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Australia's landscapes in a changing climate—caution, hope, inspiration, and transformation

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Abstract. Australia's future landscapes will be shaped by global climatic, economic, and cultural drivers. Landscapes evolve. They are manifestations of the complex negotiations between nature and cultures, over millennia. In the Anthropocene, humans are the dominant evolutionary force reshaping the biosphere.

Landscape management involves all human activities and interventions that change the forms and functions of landscapes. It also involves the ways we learn about, and understand the world, and our place in it. Responses to climate change are driving changes in natural resources policy, research and management. Building capability for large-scale, adaptive management is critical in an era of global change. By rigorously examining and learning from recent experience—bioregional conservation planning, natural resource management (NRM), landcare, and water reform—Australia can build capacity for integrated and adaptive resource management.

Climate change compounds existing stressors on ecosystems. It adds complexity and presents new challenges for integrated assessment, planning, and management of natural resources. Given the dynamic nature of the ecosystems, static conservation paradigms and stationary hydrology models are increasingly redundant. In the face of inherent complexity and uncertainty, 'predict and control' strategies are likely to be less useful. Adaptive approaches are called for, due to the complex relationships and non-linear feedbacks between social, ecological, and climatic systems. Australia should invest in building professional and community capacity. Australia's scientific and professional capacity in natural resources provides useful foundations, but substantially increased investment is called for. Research should be focused on guiding and influencing management at large scales and on avoiding undesirable thresholds or tipping points in complex ecological systems.

Cultural and governance aspects are emphasised as central to effective adaptation strategies, because landscape management is an intergenerational, societal challenge that requires participatory, adaptive learning approaches.

Additional keywords: bioregional planning, climate adaptation, integration, landscape management.

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Introduction

Australia's vulnerability to extreme events—catastrophic fires, floods, and droughts—may constrain future settlement patterns and economic activities. Abandoned farm lands, new generations of ghost towns, and coastal cities protected by sea walls are plausible landscapes of the future (Palutikof 2010).

This paper provides a broad assessment of the challenges and options for Australian landscape management in the face of climate change. Three questions guided my investigations and persist as legitimate areas for further research:

- What are the critical capabilities and relationships that determine capacity to actively manage landscapes, natural resources, and environmental systems?
- What has been learnt about managing at a landscape scale that is relevant to climate change adaptation?
- How equipped is Australia to proactively shape its landscape under a changing climate?

Australia's ability to influence the trajectories of its diverse bioregions, under changing climatic conditions, will depend on the way our scientific, economic, and governance processes interact within what are already inherently complex institutional systems (Wallis and Ison 2011).

As a starting point, it must be accepted that regional landscapes are rarely 'designed' in a deterministic or architectural way, but evolve through dynamic interrelationships between the natural endowments of climate, geology and evolutionary biology, and the cultural and economic factors such as social institutions, and genetic and technological resources (Diamond 1997; Hobhouse 1999). While there are many technical aspects of landscape management applicable to specific locations, bioregions, and management objectives, for this paper a broad view of landscape management as a challenge of governance and culture is adopted. The nature of landscape management and land use in Australia is briefly outlined. Landscape management is used as an inclusive and integrative term that respectfully includes humans and their role in managing and shaping the environment (Campbell 2006).

All societies transform their environments—there is no wilderness (Gammage 2011) except due to blind or deliberate ignorance of history (Reynolds 2011). Australia's diverse ecosystems were shaped by >50 000 years of indigenous occupation (Mulvaney 1969; Gammage 2011) and the 300 million years of separate evolution (Keating and Harle 2004; Steffen *et al*. 2009) that laid the foundations for the continent's contemporary landscapes, including the urban, agricultural, and conservation estates fashioned over the past two centuries (Lines 1994).

Climate change is likely to compound the magnitude, extent, and impact of Australia's natural resource and conservation problems. Continental-scale land and water degradation and the loss of priceless evolutionary treasures are well documented, with further losses of biodiversity expected from climate change (NLWRA 2002*a*; Steffen *et al*. 2009). Climate change impacts and possible responses are many and varied and will depend on many factors.

A brief assessment of current settings and capacity is provided here. By looking to the past for lessons, the experience of operating in Australia's diverse and highly variable climate provides some basis for preparing for a changing climate. Much can be learnt by critically examining Australia's approaches to the challenges of securing reliable water supplies and minimising the social and economic impacts of fires, floods, and droughts. Stress-tested by recurrent droughts, the nation has demonstrated a persistent reluctance to fully accept the reality of the continent's drought-proneness (Lake 2008) and the severity of the climatic constraints to European-style settlement (Taylor 1940).

Scenario planning is an established technique used to explore and articulate possible, alternative futures which can be applied to the long-range concerns of our civilisation (Slaughter 2002). In this paper, a future scenario is used to illustrate a range of possible climate responses and the way the dynamic interplay between governance arrangements, policy settings, scientific endeavours, and business investments could accelerate their adoption. Cultural and governance dimensions of landscape management are emphasised because the challenges faced are local and global, and immediate and intergenerational. Capacity to adapt is dependent on the capacity of societies to learn, to organise, and to institutionalise useful rules, practices, and systems of learning. It is a case of learning to adapt and adapting to learn. Simple prescriptions are dangerous. Long-term, systems-wide perspectives are required.

Global challenges

As we enter the Anthropocene, humans have become the world's dominant evolutionary force, rapidly altering the atmosphere and the biosphere. Technology, consumption patterns, and growth in populations are delivering unprecedented rates of change to global systems, placing future social cohesion and wellbeing at risk (IGBP 2001; Millennium Ecosystem Assessment 2003).

Evidence from the ecological, climate, and earth sciences forms the basis of powerful precautionary warnings about curbing greenhouse gas emissions, and the severity of planetary-scale consequences if these warnings are not acted upon (Richardson *et al*. 2009). Acceptance of shared responsibility to act on this knowledge is the basis of a new global agenda, with new sets of rules that are redefining the relationships of societies with the Earth (Stiglitz 2006; Richardson *et al*. 2009)

The increased frequency, costs, and consequences of weather-related disasters provide a stark backdrop to global treaty negotiations on responses to climate change. Warnings from the science community are reinforced by the global re-insurance company, MunichRE, which states that the impacts, frequency and intensity of weather-related natural disasters emphasises the vulnerability of societies to extreme climatic events, such as the 2010 Russian forest fires which killed 56 000 people—the most deadly natural disaster in Russia's history—and that '*the high number of weather-related natural catastrophes and record temperatures . . . provides further indications of advancing climate change*' (MunichRE 2011). The evidence of rising temperatures throughout the second half of the 20 Century is incontrovertible (IPCC 2007; CSIRO 2010), with sobering predictions of the impacts of further increased temperatures on countries prone to drought and fire (Richardson *et al*. 2009).

Every nation and every sector will be impacted by changing climatic conditions and by the scale of mitigation and adaptation endeavours. Increasingly severe droughts in the mid-latitudes and the intensification of tropical monsoons will affect billions of people, justifying decisive adaptation interventions. Human vulnerability to climate change emphasises the need to proactively integrate climate adaptation into all spheres of economic and natural resources policy, particularly in water resources management and agricultural systems (Howden *et al*. 2007; Richardson *et al*. 2009).

Adapting to climate change is one of the great challenges facing water resources management, with links to poverty reduction, economic development, food security, and geopolitical stability. The Himalayas are the source of the major rivers of Asia, supplying water and food to billions of people. Pomeranz (2009) argues that glacial retreat could induce water stresses in the greater Himalayan region that may inflate historic disputes.

Preparing for and mitigating the adverse effects of climate change is a pressing, global concern for river basin managers, who are attempting to plan for a range of impacts including: increased water scarcity and more severe drought; changing precipitation patterns; reduced snow pack and glacier retreat; and increased frequency and intensity of flooding. Furthermore, the complexity of this planning is exacerbated by the need to rethink the fundamentals of hydrology, due to the 'death of stationarity' (Milly *et al*. 2008). To cope with changing global conditions, new social demands, and climate uncertainty, water management systems needs a paradigm shift from regimes based on 'predict and control' to adaptive governance models (Pahl-Wostl 2007; Wallis and Ison 2011).

While the European Union recognises the integrated nature of the policy challenges and the need '*to promote strategies which increase the resilience to climate change of health, property and the productive functions of land, inter alia by improving the* *management of water resources and ecosystems*' (EU 2009), the water sector often lacks capacity to change to adaptive governance because historic models reinforce the status quo and other factors stabilise and buffer current regimes against change (Pahl-Wostl 2007).

