Publishing, Melbourne.

Mackey BG, Soulé ME, Nix HA, Recher HF, Lesslie RG, Williams JE, Woinarski JCZR, Hobbs J and Possingham HP 2007, 'Towards a scientific framework for the WildCountry project', in Wu J and Hobbs RJ (eds), *Key topics and perspectives in landscape ecology*, Cambridge University Press, pp 92–108.

Mackey BG, Watson J and Hope G 2008a, 'Climate change, biodiversity conservation, and the role of protected areas: an Australian perspective', *Biodiversity* 9, pp 11–18.

Mackey BG, Keith H, Berry S and Lindemayer D 2008b, *Green carbon: the role of natural forests in carbon storage. Part 1. A green carbon account of Australia's south-eastern Eucalypt forests, and policy implications*. ANUE Press, Canberra, available at http://epress.anu.edu.au/green_carbon_citation.html

Mackey B, Berry S and Brown T 2008c, 'Reconciling approaches to biogeographic regionalization: a systematic and generic framework examined with a case study of the Australian continent', *Journal of Biogeography* 35, pp 213–229.

Mansergh I and Cheal D 2007, 'Protected area planning and management for eastern Australia temperate forests and woodland ecosystems under climate change – a landscape approach', in Taylor M and Figgis P (eds), *Protected areas: buffering nature against climate change*, WWF Australia, Sydney. pp 58–72.

Margules CR and Pressey RL 2000, Systematic conservation planning, *Nature* 405, pp 243–253.

May S and Norton TW 1996, 'Influence of fragmentation and disturbance on the potential impact of feral predators on native fauna in Australian forest ecosystems', *Wildlife Research* 23, pp 387–400.

Mayr E 2001, *What evolution is,* Basic Books, Washington.

McCloskey JM and Spalding H 1989, 'A reconnaissance-level inventory of the amount of wilderness remaining in the world', *Ambio* 18, pp 221–227.

McGarigal K, Cushman SA, Neel MC and Ene E 2002, 'FRAGSTATS: Spatial Pattern Analysis Program for Categorical Maps', computer software program produced by the authors at the University of Massachusetts, Amherst, available at www.umass.edu/landeco/research/fragstats/fragstats.html.

MEAB (Millennium Ecosystem Assessment Board) 2005, *Millennium Ecosystem Assessment Report, Ecosystems and human well-being: biodiversity synthesis*, World Resources Institute, Washington DC, pp 1–100.

Means DB and Simberloff D 1987, 'The peninsula effect: habitat correlated species decline in Florida's herpetofauna', *Journal of Biogeography* 14, pp 551–568.

Menkhorst P (ed) 2003, *The field guide to the birds of Australia* (seventh edition), Harper Collins, Sydney.

Midgley GF and Thuiller W 2005, 'Global environmental change and the uncertain fate of biodiversity', *New Phytologist* 167, pp 638–641.

Miller JR and Cale P 2000, 'Behavioral mechanisms and habitat use by birds in a fragmented agricultural landscape', *Ecological Applications* 10, pp 1732–1748.

Mittermeier RA, Mittermeier CG, Brooks TM, Pilgrim JD, Konstant WR, da Fonseca GAB and Kormos C 2003,'Wilderness and biodiversity conservation', *Proceedings of the National Academy of Sciences* 100, pp 10309–10313.

Moritz C 2002, 'Strategies to protect biological diversity and the evolutionary processes that sustain it', *Systematic Biology* 51, pp 238–254.

Morton SR, Short J and Barker RD 1995, *Refugia for biological diversity in arid and semi-arid Australia,* Biodiversity Series, Paper No. 4. Department of the Environment, Sport and Territories, Canberra.

Moss L (ed) 2006, *The amenity migrants: seeking and sustaining mountains and their cultures,* Cabi International, United Kingdom.

Murdoch W, Polasky S, Wilson KA, Possingham HP, Kareiva P and Shaw S 2007, 'Maximizing return on investment in conservation', *Biological Conservation* 139, pp 375–388.

