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Current perspectives in plant conservation biology

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Introduction

In the past two decades, conservation has emerged as one of the central goals of modern biology in response to the impending extinction crisis and the burgeoning loss of species and habitats. Conservation biology is increasingly viewed as a meta-discipline (Lindenmayer and Burgman 2005), with its diversity and complexity reflected in an applied science that covers ecology, genetics, evolutionary biology and systematics (Soule 1985). Scientists and practitioners have used the umbrella of conservation biology to describe the array of research and operational activities that are undertaken in the name of conservation of biological diversity at all levels of organisation and the ecological and evolutionary processes that sustain that diversity. At the same time, conservation science has expanded to cover several new research disciplines such as conservation genetics, landscape ecology, restoration ecology, conservation planning and ecological economics (Meffe *et al*. 2006). Although conservation biology has grown considerably more complex since its inception, its characteristics and goals, as overviewed by Soule (1985), have changed little in the sense that it 'is concerned with the long-term viability of whole systems' and 'its goal is to provide principles and tools for preserving biological diversity'.

The conservation of biodiversity is a global issue, often predicated by governments and communities on the intrinsic value of biodiversity (Sinclair *et al*. 1995). There is also awareness that biodiversity can provide financial returns (Daily *et al*. 2000). These values were traditionally tied to ethnobotanical uses of biodiversity for food, fibre, medicines and cultural reasons (Bussmann 2002). However, recent scientific evidence points to the direct role of biodiversity (as producers, consumers, decomposers) in delivery of a broad range of benefits considered vital for human life and welfare (such as regulation of soil and water quality, waste recycling, moderation of toxic wastes and greenhouse gas emissions). Despite this, the conversion of natural habitats for agriculture, urbanisation and other anthropogenic activities continues unabated in many parts of the world. Take, for example, the large-scale clearing from 1920 to 1950 of the once biodiverse wheatbelt region of Western Australia. Covering some 180 000 km^2, the loss of biodiverse shrub and tree canopies has resulted in estimates that 25% of the landscape and 40–50% of valley floors will be salt-affected within the century, and there will be a 4% decrease in rainfall attributable in part to the loss of radiation balance of the native vegetation. Furthermore, 13% of agricultural land is already affected by wind erosion and 11% of soils are degraded (Hobbs 2003). Retention of the natural biodiversity, particularly the diverse range of tree species in the Western Australian wheatbelt, would clearly represent the most cost-effective means for maintaining hydrological processes and sustaining agriculture (Lefroy 2003). The challenge for the Western Australian wheatbelt, with some 75% of the native vegetation cleared (Beeston *et al*. 1994), is how to restore eco-hydrological balance in partnership with production systems. The scale of such an undertaking, even though recognised as an issue for nearly 50 years, is daunting and will require new scientific paradigms, paradigms that will draw upon all parts of conservation biology and its many subdisciplines. Radical measures such as 'stretch goals' (Manning *et al*. 2006), where ambitious long-term goals are used to inspire creativity and innovation to achieve outcomes that currently seem impossible in large-scale ecological restoration, are the types of approaches that may need to be developed if we are to succeed with science-based solutions.

The science-operational continuum

Defining the role of science and research and the nexus of science with the end-user in conservation practice represents one of the more important areas of debate. Although conservation biology has made significant advances and we have dramatically improved our scientific understanding of patterns and processes at the population, species, biological communities, ecosystem and landscape levels, achieving conservation outcomes has been far less successful (Salafsky and Margoluis 1999). Conservation scientists and restoration ecologists need to take heed that their science should formulate 'positive, plausible visions' that link to society's aspirations for conservation solutions (Carpenter and Folke 2006). Although considerable research energy has been expended in building conceptual foundations for conservation biology, there remains a significant need for speed to address the size and scale of the global conservation crisis by melding the conceptual with the applied (Young 2000). For example, in such a crisis-driven discipline there is frequently a need to provide immediate answers where knowledge is incomplete if successful conservation outcomes are to be achieved. To become more relevant 'conservation biology must generate answers even

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when full scientific knowledge is lacking, structure scientific research around policies and debates that influence what we value as conservationists, go beyond certitude of the biological sciences into more contextual debates of the social sciences . . .' (Robinson 2006). We do not disagree with this but preface such a view by noting that the popularisation of the conservation debate can lead to a level of pragmatism for action that drives conservation practitioners to the exclusion of science.