Globally, the challenges of resource management remain profound, with a growing acceptance of the need to decouple production, resource use, and pollution intensity. Furthermore, because economic development, biodiversity conservation, water and land use, energy production, carbon intensity, and global food supplies are intimately linked, these challenges need to be conceived of and addressed together rather than in isolation (IGBP 2001). Research and innovation systems are required to accelerate the development and implementation of integrated and scalable solutions, given the constraints to increasing resource use and intensity (Weaver *et al*. 2000).

Landscape management and climate change adaptation intersect with a range of societal concerns, including fire, flood, and disaster management; food and water security; resilient settlement patterns; and biodiversity conservation. With climate change likely to induce a wave of extinctions (Thomas *et al.* 2004) and erode the planet's capacity to deliver ecosystem services (Millennium Ecosystem Assessment 2003), more rigorous vulnerability and risk assessment methods are called for (Wilson *et al*. 2005). Management and science paradigms are required which deliver capacity to understand and manage ecosystems at larger scales (Folke *et al*. 2002; Likens *et al*. 2009).

Climate policy responses can also induce perverse outcomes. For example, the creation of carbon offset markets and subsidies for biofuels have provided incentives for the expansion of palm oil plantations and carbon forests that have displaced traditional land owners and destroyed high value ecosystems (CCB 2011). Recognition that carbon sequestration can be integrated with other landscape values such as production and conservation, rather than displace these, has led to the development and adoption of various carbon standards and quality assurance initiatives. The Carbon, Community and Biodiversity Standards aim to inform and guide multi-functional carbon sequestration projects so the investment derived from carbon markets achieves multiple aims (CCB 2011).

There are inherent risks in attempting to apply simplistic approaches to climate adaptation in river basin planning and ecosystem management. Instead, approaches to understanding and working skilfully with the dynamic social, economic, and ecological systems are required. Investments in large-scale science, monitoring, and professional capacity building need to complimented with commitments to deliberative governance, participatory management, and social learning (Walker *et al.* 2002; Everard *et al*. 2009; Alston and Whittenbury 2011, Wallis and Ison 2011).

In summary, both landscape management and climate adaptation require long-term, systemic approaches. While coordinated global action on mitigation is called for (Richardson *et al*. 2009), regional diversity must be accommodated and simplistic policy prescriptions avoided in adaptation. Adaptive governance arrangements are required that actively steer policy, govern systemic change, and build capacity for transformation (Walker *et al*. 2002; Folke *et al*. 2002; Ryan *et al*. 2010).

Landscape management

Definition and connections

Landscapes give tangible expression to culture's negotiations with nature, reflecting in the longer term peoples' dominant values, capabilities, technologies, and resources, including genetic resources (Diamond 1997; Hobhouse 1999). Many cultures have holistic terms for the integrated and intimate evolution of human societies and their landscapes. The Japanese use the word *fudu* to describe the co-evolution of their culture and their landscapes (Nogyodoboku and Kenkya-Kai 2004). In Australia, the word 'country' is used to indicate aboriginal peoples' relationship to their territories or ancestral lands. Its use is ritualised in formal 'Welcome to Country' ceremonies used to open conferences and public meetings.

Landscape management encompasses the sum of human interactions with landscapes (LWA 2005), incorporating both planned intervention (active management) and passive or default management. Both approaches can and do have unintended consequences (Holling and Meffe 1996) at a range of scales from local to global, due to the nature of feedback processes in global systems (IGBP 2001).

Research into the impact of vegetation clearing indicates strong causal relationships, with feedbacks between local-scale actions and continental-scale impacts. Large-scale vegetation clearing results in transformative changes to river catchments (Walker *et al*. 1989; NLWRA 2001*a*, 2001*b*) and detectable and potentially significant changes to climate, including through reducing rainfall and increasing severity and intensity of droughts (Makarieva *et al*. 2009; Deo *et al*. 2009; McAlpine *et al*. 2009). Makarieva *et al*. (2009) propose that their findings indicate the potential for strategic reforestation to be used as an applied solution to desertification.

In Australia, contemporary landscape management varies enormously depending on location, intensity of resource use, infrastructure, economic activity, and regional capacity (NLWRA 2002*a*, 2002*b*). Over the past two decades, Australian public policy has attempted to give effect to broad sustainability objectives, such as the conservation of natural resources and biodiversity. The governance of natural resources involves numerous State and Commonwealth agencies and 56 regional NRM organisations. The latter vary in scale, scope, legislative basis, and remit, but all have developed regional plans for working towards more integrated and sustainable resource management (for a fuller examination of Australian NRM governance arrangements, see Ryan *et al*. 2010; Lane *et al*. 2011; Robins and Kanowski 2011).

The diverse public, community and private sector 'actors' involved in NRM are connected via complex networks of relationships that span from local to national scales (Ryan *et al*. 2010). These can be defined as direct or indirect actors. Direct actors undertake direct management action and include, for example, pastoralists, miners, fire agencies, national park and indigenous rangers, forestry companies, landcare and friends of parks volunteers, etc. Indirect actors include a diverse range of parties, e.g. parliaments, courts, NGOs, industry organisations, and lobbyists, who influence NRM governance through the development of policies and laws. Quarantine agencies and agricultural agencies also influence landscapes through the introduction or restrictions on entry of species to Australia. Education and research institutes, artists, writers, and multi-lateral organisations influence landscapes through the propagation and transmission of ideas that help to shape norms and values. The public at large influences landscape management by voting and consumer choices.

Landscape management involves policy, practice, and knowledge. It is fundamental to a society's relationships to its resources and has dimensions which span a wide range of societal concerns. The interactions and feedbacks are significant across social–ecological systems spanning multiple temporal and spatial scales (Folke *et al*. 2002; IGBP 2001). In many cases, explicit processes for representing the complexity of, and for influencing, these systems are absent and more implicit and diffuse processes of influence occur.

Bioregional planning and management

Australia uses a bioregional classification system that defines 85 bioregions as the spatial basis for bioregional conservation planning (Fig. 1). Landscape management occurs throughout Australia's 85 bioregions, with varying degrees of intensity, capacity, and effectiveness (NLWRA 2002*a*; Cork *et al*. 2006).

Other useful systems for classifying ecosystems include McIntrye and Hobbs's (1999) framework based on Australia's 11 agro-ecological zones (Fig. 2), in combination with the relative degrees of vegetation fragmentation. Thackway and Leslie (2006) also propose a 'Vegetation Assets, States and Transitions' framework based on levels or stages of vegetation modification. The national assessment of landscape health and river condition strongly correlates high rates of vegetation clearance and fragmentation with landscape stress and changes to hydrological functioning of catchments (NLWRA 2001*a*, 2001*b*).

Increasing the size of the formal conservation estate has been a primary focus of many national conservation strategies. Systematic conservation planning tools have been developed for use in terrestrial, marine, and freshwater systems (Linke *et al*. 2007; Hermoso *et al*. 2011). It is increasingly acknowledged that management is required across all tenures if conservation goals are to be achieved and that highly modified landscapes have a range of conversation values (Lindenmayer *et al*. 2003; Cork *et al*. 2006; Fischer *et al*. 2008).