Myers N and Knoll AH 2001, 'How will the sixth extinction affect the evolution of species', *Proceedings of the National Academy of Sciences* 98, pp 5389–5392.

Naeem S 1998, 'Species redundancy and ecosystem reliability', *Conservation Biology* 12, pp 39–45.

Nakicenovic N 2000, 'Global greenhouse gas emissions scenarios: Integrated modeling approaches', *Technological Forecasting and Social Change* 63, pp 105–109.

Nepstad DC, Veríssimo A, Alencar A, Nobre C, Lima E, Lefebvre P, Schlesinger P, Potterk C, Moutinho P, Mendoza E, Cochrane M and Brooks V 1999, 'Large-scale impoverishment of Amazonian forests by logging and fire', *Nature* 398, pp 505–508.

Newmark WD 1987, 'A land-bridge island perspective on mammalian extinctions in western North-American parks', *Nature* 325, pp 430–432.

Newmark WD 1995, 'Extinction of mammal populations in western North-American national parks', *Conservation Biology* 9, pp 512–526.

Nix HA 2004, 'Inverting the paradigm', *Pacific Conservation Biology* 10, p 76.

Nix HA 1982, 'Environmental determinants of biogeography and evolution in Terra Australis', in *Evolution of the fauna and flora of arid Australia*, (eds Barker WR and Greenslade PJM), Peacock Publications, Fremville South Australia, pp 47–66.

NLWRA (National Land and Water Resources Assessment) 2001, *Australian Native Vegetation Assessment*, Commonwealth of Australia, Canberra.

NLWRA (National Land and Water Resources Audit) 2002, *Australian Terrestrial Biodiversity Assessment, 2002*, National Heritage Trust. Commonwealth of Australia, Canberra.

Noble JC, Müller WJ, Detling JK and Pfitzner GH 2007, 'Landscape ecology of the burrowing bettong: Warren distribution and patch dynamics in semiarid eastern Australia*', Austral Ecology* 32, pp 326–337.

Norman JA, Rheindt FE, Rowe DL and Christidis L 2007, 'Speciation dynamics in the Australo–Papuan Meliphago honeyeaters', *Molecular Phylogenetics and Evolution* 42, pp 80–91.

Nussey DH, Postma E, Gienapp P and Visser ME 2005, 'Selection on heritable phenotypic plasticity in a wild bird population', *Science* 310, pp 304–306.

Ollier CD 1982, 'The Great Escarpment of eastern Australia: tectonic and geomorphic significance', *Journal of Geologic Society of Australia* 29, pp 13–23.

Opdam P and Wascher D 2004, 'Climate change meets habitat fragmentation: linking landscape and biogeographical scale levels in research and conservation', *Biological Conservation* 117, pp 285–297.

Osborne MJ and Christidis L 2002, 'Molecular relationships of the cuscuses, brushtail and scaly-tailed possums', *Australian Journal of Zoology* 50, pp 135–149.

Parkes D, Newell G and Cheal D 2003, 'Assessing the quality of native vegetation: the habitat hectares approach', *Ecological Management and Restoration* 4, (Supplement) S29–S38.

Parmesan C, Ryrholm N, Stefanescu C, Hill JK, Thomas CD, Descimon H, Huntley B, Kaila L, Kullberg J, Tammaru T, Tennent WJ, Thomas JA and Warren M 1999, 'Poleward shifts in geographical ranges of butterfly species associated with regional warming', *Nature* 399, pp 579–583.

Parmesan C and Yohe G 2003, 'A globally coherent fingerprint of climate change impacts across natural systems', *Nature* 421, pp 37–42.

Paton DC 2000, ‘Disruption of bird-plant pollinators systems in southern Australia’, *Conservation Biology* 14, pp 1232–1234.

Peterson AT 2003, ‘Projected climate change effects on Rocky Mountain and Great Plains birds: generalities of biodiversity consequences’, *Global Change Biology* 9, pp 647–655.