In the last decade, the notion that there needs to be more emphasis on a science-operational continuum in conservation practice has become increasingly prevalent in natural-resource management policy and planning. The emerging concept of adaptive management, i.e. implementing policies as experiments (Holling 1978), has subsequently gained a much broader acceptance as a means for addressing this issue. This is usually presented as an idea, or a notion, although there are few examples where the approach is applied in a practical manner for delivering conservation outcomes and advancing knowledge. Adaptive management encapsulates the very essence of attempting to deliver effective and timely science-based solutions within an operational setting. Many definitions are now available but this can basically be viewed as a process for implementing policy decisions as an ongoing activity that requires monitoring and adjustment. Adaptive management applies scientific principles and methods to improve resource management incrementally as managers learn from experience and as new scientific findings and social changes demand. Although the wording may vary, the definitions have similar basic ingredients of uncertainty of knowledge, learning by doing, treating management activities as quasi-experiments and monitoring (Burrows 2006). We highlight this approach here because we feel that it will increasingly play a central role in conservation practice and it provides that important scientific connection to on-ground biodiversity management.

The success of conservation biology as a scientific discipline is no better demonstrated than in the extent and quality of publications in the key conservation-biology journals (see Fazey *et al*. 2005). Despite this, it still struggles to adequately deliver key information that will influence policy decisions that drive government actions and direct conservation outcomes (see Bawa 2006). Part of this appears to be due to the timely availability of research findings to conservation practitioners and land managers, and that many of the conclusions of the papers are not sufficiently clear regarding their influence on policy or management (Fazey *et al*. 2005). For example, Pullin *et al*. (2004) found that only 23% of practitioners 'always' or 'usually' used scientific publications when developing management plans. Fazey *et al*. (2005) emphasised that a key issue is likely to be the ready accessibility of research to practitioners. This is partly because of the time it takes to publish new research findings but also because of the time it takes to gather all the relevant literature. They suggest that concise reviews would significantly alleviate this problem although they found that only 6% of all studies are reviews. Part of the aim of this Special Issue of *Australian Journal of Botany* has been to encourage authors to broaden the focus of their papers and provide more comprehensive reviews even where they may be covering a specific research outcome.

Conservation biology, until relatively recently, has had more of a focus on populations, single species and assemblages rather than ecological communities, ecosystems and landscapes. It is also noticeable from investigations by both Young (2000) and Fazey *et al*. (2005) that of the publications they reviewed in the major conservation-biology journals less than a quarter specifically cover plants, with vertebrates by far the dominant taxonomic group investigated. In contrast, with the dramatic growth in disciplines focusing on community and ecosystem ecology such as restoration ecology and landscape ecology, we now see a significant increase in focus on plants and plant communities. This, as noted by Young (2000), is not unexpected, given that we typically define ecosystems by their botanical components and most restoration programs concentrate on establishing a basic suite of plant species. We therefore feel that this Special Issue provides a timely overview of some of the critical perspectives and key future directions in plant conservation biology.

This Special Issue

This issue of *Australian Journal of Botany* follows a symposium on 'Advances in plant conservation biology: implications for management and restoration' held in Perth, Western Australia, 25–27 October 2005. It incorporates a selection of papers presented at that symposium in an attempt to bring together core elements in conservation sciences that demonstrate both integrated approaches within and the continuum among the many conservation biology subdisciplines. Drawing upon species as well as ecosystem approaches to conservation, this Special Issue demonstrates levels of conservation activity that show that an integrated model is being attempted at several levels, particularly at the *ex situ* to *in situ* conservation continuum. The papers demonstrate how plant conservation biology is advancing rapidly on many fronts. This no doubt reflects the urgent need for the acquisition of knowledge and the need to develop innovative approaches to ameliorate the degradation and loss of native vegetation and prevent the extinction of tens of thousands of plant species globally.

We have divided the papers in this Special Issue into the following five broad themes: (1) rarity and threat, (2) population biology and genetics, (3) biodiversity patterns, (4) *ex situ* conservation and reintroduction and (5) restoration ecology.

Rarity and threat

This first theme reflects what has been and what will no doubt continue to be a significant focus in conservation biology—namely, understanding rarity and how it relates to threat and threatening processes. Rarity describes a taxon's distribution, abundance and habitat specificity, whereas threat relates to the taxon's ability to persist over time and its risk of extinction. Thus, the issues overviewed by the papers under this theme are largely taxon- and population-based and provide the basis for assessing conservation status, proneness to extinction and assigning species to different categories of threat. The latter has been developed and used by the IUCN to compile the comprehensive Red Lists of the world's plant species threatened with extinction. It is worthwhile noting that on a worldwide scale some 34 000 species or ~12.5% of the estimated world's vascular plants are listed as Threatened. Yet this is generally viewed as a significant underestimate and it is alarming to note that recent estimates of the world's threatened flora indicate that the number of species threatened is likely to fall between 94 000 and 144 000 or as high as 47% of the global flora (Pitman and Jorgensen 2002).