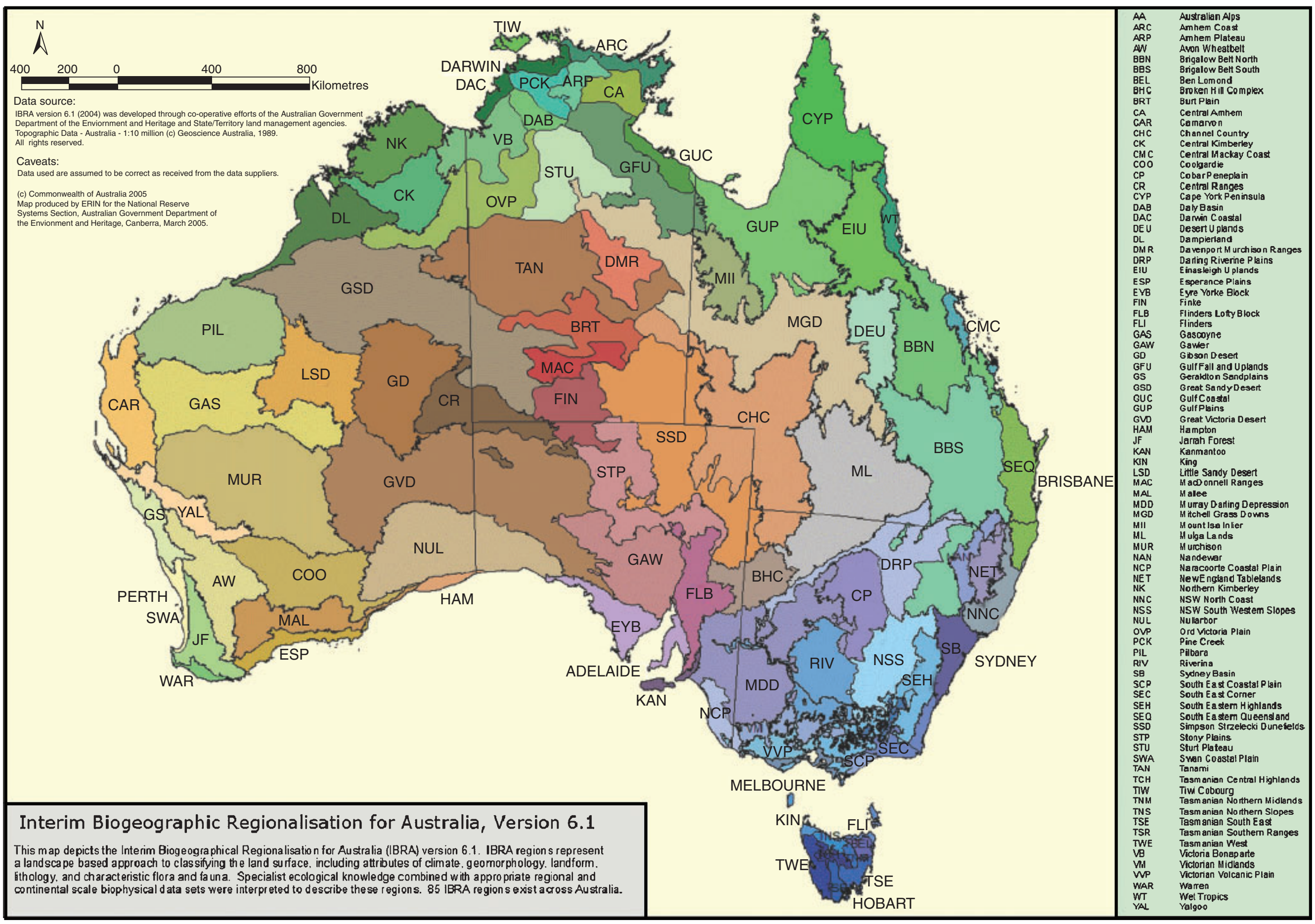

Fig. 1. Interim Bioregionalisation of Australia (IBRA). Source: www.environment.gov.au/parks/nrs/science/bioregion-framework/ibra/index.html.

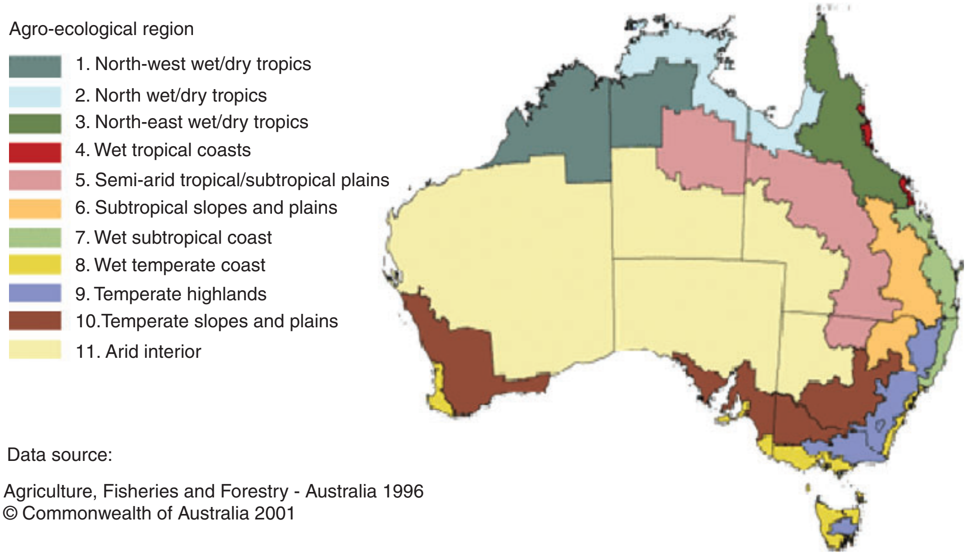

Fig. 2. Australia's agro-ecological zones.

Analysis of landscape management, by necessity, involves consideration of tenure and its influences, land use patterns, and management approaches but should not be limited to these, as critical ecological process drive changes across all tenures (Lindenmayer *et al*. 2008). Management strategies must actively work with the key drivers that exert an influence on long-term conditions, such as the movement of water, the succession and recruitment of plant and animal species, and the patterns of fire, none of which respect property boundaries or tenure arrangements.

Vast areas of Australia have outstanding biodiversity values that require active management to conserve (NLWRA 2002*a*), and healthy functioning landscapes are critical for rivers, wetlands, estuaries, and coastal waters (NLWRA 2001*a*, 2001*b*). Nonetheless, land-use conflicts are frequent and inevitable, due to fundamental differences of values and perspectives in contemporary Australia. Robust planning and institutional frameworks are needed to accommodate changing, diverse, and conflicting views on competing economic, cultural, and natural values of landscapes (Alexandra and Campbell 2003). These conflicts have been persistent in relation to Australia's forest estate (Dargavel 1995) but are also apparent in relation to the plans for water resource development in Northern Australia. CSIRO (2009) found that rivers and catchments in northern Australia have important and diverse natural and cultural values and that severe natural constraints limit the attractiveness and feasibility of large-scale irrigation development. These findings indicate the merit of the approach adopted by Hill *et al*. (2008), who explored ways of strengthening the conservation and cultural economy of northern Australia. Regional communities are planning ways to use multi-functional and diverse natural and cultural values as part of their economic foundations (Hill *et al*. 2008) and will increasingly be able to include payments for ecosystem services, such as carbon sequestration, to support their management aspirations (Russell-Smith *et al*. 2009; DCCEE 2011).

Land use and land-use change in Australia

In Australia, both land tenure and land use remain dynamic, with significant changes occurring in recent decades. The Wik and Mabo decisions of the High Court fundamentally altered established concepts of land tenure and associated laws (Keating 2011). Changes in land tenure, ownership, and dominant use can trigger significant changes in landscape management, because these changes often result in fundamental changes in management objectives. For example, changes in tenure from production forest or pastoral land to conservation reserve change the tenure, the underlying land use, and the objectives of management. Change of use without change in tenure can also trigger profound change in management. A change from grazing to plantation forests results in fundamental changes in landscapes appearance, function, management, and often ownership. Since the late 1990s, many hundreds of thousands of hectares of higher rainfall grazing land in Australia was changed to plantations, due to an alignment of policy and economic drivers (Alexandra and Campbell 2003), some of which changed in 2008, leading to the dramatic bankruptcy of several major plantation companies and rapid decline in the rate of plantation establishment.

The most recent published statistics on Australian land use (ABARE-BRS 2010) have been analysed and grouped into the following three categories: extensive; rain-fed intensive (agriculture and forestry), and intensive other (irrigation, urban, mining, etc.) (Fig. 3, Table 1). Extensive land uses occur on 83% of the continent, consisting of nature conservation reserves (7.41%); other protected areas, including indigenous conservation areas (13.21%); minimal use (16.17%); and the grazing of native vegetation (46.30%). Rain-fed intensive agriculture and forestry combined occupy ~14.5% of the continent. Of this, dryland agriculture totalled ~12.7%, with cropping at 3.3%, and improved pastures 9.37%. Plantation forestry occupies

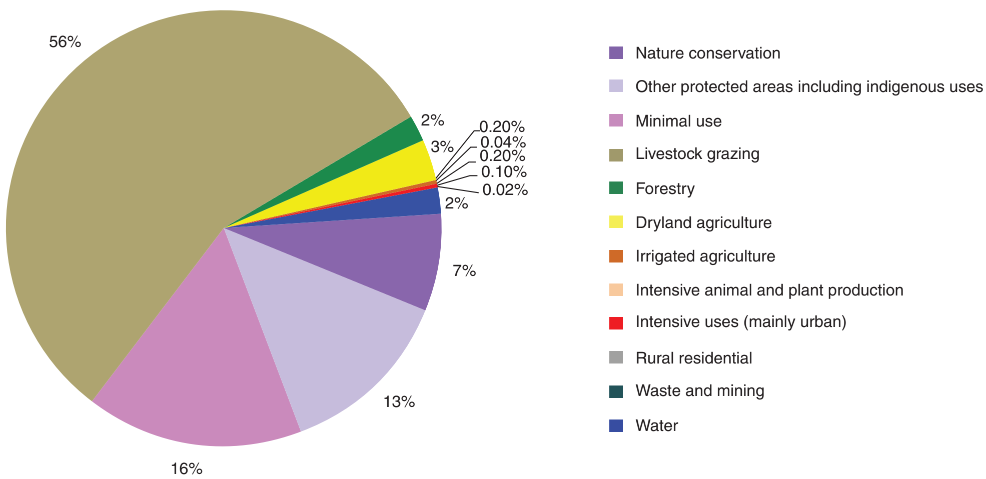

Fig. 3. Land use by area in Australia (ABARE-BRS 2010).