Petit JR, Jouzel J, Raynaud D, Barkov NI, Barnola J-M, Basile I, Benders M, Chappellaz J, Davis M, Delayque G, Delmotte M, Kotlyakov VM, Legrand M, Lipenkov VY, Lorius C, Pépin L, Ritz C, Saltzman E and Stievenard M 1999, ‘Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica’, *Nature* 399, pp 429–436.

Pope ML, Lindenmayer DB and Cunningham RB 2004, ‘Patch use by the greater glider in a fragmented forest ecosystem. I. Home range size and movements’, *Wildlife Research* 31, pp 559–568.

Possingham HP, Andelman SJ, Noon BR, Trombulak S and Pulliam HR 2001, ‘Making smart conservation decisions’, in Soulé ME and Orians GH (eds) *Conservation biology: research priorities for the next decade*, Island Press, Washington, pp 225–244.

Possingham H and Wilson K 2005. ‘Biodiversity – Turning up the heat on hotspots’, *Nature* 436, pp 919–920

Possingham H, Wilson K, Andelman S and Vynne C 2006, ‘Protected areas: goals, limitations, and design’, in Groom MJ, Meffe GK and Carroll CR (eds), *Principles of conservation biology,* pp 509–533, Sinauer Associates Inc., Sunderland, Massachusetts, USA.

Pounds AJ, Bustamante MR, Coloma LA, Consuegra JA, Fogden MPL, Foster PN, La Marca E, Masters KL, Merino-Viteri A, Puschendorf R, Ron SR, Sanchez-Azofeifa GA, Still CJ and Young BE 2006, ‘Widespread amphibian extinctions from epidemic disease driven by global warming’, *Nature* 439, pp 161–167.

Pounds JA and Crump ML 1994, ‘Amphibian declines and climate disturbance: the case of the golden toad and the harlequin frog’, *Conservation Biology* 8, pp 72–85.

Pressey RL, Cabeza M, Watts ME, Cowling RM and Wilson KA 2007, ‘Conservation planning in a changing world’, *Trends in Ecology and Evolution*, 22, pp 583–592.

Pressey RL and Cowling RM 2001, ‘Reserve selection algorithms and the real world’, *Conservation Biology* 15, pp 275–277.

Pressey RL, Whish GL, Barrett TW and Watts ME 2002. ‘Effectiveness of protected areas in north-eastern New South Wales: recent trends in six measures’, *Biological Conservation* 106, pp 57–69.

Pressey RL, Cowling RM and Rouget M 2003, ‘Formulating conservation targets for biodiversity pattern and process in the Cape Floristic Region, South Africa’, *Biological Conservation* 112, pp 99–127.

Pressey RL, Watts ME and Barrett TW 2004, ‘Is maximizing protection the same as minimizing loss? Efficiency and retention as alternative measures of the effectiveness of proposed reserves’, *Ecology Letters* 7, pp 1035–1046.

Preston BL and Jones RN 2006, *Climate change impacts on Australia and the benefits of early action to reduce global greenhouse gas emissions,* a consultancy report for the Australian Business Roundtable on Climate Change, CSIRO, Australia.

Pretty J and Smith D 2004, ‘Social capital in biodiversity conservation and management’, *Conservation Biology* 18, pp 631–638.

Pyke G, Saillard R and Smith R 1995, ‘Abundance of eastern bristlebirds in relation to habitat and fire history’, *Emu* 95, pp 106–110.

Randall 2007, *The introduced flora of Australia and its weed status*, CRC for Australian Weed Management, Department of Agriculture and Food, Western Australia.

Ray DK, Welch RM, Lawton RO and Nair US 2006, ‘Dry season clouds and rainfall in northern Central America: Implications for the Mesoamerican Biological Corridor’, *Journal of Global and Planetary Change* 54, pp 150–162.

Recher HF, Shields J, Kavanagh RP and Webb G 1987, ‘Retaining remnant mature forest for nature conservation at Eden, New South Wales: a review of theory and practice’, in Saunders DA, Arnold GW, Burbidge AA and Hopkins AJ (eds), *Nature Conservation: The role of remnants of vegetation*, Surrey Beatty and Sons, Chipping Norton, pp 177–194.