A key factor in the underestimate of the world's flora threatened with extinction is a reliable estimate of the number of species at risk in tropical regions where a high proportion of plants are found. Yet, even in parts of the world where the flora is relatively well known, there remain significant knowledge gaps in our understanding of issues associated with rarity and threat, which will inevitably have an impact on our ability to assess risk of extinction and potentially prevent extinction. The four papers in this section address a range of issues relating to understanding rarity, assessing threat and developing approaches that might assist the recovery of threatened species.

Understanding causes of rarity has been investigated in the context of various frameworks (see Rabinowitz 1981) that were extended and refined by Fiedler and Ahouse (1992), who considered categories of rarity both in terms of temporal persistence and spatial distribution. The first paper in this section by Yates, Ladd, Coates and McArthur (*Hierarchies of cause: understanding rarity in an endemic shrub* Verticordia staminosa *(Myrtaceae) with a highly restricted distribution*) uses data on the pollination biology, habitat requirements, seed production, germination, seedling establishment and demography of the rare shrub *Verticordia staminosa* subsp. *staminosa* to test the validity and utility of the Fiedler and Ahouse (1992) hierarchical classification. These authors provide evidence to suggest that *V. staminosa* subsp. *staminosa*, a taxon known only from a single population on a granite outcrop, is phylogenetically well separated from another subspecies and that this probably reflects historical isolation since the early Pliestocene. They conclude that rarity in this taxon is best explained by evolutionary history and the interaction of climate change and disturbances such as fire, whereas there is nothing about the life history of the taxon that is critical to its survival as a rare species.

One of the major challenges with rare and threatened plant conservation is effectively achieving recovery where multiple species are being targeted simultaneously within the same region. As highlighted in the next two papers, issues may not only be biological but can in many cases be socio-economic and these may be of critical importance for successful on-ground conservation outcomes. In the second paper in this section, Fiedler, Keever, Grewell and Partridge (*Rare plants in the Golden Gate Estuary (California): the relationship between scale and understanding*) assess whether generalisations in relation to a range of factors can be used to develop and implement successful species conservation. They highlight several issues that have come out of some 20 years of field research, monitoring and survey of rare plants in the Golden Gate Estuary area in California. They find that an ecosystem approach to rare-flora protection is the most successful and effective means of achieving conservation, whereas understanding ecosystem functions that support rare species is considered to be the highest priority for successful recovery programs. Following on from this, Kirkpatrick (*Collateral benefit: unconscious conservation of threatened plant species*) highlights not only the importance of understanding ecosystem function but also the significance of disturbance regimes in the persistence of rare and threatened plants. Kirkpatrick points out that in Tasmania there are many rare and threatened species that appear to be disturbance-dependent and usually have poor competitive abilities. The key to the persistence of these species' will involve the manipulation of anthropogenic disturbance regimes rather than the mitigation of human-induced threats. Kirkpatrick points out that such an approach is not unusual in the conservation of European species but is rarely considered in the case of the relatively recently perturbed Australian flora.

Finally, in this section we move from rarity and threats to single plant species or groups of species within particular communities or ecosystems to a major threatening process that is having an impact on numerous species within many ecosystems. This particular example is disease caused by the invasive soil-borne pathogen *Phytophthora cinnamomi*, which was introduced in the South-west Botanical province of Western Australia in the early 1900s. Some 40% of the flora and nearly 50% of the listed threatened plant species are estimated to be susceptible. Shearer, Crane, Barrett and Cochrane (Phytophthora cinnamomi *invasion, a major threatening process to conservation of flora diversity in South-west Botanical Province of Western Australia*) point out that the soils, topography and climate, in conjunction with the hydrological cycle and numerous susceptible species, provide particularly favourable conditions for this pathogen, leading to many irreversibly altered plant communities within the region. As a consequence, several the most *Critically Endangered* plants in Australia are under the immediate threat of extinction. In reviewing current control measures, Shearer *et al*. demonstrate that phosphite application represents the most effective means currently known for controlling the loss of species infected by *P. cinnamomi*. However, a greater understanding of the mechanisms of phosphite efficacy will be important for understanding the wider use of this disease-control agent for conserving susceptible plant species. Although perhaps less obvious, disease at this scale is a serious threat to biodiversity and in this case *P. cinnamomi* has been listed under Australia's Environment Protection and Biodiversity Conservation Act as a major threatening process.