Table 1. Land use by area in Australia (Source ABARE-BRS 2010)
Land use in Australia (based on Land Use of Australia 2005–06, Version 4, ABARE–BRS (2010)

Land use	Area (km^2)	Area (%)
Intensive other		
Dryland horticulture	1092	0.01
Irrigated pastures	10 011	0.13
Irrigated cropping	12 863	0.17
Irrigated horticulture	3954	0.05
Intensive animal and plant production	3329	0.04
Intensive uses (mainly urban)	16 822	0.22
Rural residential	9491	0.12
Waste and mining	1676	0.02
Total intensive: irrigation, urban, other	59 238	0.76
Extensive uses		
Nature conservation	569 240	7.41
Other protected areas including Indigenous uses	1 015 359	13.21
Minimal use	1 242 715	16.17
Grazing natural vegetation	3 558 785	46.30
Total extensive	6 386 099	83.09
Intensive rainfed		
Production forestry	114 314	1.49
Plantation forestry	23 929	0.31
Grazing modified pastures	720 182	9.37
Dryland cropping	255 524	3.32
Total intensive: primary industries	1 113 949	14.49
Water (inland)	125 618	1.63

0.31% and production forests 1.49%. In contrast, all intensive uses occupied <0.76%. This includes all irrigated agriculture 0.33%, urban and peri urban 0.34%, and mining 0.02%.

Options for adaptation

Foresighting and scenario planning methods

Here, I offer a brief scenario to illustrate a range of adaptation options and the interplay between policy, research, and practice change. Scenario planning is an established technique used within the discipline of future studies to explore alternative futures (Slaughter 2002). It is a recognised method of investigation, capable of dealing with the non-linearity of complex systems because it does not rely on extrapolating existing trends. Scenario planning is commonly used in the development of corporate strategies and has been applied to national science planning and natural resource management (Cork *et al*. 2008).

The Australian Science Technology and Engineering Council study '*Matching Science and Technology to Future Needs 2010*' found foresighting useful for redirecting established mindsets and for identifying global trends that could help Australia's international competitiveness (ASTEC 1996). In 1996, the major forces that would shape Australia's future and the future roles of science were identified as: global integration, information and communication technology, gene technology, and environmental sustainability (ASTEC 1996).

Below is a scenario, set in an era in the not-too-distant future, when invigorated national policies and international agreements lead to transformational change in public policy, popular culture, and private sector practice. These have been provided to illustrate possible futures in which landscape-scale management becomes an element of Australia's comparative advantage. The balance of paper offers an analysis of the present setting and challenges.

A story from the future

'The ecological and financial shocks of the early 21 Century triggered the redirection of political and financial capital to the cooperation and economic transformations needed for climate stabilisation and sustainability. This level of global cooperation was similar in its intent, broad reach, and intended scale of impacts to the establishment of the Breton Woods Institutions (World Bank, IMF, and WTO) to support post World War II reconstruction (Judt 2007).

'Australia sought to capitalise on its competitive advantages in environmental management, based on experience in stress-tested water policy, and social innovations in conservation, community empowerment, and devolved NRM governance (Ryan *et al.* 2010; Lane *et al.* 2011). Australia became recognised for its disciplined use of cost-effectiveness assessment and prefeasibility tools to guide investment in large-scale bioregional management (Pannell 2008). It gained an international reputation for its experience in the restoration, conservation, and management of diverse bioregions, from tropical savannas to the temperate climate zones. Experience in NRM led to the institutionalisation of participatory governance arrangements, which combined local knowledge and responsive management capacity with scientific rigour in the design of large scale experimentation (Likens *et al.* 2009). Modern adaptive-management practice emphasised the need for clarity of regional objectives, explicit system models, the testing of interventions, and rigorous monitoring (Holling 1978). New disciplines emerged in integrated regional planning. Central governments focused on ensuring that regions are cost-effective in the delivery valuable ecosystem goods and services, including carbon sequestration, biodiversity conservation, catchment and water system stabilisation, food and fibre production, and cultural, educational, lifestyle, and spiritual services (Alexandra and Riddington 2007; Hill *et al.* 2008).

A new global consensus: sustainability science and innovation

'The emergence of a global consensus on climate stabilisation and sustainability invigorated Australia's attempts at transformational change (WWF 2002). Scientific initiatives flourished. China's twelfth 5-year plan focused on 'sustaining the revolution through sustaining evolution'. It sponsored major initiatives on water, pollution reduction, clean energy, urban systems, and conservation. China's lead was followed by her major trading partners. Countries also followed Britain's example of reducing military expenditure. The new alignment between fiscal restraint and sustainability imperatives led to the redirections of budgets through environmental tax reform (Hamilton *et al*. 2000). Increased expenditure on sustainability research and development resulted in significant breakthroughs in production, consumption, habitation, and governance systems (Weaver *et al*. 2000). The interplay between policy settings, markets, and practice change was recognised as central to successful transformations (Everard *et al.* 2009).

'Australia adopted novel outcomes-based incentives for regional landscape management. Regions competed for financial rewards and prestige granted by central governments for every threatened species securely recovered *in situ*. Similar payments were offered for the stabilisation of any species deemed at risk from climate change. The ecological sciences flourished due to the need for stringent verification of species status and demands for advice on population recovery and ecological restoration. Ecological architecture, low impact mining technology, and applied restoration ecology are promoted as some of Australia's leading environmental industry exports.

Life sciences and the new agro-industrial systems

'The life sciences also flourished. Fermentors and bio-digesters were big business, harnessing the power of microbes for a range of applications in agriculture, industry, and waste management. Applied microbiology—once the relatively narrow domain of medicine and food technology—was applied to increasing soil fertility and carbon sequestration capacity, for waste management and recycling, and for understanding the genetic diversity within fragmented landscapes. The concept of 'waste' became increasingly redundant as more and more materials, historically regarded as waste, became the feedstock of agro-industrial systems designed as industrial ecosystems (Hill 1998, 2002).

'Intensive animal and food processing and sewerage treatment plants were transformed into major organic-recycling centres. No longer discharging polluted water, they recycled water for use in intensive agriculture and produced electricity from biogas, nutrient-rich composts, and microbial 'soups' (somewhat similar to compost teas used by organic farmers of the past; tightly specified and tested, quality-assured products). Several of Australia's top universities competed for the most highly recognised 'Centres for Composting and Applied Microbiology' offering generous scholarships to attract the best and brightest to this exciting field of research.

'Taking the lead from Cuba's 'green revolution' food gardens and urban farms were promoted to reduce food miles, improve nutrition, increase food security, and reduce poverty (Rosset and Benjamin 1994; Altieri *et al*. 1999). Around the world, urban food gardens acted as community and educational centres, pivotal to the new food systems which emphasise culturally nourishing celebrations of localism, seasonalism, and bioregionalism (Altieri *et al*. 1999).

'Many countries formally adopted village and urban agriculture as the basis of their food security policies (Altieri *et al*. 1999; Marsh 1998) and shifted their R&D focus from increasing grain production to advancing the theory and practice of permaculture systems and mixed species, polyculture production (Mollison 1988; Geno and Geno 2001; Alexandra and Stanley 2007).

'Throughout the world, policies were aimed to increase food and bio-energy output 3–4-fold from the same land areas—a second green revolution with origins in many places including the *barrios* of Cuba (Altieri *et al*. 1999) and villages gardens in Bangladesh, where breakthroughs in improving the productivity of small scale production systems were pioneered (Marsh 1998). Global food insecurity reduced due to technical, scientific, and design breakthroughs resulting from systematic R&D into integrated food systems (Weaver *et al*. 2000). Despite these changes, demand for Australia's primary industry export products (proteins, grains, wine, fibre, etc.) remained high due to the increased affluence of populous nations such as China (Hutton 2007).