Recher HF 2004,’WildCountry’, *Pacific Conservation Biology* 10, pp 221–222.

Ricketts TH, Dinerstein E, Olson DM, Loucks CJ, Eichbaum W, DellaSala D, Kavanagh K, Hedao P, Hurley PT, Carney KM, Abell R and Walters S 1999, *Terrestrial ecoregions of North America. A conservation assessment,* Island Press, Washington DC.

Rodrigues ASL, Akcakaya HR, Andelman SJ, Bakarr MI, Boitani L, Brooks TM, Chanson JS, Fishpool LDC, Da Fonseca GAB, Gaston KJ, Hoffmann M, Marquet PA, Pilgrim JD, Pressey RL, Schipper J, Sechrest W, Stuart SN, Underhill LG, Waller RW, Watts MEJ and Yan X 2004a, 'Global gap analysis: Priority regions for expanding the global protected-area network', *Bioscience* 54, pp 1092–1100.

Rodrigues ASL, Andelman SJ, Bakarr MI, Boitani L, Brooks TM, Cowling RM, Fishpool LDC, da Fonseca GAB, Gaston KJ, Hoffmann M, Long JS, Marquet PA, Pilgrim JD, Pressey RL, Schipper J, Sechrest W, Stuart SN, Underhill LG, Waller RW, Watts MEJ and Yan X 2004b, 'Effectiveness of the global protected area network in representing species diversity', *Nature* 428, pp 640–643.

Rodrigues ASL and Gaston KJ 2001, 'How large do reserve networks need to be?' *Ecology Letters* 4, pp 602–609.

Root TL 2003, 'Fingerprints of global warming on wild animals and plants', *Nature* 421, pp 57–60.

Rowe KC, Reno ML, Richmond DM, Adkins RM and Steppan SJ 2008, 'Pliocene colonization and adaptive radiations in Australia and New Guinea (Sahul): multilocus systematics of the old endemic rodents (Muroidea: Murinae)*', Molecular Phylogenetics and Evolution* 47, pp 84–101.

Roxburgh SH, Wood SW, Mackey BG, Woldendorp G and Gibbons P 2006a, 'Assessing the carbon sequestration potential of managed forests: A case study from temperate Australia', *Journal of Applied Ecology* 43, pp 1149–1159.

Roxburgh SH, Mackey BG, Dean C, Randall L, Lee A and Austin J 2006b, 'Organic carbon partitioning in soil and litter in subtropical woodlands and open forests: a case study from the Brigalow Belt, Queensland', *Rangeland Journal* 28, pp 115–125.

Sala OE, Chapin FS, Armesto JJ, Berlow E, Bloomfield J, Dirzo R, Huber-Sanwald E, Huenneke LF, Jackson RB, Kinzig A, Leemans R, Lodge DM, Mooney HA, Oesterheld M, Poff NL, Sykes MT, Walker BH, Walker M and Wall DH 2000, 'Global biodiversity scenarios for the year 2100', *Science* 287, pp 1770–1774.

Sanderson EW, Jaiteh M, Levy MA, Redford KH, Wannebo AV and Woolmer G 2002, 'The human footprint and the last of the wild', *BioScience* 52, pp 891–904.

Sanderson J, Fonseca GAB, Galindo-Leal C, Alger K, Inchausty VH, Morrison K and Rylands A 2006, 'Escaping the minimalist trap: design and implementation of large-scale biodiversity corridors', in Crooks K and Sanjayan M (eds), *Connectivity Conservation*, Cambridge University Press, Cambridge, pp 620–648.

Sattler P 2007, 'Directions for the National Reserve System in the context of climate change, in Taylor M and Figgis P (eds), *Protected areas: buffering nature against climate change*, WWF Australia, Sydney, pp 117–127.

Sattler PS and Taylor MFJ 2008, *Building Nature's Safety Net 2008. Progress on the directions for the National Reserve System*, WWF Australia Report, WWF Australia, Sydney.