Population biology and genetics

This section covers a broad research field in conservation biology that focuses on individuals, populations and species. Population biology and conservation genetics can be very much viewed as overlapping disciplines in conservation biology, with population biology covering demographic, life-history and genetic characteristics of populations, whereas conservation genetics not only covers a broad range of research in population genetics but also issues relating to the identification of conservation units, systematics and forensics. We have combined these two disciplines in this section, partly because many studies use combined demographic and genetic approaches to better inform conservation actions and also because we strongly believe that studies which combine information from these disciplines should be encouraged as they inevitably lead to a much broader understanding of the key issues that should be considered for the conservation of populations and species (see Oostermeijer *et al*. 2003). The six papers in this section cover a very broad range of topics, including habitat fragmentation, fire ecology, demography and mating systems.

Habitat fragmentation is increasingly viewed as a major threat to biodiversity conservation at a global scale and is often highlighted as an ongoing priority for research in conservation biology (see Hobbs and Yates 2003). In the last decade there have been significant recent advances in our understanding of the impact of habitat fragmentation on biodiversity. Yet, as Hobbs and Yates (2003) emphasise, 'we are still a long way from developing a conceptual framework for how fragmentation influences either community composition and species diversity or the dynamics of individual species'. A particular focus for studies on habitat fragmentation has been the impact it may have on genetic and demographic factors that may be critical for plant-population viability and are often associated with small and declining populations. These include loss of genetic variation, increased inbreeding and a range of demographic and life-history effects associated with reduced fitness. In their paper (*Plant mating systems and assessing population persistence in fragmented landscapes*) Coates, Sampson and Yates focus specifically on the impact of habitat fragmentation on changes in the mating system. They emphasise that tracking mating-system change is important for understanding contemporary patterns of gene flow and inbreeding within populations, and related factors such as pollinator availability and behaviour, mate limitation and the size of the pollen pool. A major point of the paper is that many and in some cases all of these factors are likely to be critical for the persistence of plant populations following anthropogenic habitat fragmentation and associated landscape changes. Following on from this paper, Broadhurst and Young (*Seeing the wood and the trees—predicting the future for fragmented plant populations in Australian landscapes*) overview not only genetic factors affecting the reproductive cycle but also ecological factors and how they may be influenced by habitat fragmentation. Their review centres on the Australian landscape and vegetation systems but in many respects the genetic and ecological processes they describe in fragmented plant populations are typical for many fragmented ecosystems globally. They reiterate the need for integrated ecological and genetic studies not only on rare and threatened species but also on more common and widespread components of the flora if a suitable understanding of fragmentation is to be developed that will ultimately result in improved biodiversity conservation. They conclude that habitat fragmentation will not only result in population-size effects but will also lead to changes in terms of physical attributes such as soils, hydrology, disturbance regimes and microclimate.

Demographic changes in plant populations in response to fire and the persistence of species in fire-prone landscapes have been of increasing interest to conservation biologists, as land managers emphasise the need for fire-management regimes that incorporate biodiversity-conservation principles. Fire is a dominant ecological disturbance in many parts of the world yet, as pointed out by Abbott and Burrows (2003), it is not often referred to in modern general ecological text books. Menges (*Integrating demography and fire management: an example from Florida scrub*) utilises life history and demographic data from a range of Florida-scrub species combined with population viability analyses of habitat specialists to investigate ranges for appropriate fire-return intervals. Significantly, he concludes that pyrodiversity, diversity of fire regimes in space and time, combined preferably with variation in fire intensity, patterns and seasonality, is the most appropriate fire regime for most types of Florida scrub. He points out that the patch-mosaic burning used in Australian and South African landscapes would be a useful model to follow. In the next paper (*The persistence niche: what makes it and what breaks it for two fire-prone plant species*), Keith, Tozer, Regan and Regan investigate the key life-history processes involved in the persistence of two different resprouter species from fire-prone environments in Australia. Like Menges, they use population models to assess key factors influencing population viability that relate to fire and also investigate the confounding influence of disease caused by the soil-borne pathogen *Phytophthora cinnamomi*. They conclude that the persistence niche is mediated by processes that reduce survival, such as disease and habitat loss, rather than processes that impede seed production and recruitment.