Corporate involvement, fast bucks and patient capital

'The potential for capital gains from sustainability and NRM led to corporate interest. Corporate involvement started during the first waves of large-scale carbon sequestration investment. Corporations promoted CO_2 forests, 'woody weed wonderlands', 'biochar bonanzas', and savanna-burning schemes. Each approach ultimately succeeded in increasing carbon sequestration, but only after a predictable business pattern of speculative boom and bust. The second wave of corporate investment was more sophisticated. Major landscape restoration and transformation projects packaged a mixture of landscape functions and ecosystem services into profit-making components: carbon, biodiversity, heritage, water quality, and capital stocks (Alexandra and Associates Pty Ltd 2002). Companies vigorously adhered to the international carbon, community, and biodiversity standards (CCB 2011). The first such scheme in Australia was pioneered by a VicSuper subsidiary that reconfigured farms across northern Victoria, becoming a sizable holder of water rights, land, and floodplain assets. VicSuper became recognised as a market leader for pioneering in use of patient capital for long-term eco-renovation and natural asset accumulation. The third wave combined profit seeking with branding and positioning through 'philanthropic' sponsorship. A major investment bank funded the recovery of the Macquarie perch, the Macquarie River, and the Macquarie Marshes so it would beat its competitors in being recognised as a market leader in corporate responsibility in a climate-changing world.

Reformed governance models

'Landscape management became increasingly important to successive national governments as a result of domestic and international pressure for demonstrating progress towards a low carbon, high conservation future. Policy frameworks based on devolved, regional governance continued to evolve (Ryan *et al.* 2010; Lane *et al.* 2011), and predictably, every time arrangements were changed somebody claimed NRM was less effective. Deliberate transformations of regional economies were attempted in ways which built regional capacity, rewarded innovation and productivity, and revitalised established industries and communities (Alston and Whittenbury 2011). However, not all previously prosperous regions survived—a new wave of ghost towns resulted from population and climate shifts (Palutikof 2010).

Scaled-up savannas burning

'Across Australia's savannas (approximately one-third of the continent) the program of early-season burning was well established. This program, modelled on and continuing indigenous patchwork burning patterns, was funded by carbon offset payments from large energy companies. Building on extensive trials, research consistently confirmed and quantified the value of early-season burns compared with late-season fires, with benefits including reduced CO_2 emissions, conservation of biodiversity and cultural practices, and connections to country and improvements in health and education in remote communities (Russell-Smith *et al.* 2009). The cooperative program covered the great bulk of the savannas and involved indigenous communities, conservation NGOs, graziers, and government agencies. It used a range of high and low technology burning techniques and advanced analysis and remote sensing to quantify results (see for example: www.firenorth.org.au/nafi2).'

Climate change impacts

Like the rest of the world's tropics and mid-latitudes, Australia's future climate is likely to be driven by increasingly frequent and severe droughts in the mid-latitudes and the intensification of monsoonal systems (IPCC 2007; Richardson *et al.* 2009). Both trends offer sizable challenges for landscape management. Furthermore, the factors that make Australia's climate highly variable may be driven to new states of frequency or intensity by global warming, potentially exacerbating the established patterns of extended years of dry conditions (droughts), punctuated by 'big wets' (Cai *et al*. 2011). For example, Cai *et al*. (2009) found that climate change is contributing to more frequent, consecutive positive, Indian Ocean Dipole events, which exert powerful influence over southern Australian rainfall patterns.

Drying of south-eastern Australia is predicted by the majority of models assessed by CSIRO (CSIRO 2010). Significant reduction in stream flows is another likely prospect. Under such conditions, previously reliable water resources could become less reliable and more episodic, resulting in the need for changed expectation of water availability and therefore more opportunistic primary production systems.

Different bioregions and their landscape-based production systems will be impacted differently. Those already adaptive to highly variable climatic conditions, such as rangelands grazing, may adapt with greater ease than those dependent on reliable annual production. The latter are likely to be more heavily impacted by changing climate patterns due to their higher capital and operating costs. Over large areas of Australia, the economics of commodity production will be an underlying driver of changes to agricultural practices. Changing profitability of productions systems in different regions will be reflected in changing property values. Increasing populations in the coastal and peri-urban areas (Buxton *et al*. 2006) may retreat in the face of more frequent, catastrophic bush fires and cyclones, and sea level rise. Low-lying coastal areas may have to accept planned retreat or expensive engineering to protect against inundation (Palutikof 2010).

Climate change is likely to intensify and compound existing NRM problems and is also likely to reinforce existing trends of intensification and extensification in Australia agriculture (NLWRA 2002*b*). Intensive systems, such as irrigated horticulture, are capital-, expertise-, and technology-intensive. Rising temperatures and changes to precipitation patterns may increase risks and frequency of pests and disease and may also damage sensitive crops directly or reduce the quality of produce from sensitive varieties of vine grapes (Webb *et al*. 2008). Vulnerable crops are likely to move, over time, to the more favourable, profitable, and climate-secure growing locations, with flow-on effects to regional landscapes. This is particularly the case for intensive systems.

Climate change impacts will not be limited to, but may include:

- Increasing aridity and increasingly frequent and severe droughts in the mid-latitudes, impacting on much of the sheep–wheat belt, and the intensive plantation and grazing areas in SE and SW Australia (CSIRO 2010);
- An expansion of the influence from the tropics and the intensification of tropical monsoons with a southern extension of both their wet and dry influences;
- A poleward shift of the Southern Hemispheric circulation and a reduction in influence of rain-bearing storms over SE Australia;

- Intensification of the East Coast Current, bringing more, warmer water southward along the coast;
- More powerful and frequent east-coast lows and cyclones causing flooding and damaging crops, plantations, and infrastructure along the east coast from Sydney to Cooktown, but benefiting industries dependent on rainfall in both the coastal strip and interior such as grazing in the savannas and rangelands;
- Less reliable water supplies, and water scarcity and competition between sectors for available water in southern Australia;
- More extreme events, including periods of high temperature and intense storms, which will impact all types of horticulture and viticulture, infrastructure and settlements;
- A wide range of impacts resulting from climate-induced disasters such as fire, drought, and flood, including the need for new strategies for public land management, rural settlement patterns, and disaster prevention and responses;
- Unseasonal weather patterns, bringing unseasonal rains and changing pest and disease patterns;
- Sea-level rise affecting coastal and estuarine systems but also impacting on significant transport infrastructure, and urban markets.

Options for adaptation to new climate

Adaptation options

Adaptation requires many locally appropriate responses as well as pro-adaption policy and institutional settings. Procter *et al.* (2009) concluded that further research and policy development aimed at enabling adaptive capacity should include:

- Foresighting regional landscape futures using a range of standardised climate scenarios;
- Exploring adaptive institutions and governance arrangements at local, regional, and national scales;
- Ongoing assessment of adaptive capacity and vulnerability including the development of local and regional self-assessment tools.

Examples of options for adapting to climate change at a scale relevant to landscape management deserving of further investigation include:

- Reform to regional water and NRM planning to more fully integrate catchment, NRM, and conservation planning;
- Further research into bio-fuels production, ranging from firewood to avgas from algae (Virgin Blue 2010) to bio-digesters converting lingo-cellulose and bio-energy industries with production locations driven by advances in generation and harvesting technology (Foran 2009);
- Urban and peri-urban settlement patterns that integrate food gardens, and urban forests used for climate conditioning, and food and fuel production (Altieri *et al.* 1999);
- Stricter land-use planning controls to minimise development in areas with high risk-exposure to fire, flood, or sea level rise; for example, new peri-urban housing could be limited to non-bushland areas zoned for multiple uses, so that intensification of agricultural production around cities and towns is focused on areas that can reduce bushfire hazards;
- Use of river basin planning and water networks to protect and enhance urban water supply security; this may result in water being harvested from larger areas, or the use more novel technologies to help cities survive deepening droughts;
- Carbon sequestration payments supporting a diversity of carbon sequestration options, from reforestation to soil storage;
- Modification of rangelands burning and grazing to maximise carbon sequestration;
- Savanna burning systems to minimise CO_2 emission and maximise biodiversity and cultural conservation;
- Allocation of water and other resource use rights through markets, allowing for greater flexibility in decision and risk management;
- Other ecosystem services payments, e.g. biodiversity and water quality bonds;
- The translocation of species, planned movement of production functions, and settlements to favourable locations
- Asset protection—define core, highly valued built assets, e.g. urban settlements, and plan to protect these against climate change impacts such as sea-level rise and flooding;
- Industrial intensification—use of technology such as desalination, climate-controlled intensive horticulture, and underground housing to overcome climate constraints to settlements.