Saunders D, Beattie AJ, Eliott S, Fox M, Hill B, Pressey RL, Veal D, Venning J, Maliel M and Zammit C 1996, *Biodiversity. Australia: State of the Environment* 1996, State of the Environment Advisory Council, CSIRO Publishing, Melbourne.

Silberstein R, Best A, Hickel K, Gargett T and Adhitya A 2004, *The effect of clearing of native forest on flow regime*. Cooperative Research Centre for Catchment Hydrology, Technical Report 04/4.

Simberloff D, Farr JA, Cox J and Mehlman DW 1992, 'Movement corridors – conservation bargains or poor investments', *Conservation Biology* 6, pp 493–504.

Sniderman JMK, Pillans B, O'Sullivan PB and Kershaw AP 2007. 'Climate and vegetation in southeastern Australia respond to Southern Hemisphere insolation forcing in the late Pliocene-early Pleistocene', *Geology* 35, pp. 41–44.

SoE 2006, *State of the Environment Report 2006*, State of the Environment Advisory Council. Department of Environment and Water Resources, available at www.environment.gov.au/soe/2006/index.html.

Soulé ME and Sanjayan M 1998, ‘Conservation targets: do they help?’, *Science* 279, pp 2060–2061.

Soulé ME and Terborgh J 1999, *Continental conservation: scientific foundations of regional reserve networks*, Island Press, Washington DC.

Soulé ME, Estes JA, Berger J and Martinez Del Rio C 2003, ‘Ecological effectiveness: conservation goals for interactive species’, *Conservation Biology* 17, pp 1238–1250.

Soulé ME, Mackey BG, Recher HF, Williams JE, Woinarski JCZ, Driscoll D, Dennison WG and Jones ME 2004, ‘The role of connectivity in Australian conservation’, *Pacific Conservation Biology* 10, pp 266–279.

Soulé ME, Mackey BG, Recher H, Williams J, Woinarksi JCZ, Driscoll D, Dennison WC and Jones M 2006, ‘The role of connectivity in Australian conservation’, in Crooks K and Sanjayan M (eds), *Connectivity Conservation*, Cambridge University Press, Cambridge, pp 649–675.

Southwood TRE, Brown VK and Reader PM 1983, ‘Continuity of vegetation in space and time: a comparison of insects’ habitat templet in different successional stages’, *Resources Population and Ecology* (Supplement) 3, pp 61–74.

Steffen W, Burbidge AA, Hughes L, Kitching R, Lindenmayer D, Musgrave W, Stafford Smith M and Werner PA 2009, *Australia’s Biodiversity and Climate Change*, Australian Government, Canberra.

Summer J, Moritz C and Shine R 1999, ‘Shrinking forest shrinks skink: morphological change in response to rainforest fragmentation in the prickly forest shrink’, *Biological Conservation* 91, pp 159–167.

Svancara LK, Brannon R, Scott JM, Groves CR, Noss RF and Pressey RL 2005, ‘Policy-driven versus evidence-based conservation: A review of political targets and biological needs’, *BioScience* 55, pp 989–995.

Thackway R and Lesslie R 2006, ‘Reporting vegetation condition using the Vegetation Assets, States and Transitions (VAST) framework’, *Ecological Management and Restoration* 7, pp S53–S62.

Thomas CD, Cameron A and Green RE 2004, ‘Extinction risk from climate change’, *Nature* 427, pp 145–149.

Thompson I, Mackey B, McNulty S, Mosseler A 2009, *Forest Resilience, Biodiversity, and Climate Change. A Synthesis of the Biodiversity/Resilience/Stability Relationship in Forest Ecosystems*, Secretariat of the Convention on Biological Diversity, Montreal, Technical Series no 43, 67 pages.

Thompson JN 2005, *The geographic mosaic of coevolution*, The University of Chicago Press, Chicago.