The final two papers in this section highlight the value of an integrated approach in developing conservation strategies for groups of related taxa, in this case species from two important plant groups—the Australian genus *Banksia* and terrestrial orchids—represented by some 400 taxa known from Western Australia. Both overview findings from a range of research disciplines aimed at improving our understanding of factors critical in the conservation of species in these plant groups. Lamont, Enright, Witkowski and Groeneveld (*Conservation biology of banksias: insights from natural history to simulation modelling*) summarise studies from the last 25 years on the ecology and conservation biology of banksias in south-western Australia. They review a broad range of issues, including demographic attributes, fire regimes, growing conditions and interactions within other species. Some of the key outcomes mentioned include the assessment of optimum fire intervals on the basis of empirical models and the unexpected possibility of long-distance seed dispersal in some *Banksia* species. Similarly, Brundrett (*Scientific approaches to Australian temperate terrestrial orchid conservation*) reviews several key issues relevant to the conservation of Australian terrestrial orchid species, including mycorrhizal associations, pollination, demographic attributes and genetics. He also investigates evolutionary relationships involving the orchid species, their mycorrhizal associations and their pollinators and demonstrates that the majority of Western Australian terrestrial orchids have highly specific associations with pollinating insects and mycorrhizal fungi. Such complex associations have significant implications for the conservation and recovery of many rare and threatened orchids in this region.

Patterns of biodiversity

Understanding the spatial and temporal variation in biodiversity at local, regional and global scales is one of the most significant objectives for ecologists and biogeographers (Gaston 2000) and is an integral component of conservation planning. The explanation of the patterns of species diversity must involve both historical events and current ecological processes. The two papers presented in this section cover both detailed survey work aimed at understanding biodiversity patterns within specific biogeographic regions and also phylogeographic approaches that can give valuable insight into historical relationships between populations of species and a historical perspective on biodiversity patterns within defined bioregions. Keighery, Gibson, van Leeuwen, Lyons and Patrick (*Biological survey and setting priorities for flora conservation in Western Australia*) focus on floristic patterning in the flora of Western Australia on the basis of a range of surveys undertaken at various biogeographical scales during the past 20 years. Such surveys have allowed explicit testing of congruence between floristic patterning and other components of the biota and have been a key to the planning process in developing a comprehensive and representative reserve system in this Australian State.

The second paper in this section by Byrne (*Phylogeography provides an evolutionary context for the conservation of a diverse and ancient flora*) takes a very different tact in assessing historical patterns of genetic variation on the basis of phylogeographic analyses. Phylogeography as a subdiscipline of biogeography involves the analysis of the geographical distribution of genealogical lineages and focuses on the assessment of historical factors as determinants of evolutionary patterns among populations (Avise 2000). Byrne utilises these approaches to investigate historical processes that are likely to have had major influences on the current distribution of plant species in south-western Australia. Of particular interest and relevance to conservation planning is that the analysis of phylogeographic patterns in the flora has revealed the influence of historical climate change and identified areas that may represent refugia during times of extreme climate instability.

Ex situ *conservation and reintroduction*

A fundamental component of conservation and restoration programs is the link between effective off-site protection of germplasm (including understanding genetic issues when sampling germplasm for translocation) and the translocation process. The selection of papers in this subsection explores the concepts and practical principles underpinning aspects of *ex situ* (off-site) conservation technologies as they relate to protection of germplasm by using traditional approaches (seedbanking) and the more technologically challenging areas involving biotechnology such as tissue culture and cryo-preservation.

Seed-conservation technology for non-crop wild species has advanced substantially in the past decade, in part because of the impact of the Millennium Seed Bank Project of the Royal Botanic Gardens Kew (see www.kew.org/msbp/). The project links a range of international partners and includes a significant emphasis on research to develop the science to underpin technology development in seedbanking. In this Special Issue, Millennium Seed Bank researchers Probert, Adams, Coneybeer, Crawford and Hay (*Seed quality for conservation is critically affected by pre-storage factors*) provide an analysis of data, indicating that the period between seed collection and storage may be more critical than previously thought for ensuring the longevity of off-site seedbanking of a particular species. They show that selection of post-harvest treatments to optimise longevity depends on the maturity of the collection and may vary across species and fruit types, implicating the need for empirical research in deriving general collection-to-storage protocols.