Criteria for assessing adaptation responses

Various attempts have been used in defining assessment frameworks and criteria for assessing adaptation options; however, as is argued above, adaptation is a society-wide challenge that requires systemic approaches. Smith and Lenhart (1996) propose that adaptation options should meet at least two criteria—that they are a high priority and are cost-effective, in that they generate net benefits independently of climate change.

The following qualitative criteria may be a useful basis for assessing climate adaptation options in the Australian landscape or NRM sectors. Options should meet one or more of the criteria:

(1) Generates multiple benefits and has no regrets. Responses that aim to deal with priority landscape issues and will be useful, regardless of the severity of climate change, e.g. improved land-use planning to minimise bushfire impacts on urban and peri-urban settlements (Buxton *et al*. 2006).
(2) Addresses an established or priority NRM issue driven by climate variability, e.g. drought preparedness, and assists in building institutional and cultural knowledge about long-term episodic events and their role in resetting ecosystems (Stafford-Smith *et al*. 2007).
(3) Delivers quality-assured information (both long- and short-term predictions) so that individuals and businesses are able to make informed decisions (Howden *et al*. 2007).
(4) Supports integrated and adaptive co-management of natural resources, particularly by marginalised groups (Tompkins and Adger 2004). For example, indigenous communities own and manage >20% of the Australian

landmass; clearly, further analysis of options for improving the capacity for managing these economic and cultural resources is warranted (Alexandra and Stanley 2007).

(5) Builds community resilience, participation, and professional capacity to adapt to an uncertain and unpredictable future (Walker *et al.* 2002; Tompkins and Adger 2004).

(6) Systematically aims to improve understanding of dynamic relationships across large spatial and temporal scales, including of feedbacks and non-linear changes or shifts in ecosystems through theoretical and long-term ecological research and monitoring (Folke *et al*. 2002; Scheffer *et al.* 2009).

(7) Uses best available science and economic analysis to support informed choices between options. Investment prioritisation tools such as INFER have been developed and tested, which enable more targeted public expenditure on NRM (Pannell 2008).

(8) Requires adoption of land use planning systems that are precautionary and address risk and cumulative impacts (Buxton *et al*. 2006). For example, planning controls that limit the investment of capital into high-risk areas, such as those prone to bushfires, flooding, or sea-level rise, by clearly articulating long-term policy positions of government so as to inform business and investment decisions. For example, the adoption of a planned retreat policy for coastal protection or flood-plain asset protection would clearly define those areas so that use of engineering measures can be planned to secure valuable areas against floods or sea-level rise and allow for retreat and inundation for the balance of the areas affected.

(9) Sensibly devolves decision to markets that allow for, or enhance, more flexible management of resources. For example, water markets to reallocate water rights between users (Smith and Lenhart 1996) or redefinition of grazing rights to support more flexible, non-stationary pastoralism over larger areas.

(10) Establishes property rights regimes that establish and support more equitable, efficient, and sustainable resource use or management (Young and McCoy 1995).

(11) Enhances capacity to sequester carbon in the landscape, while delivering multiple social and economic benefits (Russell-Smith et al. 2009).

(12) Builds and tests general principles and guidelines for improved resource and ecosystems management including via optimisations tools (Lindenmayer *et al.* 2008; Lewis *et al.* 2010);

Assessment of current activities and settings

Natural resource management arrangements

Australia's landscape management responsibilities are distributed across a plethora of policy, research, and management agencies, as well as the private sector, indigenous communities, and NGOs (Campbell 2006; Ryan *et al*. 2010).

Policy and institutional reforms, including ongoing government, farmer, and NGO support for NRM initiatives, indicates the depth of support for practical action on conservation, yet Australia's natural resource problems persist, having all the characteristics of wicked problems, in that they are systemic, and resistant to simple solutions (Australian Public Service Commission 2007). In 1998 the Industry Commission found that '*The incorporation of ecological sustainability into policy has been ad hoc, incomplete and tentative. The central problem is that Australian governments have yet to put in place a comprehensive, integrated and far sighted way of promoting the ecologically sustainable management of natural resources*' (Industry Commission 1998).

While challenges of sustainable management of natural resources remain, climate change introduces major new uncertainties and demands acceptance of more dynamic conservation paradigms to underpin management of Australia's ecosystems (Dunlop and Brown 2008). Historically, Australia's approach to NRM and environmental management has been based on a stationary but variable climate, fluctuating within predictable ranges. Empirical information about climate and other environmental factors (e.g. stream flow, species distribution, etc.) collected over the past ~100 years have been foundational to the use of scientific approaches. A changing climate therefore poses not only direct problems for management but also challenges to the conceptual basis of our understanding of the natural world. Thus, the 'death of stationarity' challenges fundamental assumptions not only used for water planning (Milly *et al*. 2008) but also for NRM and conservation planning, and further emphasises the need to shift from a regime of predict and control to adaptive approaches (Pahl-Wostl 2007).

Australia's broad ranging and ambitious national goals of conservation of biodiversity and sustainable resource management are stated in numerous policy documents (e.g. Commonwealth of Australia1991, 1996; Natural Resource Management Ministerial Council 2010). If these are to be achieved, Australia needs integrated approaches that are robust under the increased pressures and uncertainties of climate change (Dunlop and Brown 2008; Steffen *et al*. 2009).

Clearly defining what constitutes conservation and sustainable management of natural resources may become increasingly difficult if we abandon a static view of natural systems and introduce climate change driven dynamism to our mental models of the environment, accepting that ecosystems can shift to radically altered or new states (Scheffer *et al*. 2001). Recognition of the dynamic nature of ecosystems and an increased focus on understanding and working with the key drivers of ecosystems are required to move to a non-static paradigm that is capable of handling non-linear changes and multiple transformation processes (Holling and Meffe 1996; Folke *et al*. 2002).

There is an important interplay between large-scale policy settings and the enabling of local, diverse responses. Integrated approaches to landscape management at the regional scale can support climate preparedness and build adaptation capacity. In their insightful paper on the pathology of natural resource management, Holling and Meffe (1996) argue that understanding the key, long-term, dominant drivers of ecosystem change is critical to guiding management interventions which support resilient ecosystems and enhance human wellbeing in the long term.

Adaptive ecosystem management approaches have been developed and further refined that support anticipatory policy and management responsiveness in the face of incomplete knowledge and uncertainty (Holling 1978; Stafford-Smith *et al*. 2009). For example, generalised principles of adaptive ecosystem management have been developed by drawing together lessons from the ecological sciences (Lindenmayer *et al*. 2008), and robust approaches to systematically learning by monitoring the effects of management are documented by Stafford-Smith *et al*. (2009). These approaches provide a strong conceptual and scientific foundation for climate-change adaptation in Australian NRM, as they consistently emphasise the need to recognise the dynamic nature of ecological systems and to build 'learning institutions' with capabilities for adjustment and adaptation of management by incorporating the lessons derived from monitoring and reflection.

Australia's NRM arrangements offer fertile ground for further development of adaptive institutions. The challenge of designing institutional arrangements for sustainability is non-trivial and deserving of serious consideration (Dovers 2001). One of the pressing challenges of operating in a highly variable climate is how to build flexible institutions with capacity to genuinely learn from history so that the understanding of the full impacts of episodic climatic events, like droughts and fires, is fully embedded within the social memory (Stafford-Smith *et al*. 2007).

The principle challenge for adaptive management in Australia is not the conceptual basis of adaptive management but in building institutions with capacity for dealing with the long-term complexity of implementing sustainability policies (Dovers 2001) within a federated system, which already has significant institutional complexity (Wallis and Ison 2011) and where multiple levels of governance impede reform (Connell 2011).

Scales, boundaries, and feedbacks

Consideration needs to be given to the appropriate scale of administrative arrangements for NRM, noting that there are long-standing tensions between centralised and dispersed control. The scale of Australia's NRM regions and their adherence to catchments boundaries, where appropriate, is consistent with the approach being adopted in many parts of world, including Europe under the Water Framework Directive (Molle 2009). The river basin has risen to pre-eminence as the preferred unit for planning and reconciling conflicting interests in resource management in many parts of the world; however, it should be recognised that the adoption of any particular administrative or governance unit is explicitly political, despite claims to the rationale of using 'natural' or hydrological boundaries (Molle 2009).