Thuiller W, Broennimann O, Hughes G, Alkemade JRM, Midgley GF and Corsi F 2006, ‘Vulnerability of African mammals to anthropogenic climate change under conservative land transformation assumptions’, *Global Change Biology* 12, pp 424–440.

Thuiller W, Lavorel S, Araujo MB, Sykes MT and Prentice IC 2005, ‘Climate change threats to plant diversity in Europe’, *Proceedings of the National Academy of Sciences of the United States of America* 102, pp 8245–8250.

Tischendorf L and Fahring L 2000, ‘On the usage and measurement of landscape connectivity’,*Oikos* 90, pp 7–19.

Tracey D, Turner L, Tilden J and Dennison WG 2004, *Where river meets sea: exploring Australia’s estuaries,* Coastal CRC.

Udvardy, MDF 1975, *A classification of the biogeographical provinces of the world,* IUCN Occasional Paper No 18, International Union for the Conservation of Nature, Gland.

UNDP (United Nations Development Program) 2005, *Human Development Index Report* 2005, available at www.unpopulation.org.

UNEP-WCMC (United Nations Environment Programme – World Conservation Monitoring Centre) 2009, *World data base on protected area*s, Cambridge, available at www.wdpa.org.

Walker BH and Salt D 2006, *Resilience thinking: sustaining ecosystems and people in a changing world*, Island Press, Washington DC.

Wallace AR 1859, 'Letter from Mr. Wallace concerning the geographical distribution of birds (S52: 1859)', *Ibis 1*, available via Western Kentucky University, www.wku.edu/~smithch/wallace/S052.htm.

Walther GR 2004, 'Plants in a warmer world', *Perspectives in Plant Ecology Evolution and Systematics* 6, pp 169–185.

Walther GR, Post E, Convey P, Menzel A, Parmesan C, Beebee TJC, Fromentin JM, Hoegh-Guldberg O and Bairlein F 2002, 'Ecological responses to recent climate change', *Nature* 416, pp 389–395.

Watson J, Freudenberger D and Paull D 2001, An assessment of the Focal-species Approach for conserving birds in variegated landscapes in southeastern Australia', *Conservation Biology* 15, pp 1364–1373.

Watson JE, Whittaker MRJ and Freudenberger D 2005, 'Bird community responses to habitat fragmentation: how consistent are they across landscapes?' *Journal of Biogeography* 32, pp 1353–1370.

Welch D 2005, 'What should protected area managers do in the face of climate change?', *The George Wright Forum,* Vol 22, No 1, pp 75–93.

Westra L, Miller P, Karr JR, Rees WE and Ulanowitz RE 2000, 'Ecological integrity and the aims of the global ecological integrity project', in Pimentel D, Westra L and Noss RF (eds), *Ecological integrity: integrating environment, conservation and health*, Island Press, pp 19–44.

White ME 1986, *The greening of Gondwana*, Reed Books, Sydney.

White ME 1994, *After the greening. The browning of Gondwana*, Kangaroo Press, Sydney.

Whittaker RJ 1998, *Island biogeography: ecology, evolution, and conservation*, Oxford University Press, Oxford.

Whittaker RJ, Araújo MB, Jepson P, Ladle R, Watson JE and Willis KJ 2005, 'Conservation biogeography: assessment and prospect', *Diversity and Distributions*, 11, pp 3–23.

Wiens JA 1995, 'Landscape mosaics and ecological theory', in Hansson L, Fahrig L and Merriam G (eds), *Mosaic landscapes and ecological processes*, Chapman and Hall, London, pp 1–26.

Wilcove DS, Rothstein D, Dubow J, Phillips A and Losos E, 1998, 'Quantifying threats to imperiled species in the United States', *Bioscience* 48, pp 607–615.

Williams SE, Bolitho EE and Fox S 2003, 'Climate change in Australian tropical rainforests: an impending environmental catastrophe', *Proceedings of the Royal Society of London Series B-Biological Sciences* 270, pp 1887–1892.

Wilson EO 1992, *The diversity of life*, Belknap Press, Cambridge.