Ryan *et al*. (2010) propose further strengthening of natural resource governance arrangements for Australia that support diverse, responsive, regionalised governance. However, it is important to recognise that landscape management occurs simultaneously at local, regional, and continental scales due to complex feedbacks between scales of activity, influence, and impact (IGBP 2001).

The appearance of order found in many landscapes is consistent with the concept of the emergence of patterns in complex systems. Their appearance, form, functional relationships, and dynamics are shaped by the various ecosystem drivers and feedbacks, and the dynamic relationship between humans and their environments (Holling and Meffe 1996) over long time scales and at a range of spatial scales from local to global (IGBP 2001; McAlpine *et al.* 2009). As linked social–ecological systems, they respond in non-linear ways and have thresholds of change which can tip systems into new states, with new dominant controlling drivers (Scheffer *et al*. 2001; Folke *et al*. 2002). There is increasing interest in defining the characteristics which confer resilience of these systems, and in the role of cultural norms, institutions, and governance arrangements in steering systems and sustaining natural resources (Walker *et al.* 2002; Everard *et al.* 2009; Ryan *et al.* 2010).

Effective landscape management needs to be responsive to local conditions and changing circumstances. System change can result from deliberate management interventions, which aim to achieve preferred, defined objectives, or be a result of unpredicted consequences of management, as well as due to external or wild-card factors, such as species invasions, global economic shocks, technology, or climate change. Furthermore, activity at one scale can result in unintended consequences at different scales (IGBP 2001; McAlpine *et al.* 2009).

Walker *et al*. (2002) propose that participatory approaches to management are likely to be more adaptive, arguing that it is during periods of greatest instability and turbulence that learning to live in and adapt with systems, rather than control them, is required, because in these periods, system understanding and the impacts of planned interventions are least certain. Tompkins and Adger (2004) argue that community-based resource management is an effective way to build both social and ecological resilience and capacity to adapt to climate change.

Holling and Meffe (1996) outline why the adoption of centralised 'command and control' approaches by governments is one of the more dangerous pathologies of NRM that is indicated by the adoption of formulaic approaches and a tendency to demand certainty of results, during periods of uncertainty.

Devolved, participatory approaches and community involvement

If Australia's policy and institutional frameworks are to meaningfully contribute to sustainable natural resource management and climate change adaptation, they need to build on the lessons of the early landcare decades. Key lessons include the need to empower communities, establishing ways of negotiating consensus, enabling diverse local responses, applying subsidiarity principles (devolved responsibility), and accepting polycentric governance models (Marshall and Stafford-Smith 2010; Ryan *et al.* 2010; Robins and Kanowski 2011).

Australian policy reforms in water resources, forestry, and fisheries provide significant lessons in terms of policy development and implementation. Understanding the social and economic foundations of resource use and of resource-dependent communities is generally recognised as critical to the design and implementation of reforms. A wide range of potential policy instruments and their application to land-use change is reviewed by Alexandra and Associates Pty Ltd (2002), who recommended selection from a wide spectrum, including incentive and educative measures, planning, regulation, and redefinition of property rights, depending on the specific circumstances and objectives.

Creating synergies by aligning public policies and private investment is required to effect landscape-scale change (Alexandra 2006), because many recommended landscape conservation practices, such as fencing remnant vegetation and riparian zones, are beyond the financial capabilities of many typical farms (House *et al*. 2008). In a study into the adoption of environmental management systems (EMS) by farmers in Victoria, Australia, Cary and Roberts (2011) also found that the adoption of conservation practices by farmers was unlikely to be to sufficient to result in significant environmental impacts, despite government incentives and industry promotion of EMS.

These findings indicate that it is unrealistic to rely on voluntary adoption of conservation in agricultural landscapes, and that the use of other policy instruments, including direct payments and regulation, should be considered (Alexandra and Associates Pty Ltd 2002; Cary and Roberts 2011). Overall, it is sound public policy to select policy instruments based on their feasibility, efficiency, effectiveness, and appropriateness, and to target land-use change policies and conservation incentives programs to generate the greatest impact and public benefits (Young *et al*. 1996; Alexandra and Associates Pty Ltd 2002; Pannell 2008).

Successful natural resources reforms rely on much more than the skilful selection of policy instruments because the implementation of major policy reforms has the potential for significant transitional impacts on communities, and policy development and implementation are generally improved by active participation of the affected communities, so they are involved in the co-creation of the future (Alston and Whittenbury 2011). Community involvement, while important, is insufficient to address systemic problems; however, community engagement models that aim to mobilise and motivate people can be meaningfully applied to climate-change adaptation (Wiseman *et al*. 2011)

Studying social responses to major water reform, Alston and Whittenbury (2011) argue that the commitment to devolution and participation are critical to the success of reforms and they define the over-arching need as one of establishing functional meta-governance arrangements. The recommendations of Dovers (2001) for institutional redesign and the proposed principles for NRM governance (Ryan *et al*. 2010) are also calls for reforms that support more functional meta-governance arrangements.

Meeting the challenges of managing Australia's diverse bioregional landscapes to achieve multiple objectives in the face of climate change is a long-term, multi-generational challenge. National policy settings play a key role in reinforcing peoples' values and respect for nature, as the nation embraces the manifold challenge of learning to live in this ancient continent.

In 1990, the then Prime Minister, Bob Hawke, launched the Decade of Landcare at the junction of Murray and Darling Rivers. Twenty-one years later, many people who have been through the 'school house of landcare' are looking to a more uncertain and unpredictable future under climate change. While the goal of sustainable land use remains elusive, over the past two decades, significant momentum has been generated and a suite of reforms and innovations has contributed to changing the way Australians perceive and manage natural resources—part of the journey of learning to live as Australians in this vast, beautiful, and biologically rich continent (Alexandra and Riddington 2007; Gammage 2011). Australia's NRM policies and institutional arrangements will continue to evolve, and continue to support devolved, participatory approaches and community involvement that contributes to functional systems of meta-governance (Dovers 2001; Ryan *et al*. 2010; Alston and Whittenbury 2011).

Carbon markets

Healthy landscapes produce a variety of important ecosystems services and deliver multiple, unpriced benefits. This awareness is helping to shift the dominant view of landscapes from being primarily producers of commodities to being producers of multiple goods and services (Alexandra and Riddington 2007).

Carbon markets which pay for carbon sequestration in the landscape may become a significant stimulus to enhanced landscape management. Large-scale investment in carbon sequestration in Australia will depend on stimulating the dynamic relationships between public policy settings and private sector activity and capital allocation. Functioning large-scale carbon markets are unlikely to develop without coherent policy which establishes defined property rights that provide sufficient long-term certainty to market actors.

Functioning carbon markets could trigger transformative changes in the way some of Australia's bioregional landscapes are managed. Some regions, such as the savannas, may secure increasing income from carbon sequestration and optimisation between conservation, beef production, and carbon sequestration. These dynamics are currently being investigated (Douglass *et al*. 2011). Payments for enhanced carbon sequestration and cultural and biodiversity conservation through changing burning practices are already under way (Russell-Smith *et al.* 2009). Furthermore, these practices are likely to expand, as the Commonwealth's Carbon Farming Initiative lists savanna burning as eligible for government's carbon grants (DCCEE, www.climatechange.gov.au/government/initiatives/carbon-farming-initiative/activities-eligible-excluded/additional-activities-positive-list/positive-list-guidelines-proposal-form.aspx).

In the grassy, spotted gum dominated forests of eastern Australia, a decision support tool (the Spotted Gum Productivity Assessment Tool, SPAT) for optimisation between production of beef and timber and carbon sequestration is available to producers (Lewis *et al*. 2010). Spotted gum dominant grassy forests span from the Clarence Basin in subtropical New South Wales to far north Queensland, near Cooktown. They are an important resource for both grazing and timber industries (Lewis *et al*. 2010). In these forests there have been large areas of natural regeneration on former grazing lands, as well as private forests that have been harvested repeatedly, often resulting in forest stands in poor condition.

The extent to which a tool like SPAT will actually support optimal management depends on a range of economic and policy factors. As forest conservation policies have changed to increase areas in conservation reserves, demand for timber harvesting on private land has increased (Lewis *et al*. 2010), but unless private forest owners believe their rights to harvest are secure in the long term, they are likely to exploit forests for short-term gain based on a view that their harvest rights may be withdrawn under future revisions to private native forest policies. Furthermore, the future of Australia's carbon rights remains uncertain. How property rights are established in law and perceived in markets have significant bearing on the subsequent management of natural resources (Young and McCoy 1995).