Wilson EO 2002, *The future of life*, Alfred E. Knopf, New York.

With KA, Gardner RH and Turner MG 1997, 'Landscape connectivity and population distributions in heterogeneous environments', *Oikos* 78, pp 151–169.

Woinarski JCZ, Whitehead PJ, Bowman DMJS and Russel-Smith J 1992, 'Conservation of mobile species in a variable environment: the problem of reserve design in the Northern Territory, Australia', *Global Ecology and Biogeography Letters* 2, pp 1–10.

Woinarksi J 1999, 'Fire and Australian birds: a review', in Gill AM, Woinarksi JCZ and York A (eds), *Australia's biodiversity: responses to fire: plants, birds and invertebrates*, Environment Australia, Canberra, pp 55–111.

Woinarksi JCZ, Mackey BG, Nix H and Traill BJ 2007, *The nature of northern Australia: natural values, ecological processes and future prospects*, ANU Press, Canberra, available at: http://epress.anu.edu.au/nature_na/pdf_instructions.html

Worboys GL 2007, 'Managing Australia's protected areas for a climate shifted spectrum of threats', in Taylor M and Figgis P (eds), *Protected areas: buffering nature against climate change*, WWF Australia, Sydney, pp 18–27.

Worboys GL, Lockwood M and De Lacy T 2005, *Protected area management, principles and practice,* second edition, Oxford University Press, Melbourne.

Worboys GL, Francis WL and Lockwood M 2009, *Connectivity conservation management: a global guide*, Earthscan, London.

Young D 2004, 'Chapter 16. Economic evaluation', in *An assessment of the values of Kosciuszko National Park,* Independent Scientific Committee, NSW National Parks and Wildlife Service, Queanbeyan.

Zannette L, Doyle P and Tremont SM 2000, 'Food shortage in small fragments: evidence from an area-sensitive passerine', *Ecology* 81, pp 1654–1666.

Zackrisson O 1977, 'Influence of forest fires on the north Swedish boreal forest', *Oikos* 29, pp 22–32.

Appendix 1: Where is the GER corridor?

The Great Eastern Ranges Corridor (the GER corridor) is a vision for the conservation of natural lands that interconnect protected areas along the Great Escarpment of Eastern Australia (Ollier 1982) and the Great Dividing Range of Australia between (at least) the Australian Alps in Victoria and in NSW and Atherton in Queensland. These two national landscape features, the Great Divide and the Great Escarpment, broadly define the geography of this 2,800-kilometre-long north–south corridor and are described collectively here as the 'great eastern ranges'.

The GER corridor introduces a new land-use dynamic for Australia. Central to this approach is integration of the best possible mix of mechanisms (such as stewardship payments) to achieve voluntary conservation on private lands. This enables individuals, communities and private organisations to contribute to effective conservation of natural lands and provide effective responses to climate change. The large-scale north–south connectivity conservation vision serves as a strategic catalyst for multiple other connectivity conservation opportunities. As such, the precise geography of the GER corridor will evolve over time as local people participate in ways appropriate to their local context.

Geographic definition

The GER corridor can be defined geographically as follows.

1 **The remaining north–south interconnected natural lands** that lie between the Atherton Tablelands, Queensland and the Australian Alps in Victoria and are:

- principally along the Great Dividing Range in Victoria, although the Great Escarpment extends a short distance into East Gippsland
- along parts of both the Great Dividing Range and the Great Escarpment of Eastern Australia (and between these features) in NSW
- principally along the Great Dividing Range within Queensland, but the Queensland component of the GER corridor also includes multiple parts of the Great Escarpment of Eastern Australia, especially between Cairns and Townsville. This creates a more complex but significantly diverse corridor within Queensland.

In Queensland there are opportunities to extend the corridor further to the north towards Cape York, whilst in Victoria there are opportunities to extend it further westward.