Science-based tools which support informed management decisions by land managers are an important contribution to more economically and ecologically efficient landscape management. These kinds of tools need to be complemented by coherent policies and institutional frameworks that enable informed regional governance (Ryan *et al*. 2010), because long-term commitments to living in and learning from ecosystems being managed confer resilience in periods of complexity and transformation (Folke *et al*. 2002; Walker *et al*. 2002).

Water policy and markets

Australia is now in the third major wave of water reform since the 1990s. The Council of Australian Governments water reforms of 1994 and 2004 (COAG 2004) and the reforms of the Commonwealth Water Act 2007 (Commonwealth of Australia 2009) have been consistent in their commitment to introducing tradable water rights and have supported the development of water markets. This was highlighted during the period of severe water scarcity in the Murray–Darling Basin between 1996 and 2009 when irrigation industries were exposed to the low water availability. Water markets supported a range of adjustment and adaptation strategies. Future irrigated agriculture will reflect the drivers of change being subjected to significant adaptation pressures due to changes in global markets and climate. In theory and practice, water rights markets are pro-adaptive forms of resource allocation (Smith and Lenhart 1996).

The impacts of the recent extended drought are unprecedented, providing insights into a possible drier future under climate change. Recent studies warn that it is prudent to plan for long-term rainfall and runoff reductions, with water availability likely to be reduced (CSIRO 2010). Achieving sustainability in these predicted conditions requires flexibility and adaptability, because they allow water market participants to better manage risk and uncertainty while providing flexibility. In the face of economic and climate uncertainty, water markets support flexibility. In a period of scarcity, they supported high-value, capital-intensive production to continue by stimulating water-use efficiency and enabled structural adjustment.

Water markets have provided a pool of water entitlements for new, larger scale horticultural and viticultural developments. While water markets are an example of a pro-adaptive policy mechanism, markets cannot overcome the need for water resource planning by governments. Within appropriate policy and regulatory frameworks, markets for resource rights offer significant adaptation options, enabling greater flexibility for resource-dependent businesses and environmental managers (Young and McCoy 1995).

Assessment of gaps

Australia must anticipate the potential scale and magnitude of the climate change impacts and build capacity to manage landscapes for multiple outcomes while also anticipating the potential for catastrophic shifts and transformations in ecosystems, economies, and social systems (Scheffer *et al*. 2001; Folke *et al*. 2002).

CSIRO (2010) advises that it would be prudent to plan for drier future in south-eastern Australia; yet planning in the face of uncertainty is demanding. Analogues of known climates can support predictive capacity. For example, if catchments become more arid, they will demonstrate fewer characteristics of temperate zones, and will behave like those in adjoining arid regions, with episodic flows, flashier floods, and the movement of more sediment.

Changing climates and landscape feedbacks could have a range of impacts that will require a balance between disaster responses and pre-emptive planning for the more predictable climate-driven events such as bushfires, droughts, and floods. Economic assessment of options for early intervention may be useful, to define how investments could minimise impacts and support disaster prevention or effective responses.

A range of gaps exist in technical and professional capacity, including capacity for integrated land use and regional planning and management (NLWRA 2002*a*, 2006) and in the capacity for comprehensive risk assessments, including synergistic risks that can produce profound shifts in ecosystems (Scheffer *et al.* 2009). Capacity constraints include insufficient knowledge to predict and respond to thresholds or tipping points in complex socio-ecological (landscape) systems (Scheffer *et al*. 2001; Folke *et al*. 2002).

Due to the complexity and unpredictability of ecological and climatic systems, Australia should invest in climate and ecological sciences, and in adaptive management and integrated landscape management. Adaptive governance challenges include the policy–science integration challenges and the policy integration challenges.

Managing the conservation estate and conserving biodiversity across multiple tenures also provides significant policy, capacity, and technical challenges (Dunlop and Brown 2008; Steffen *et al*. 2009). Understanding and working with the key drivers or underlying processes that determine landscape health remains challenging, due in part to complex interaction across large spatial and temporal scales (Holling and Meffe 1996; Lindenmayer *et al*. 2008).

Further R&D investment is justified on the large-scale drivers of ecosystems, such as burning practices in the savannas and water point distribution, pasture production, and grazing dynamics in the arid rangelands and in particular how these are changing under elevated CO_2 and a changing climate. Likens *et al*. (2009) call for a significant investment in large-scale ecological science, monitoring, and professional capacity building in order to enhance management at the larger, landscape scales.

From 1990 until 2009, when it was disbanded, Land and Water Australia (LWA) played a critical role in the scoping, brokering, commissioning, and communicating of research into sustainable land use and landscape management (LWA 2005;

Campbell 2006; Campbell and Schofield 2007). In the absence of LWA or an equivalent, Australia lacks a way of brokering nationally relevant, applied R&D that focuses enabling of practical, policy, and institutional responses through knowledge generation, communication, networking, and partnerships with the primary industries sector. While it is worth noting that the Productivity Commission (2011) has recommended the establishment of new publicly funded Research and Development Corporation with a similar but boarder role (including energy) to that of the former LWA, unless this occurs, not having a dedicated agency in this role remains a significant gap nationally.

Land and Water Australia attempted to focus its R&D on the complex dynamics between biophysical understanding, community values, public policy, technological options, and markets (LWA 2005). If R&D is to be the engine of innovation, it must balance technical and biophysical work with an explicit focus on the human, policy, and social aspects of knowledge and adoption (Campbell 2006).

Solutions to the challenges of becoming a more sustainable global society will not be found randomly. Innovation is needed to tackle the 'wicked problems' plaguing sustainability (APSC 2007). Accelerated systems of innovation are needed to support transformations in the energy, food, and carbon economies and to build capacity to conserve biodiversity and protect the Earth's capacity to deliver ecosystem services. Meeting sustainability imperatives demands innovation in technology and policy, and innovation in the way we innovate (Weaver *et al*. 2000), because science's role in sustainability '*is far more than developing technical fixes or technological innovations ... science plays critical roles in articulating preferred futures and in developing smart ways to create these futures*' (Alexandra and Campbell 2003).

Conclusions

Pressing climate change and sustainability challenges are likely to drive change in nearly every aspect of society. Sustainable resource management, conservation of biodiversity, and the management of river basins and bioregional landscapes remain challenging in Australia and globally. We must continue to build governance systems and institutions which have capacity for long-term, adaptive management on a sufficient scale to address the scale of the challenges, and to protect the significant social values at stake. Landscape-scale changes occur over generational spans (Stafford-Smith *et al*. 2007). Governments need to accept that environmental outcomes cannot be achieved through 'quick fix', one-off schemes, but rather, that the natural resources sector requires ongoing commitment in the same way as health, defence, roads, infrastructure, and education portfolios. To not do so exposes the country to a range of significant risks. Policy development, adjustment, and reform are constant demand as new knowledge comes to bear and societal values change over time.

Australian NRM programs have historically focused on a range of 'traditional' NRM issues such as sustaining agriculture, minimising land and water degradation, and protecting biodiversity within and beyond the conservation estate, all of which are likely to become increasingly complex and difficult under a changing climate. However, the past two decades of reforms could be used as the basis for building the scientific, professional, and governance capacity needed. Substantial investment in research and education should focus on ecosystem and social sciences capable of guiding and influencing management at large scales and on predicting and avoiding undesirable thresholds or tipping points in complex ecological systems (Likens *et al*. 2009; Scheffer *et al*. 2009).

Institutional and technical innovations will be needed to respond to climate change across the multiple actors involved in landscape management. Like sustainable land management, climate change responsiveness is a society-wide challenge, requiring community support for cultural and practice change. Cultural and practice change at all scales will be strengthened by celebrating successes. Celebrations and stories of hope are important because they nourish motivation, inspiration, and creativity, which will be powerful tools used to meet these challenges (Wiseman *et al*. 2011).

Landscape management results from the dynamic interplay between knowledge (science, traditional, etc.), governance (how a society governs itself and establishes and changes rules), and the specific policy settings at any time (laws, rules, social norms).

Capacity to adapt depends on the functionalities of the governance arrangements and their ability to respond to new circumstances, new knowledge, and new evidence and the new values and beliefs of the people. Given that global climate change demands new rules and new relationships with the Earth (Richardson *et al*. 2009), this is even more the case in Australia because '*we have a continent to learn, if we are to survive, let alone feel at home, we must begin to understand our country. If we are to succeed, one day we might become Australians*' (Gammage 2011, p. 323).

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