2 **Opportunities for east–west interconnections of natural lands with the north–south natural lands**. Such interconnections may maintain natural connections to drier lands to the west (such as the Slopes to Summit corridor near Mount Kosciuszko and linkages to remnant woodlands that extend across the wheat–sheep belt); to riparian lands (along the inland or coastal flowing river systems); to locally higher lands; and to coastal lands to the east at various points along the north–south axis (such as the Kosciuszko to Coast corridor). Maintaining interconnections to key refugia areas, particularly along the coastal Great Escarpment lands will also be important.

A boundary for the GER corridor?

As a guide for planning, a general or indicative area for the GER corridor has been developed (see Figure 1). However, the actual boundary of the GER corridor will evolve with time, as its final definition will be subject to the involvement of governments, organisations, land owners and stewards, individuals and communities, and will be driven by a combination of:

- local contexts and opportunities
- environmental, social, economic and political imperatives
- the recommendations of systematic conservation planning (Margules and Pressey 2000).

The vision for the GER corridor is a 100-year-plus vision, and the final boundary in many locations will not be determined for many years.

The following individual bioregions and ecosystem types are of special conservation interest, and questions have been raised about whether they are part of the GER corridor. The following section clarifies their relationship to the GER corridor in light of the geographical considerations noted above.

The Brigalow Belt North

This bioregion includes flatter terrain near to and south of Townsville and lies east of the Great Divide. It is one of WWF's Priority One bioregions for Queensland, and WWF recommends that new protected areas should be added as a matter of priority (Sattler and Glanznig 2006). Connectivity conservation will play an important supporting role in this region. The map of the natural environments identified by the Queensland Government shows that many of the lands have essentially natural cover that interconnects with significant protected areas along the coast and into the Great Escarpment hinterland.

The Wet Tropics

The Great Divide meets the Great Escarpment to the north of Cairns in the Wet Tropics bioregion. This World Heritage area and refugia site includes many lands that are not formal protected areas and are worthy of conservation stewardship. Parts of this bioregion are recognised as one of WWF's Priority Four bioregions for Queensland, and new protected areas are recommended as a matter of priority (Sattler and Glanznig 2006). This bioregion should be included within the GER corridor and could be mapped by showing the corridor extending along the Great Divide to Cairns and then south and north along the Wet Tropics bioregion.

The South Eastern Corner bioregion

The Bega Valley is part of the South Eastern Corner bioregion in southern NSW. This bioregion includes the South East Forests National Park and Croajingalong National Park, both of which are part of the GER corridor. A map of the GER corridor would include parts of this bioregion and the fringe (natural) areas of the Bega Valley.

The degraded woodlands of temperate NSW and Victoria

The GER corridor will selectively and strategically extend into these areas in the future. Currently this is exemplified by the Slopes to Summit initiative. Mansergh and Cheal (2007) also identified potential for connectivity in Victoria. This issue also highlights the need for maps of the GER corridor to identify those areas where there is high potential for implementing the GER corridor vision but where such implementation is necessarily voluntary and will be supported primarily by individual property owners and the community.

The GER corridor vision therefore has 'diffuse or fuzzy' boundaries, because the actual boundaries will be dynamic as different people and communities participate. Connections to the east and to the west will be encouraged, but will be strategic to ensure maximum focus is on the goals of GER corridor connectivity conservation, and especially species conservation. New initiatives such as the 'Western Woodlands Way', for example, will interconnect with the GER corridor, and there will be a 'bulging' of the GER corridor boundary at their confluence. The actual, final GER corridor boundary at such a point will need to be defined relative to some standard guidelines that are still to be developed.

Coastal catchments

The GER corridor will include a number of coastal links based on the vision described above, including:

- east–west corridors that interconnect coastal protected areas to the hinterland (the Kosciuszko to Coast link, and the Bournda National Park–South East Forests link are two of several such links)
- part, or all of, the higher parts of catchments for most easterly flowing streams of eastern Australia.

As such, the GER corridor can form part of a national, strategic approach to protecting the Great Barrier Reef and each of the catchments of the water supply dams. The GER corridor could also link with riparian corridors that extend from the catchment to the sea if opportunities are available.

www.environment.nsw.gov.au