The theme of optimisation of seedbank physiology for ensuring longevity in seedbank collections (seedbanks rather than seed morgues; Goodman 1990) is presented by another Millennium Seed Bank partner research group in this Special Issue where Merritt, Turner, Clarke and Dixon (*Seed dormancy and germination stimulation syndromes for Australian temperate species*) investigate storage temperature and seed water content, both fundamental tenants of longevity in seeds and rarely explored in detail for non-crop wild species. With study species taken from the biodiverse south-west of Western Australia, one of the 34 global biodiversity hotspots (www.biodiversityhotspots.org/), Merritt *et al*. demonstrate that when dealing with endemic floras there is the need to establish empirical research on a species by species basis for storage parameters rather than adopt a single methodological approach.

Biotechnology represents a useful adjuvant technology in conservation science by providing a means for protection of rare plants that cannot be stored by seed (species with low or no seed production; species with recalcitrant seed; species with deep intractable dormancy) or where the critically low number of parent plants predicates the need to store clonal copies of the last remaining genotypes. Bunn, Turner, Panaia and Dixon (*The contribution of* in vitro *technology and cryogenic storage to conservation of indigenous plants*) review the advances in biotechnological approaches and demonstrate that biotechnology, although uncommon in most plant-conservation programs, can play a useful role for ensuring long-term protection of important genetic diversity while providing a source (the only source in some cases) of greenstock for reintroduction programs.

As a key target in the Global Strategy for Plant Conservation, Target 8 aims to conserve 60% of the world's threatened plant species and 10% of them included in recovery or restoration programs. This Strategy is therefore not only encouraging the active participation in *ex situ* conservation targets but is also acknowledging the need to link these targets to on-ground restoration and species recovery. This link is pursued in the next two papers, particularly in relation to the reintroduction of threatened plant species. This relationship between off-site seed collections and on-site conservation actions is overviewed by Cochrane, Crawford and Monks (*The significance of* ex situ *seed conservation to reintroduction of threatened plants*) where they demonstrate its significance and effectiveness by using examples from some 20 reintroductions of endangered species in Western Australia. The reintroduction of rare and threatened species is further explored by Guerrant and Kaye (*Reintroduction of rare and endangered plants: common factors, questions and approaches*) who investigate the factors common to reintroduction programs and, through an analysis of several plant-reintroduction projects, question the level to which practitioners in reintroduction projects operate their reintroduction programs by using robust scientific principles (e.g. hypothesis-driven research). Guerrant and Kaye, as others before them, question the scientific validity of many reintroduction programs where this is often a distinction between the biological purposes and project purposes of the program.

Restoration ecology

As indicated earlier, one of the most interesting and challenging developments has been the dramatic growth of restoration ecology, viewed by some as a discipline in its own right with both philosophical and operational differences from conservation biology (Young 2000). Restoration ecology is largely based on the view that many factors that degrade habitat are temporary, and that some proportion of habitat loss and population decline is recoverable. The papers in this section of the Special Issue outline three quite different approaches to the question of restoration ecology. Hobbs (*Managing plant populations in fragmented landscapes: restoration or gardening?*) investigates conservation actions in fragmented landscapes and questions the degree to which interventionist activities (active management, reintroduction of species) may lead to biologically unsustainable outcomes, labelling this as 'gardening' rather than restoration ecology. Hobbs recommends that a careful mix of species-based and process-based management is required if long-term, sustainable landscapes and species are to be maintained.

Building upon the Hobbs' concept presented in this Special Issue, Rokich and Dixon (*Recent advances in restoration ecology, with a focus on the* Banksia *woodland and the smoke germination tool*) show how a range of research approaches and technology can be gainfully employed in managing and restoring a complex, species-rich ecosystem. By using the iconic banksia woodland communities on the Perth coastal plain, they show how the use of smoke in this fire-adapted system can help maximise the effectiveness of restoration outcomes.

Krauss, Hermanutz, Hopper and Coates (*Population-size effects on seeds and seedlings from fragmented eucalypt populations: implications for seed sourcing for ecological restoration*) then explore the overarching principles of seed collection within fragmented landscapes, by using two common and widespread, yet declining tree species from the wheatbelt of Western Australia as indicative study species. They show that contrary to expectations and despite lower seed yields, seedling vigour and survival are unaffected by increased levels of fragmentation. Although Krauss *et al*. indicate that these findings offer some promise that smaller vegetation remnants may represent useful sources of seed for re-establishment purposes, they point out that this will depend on harvesting strategies, given the lower seed yields per plant.

Concluding remarks

Challenges in the conservation sciences remain many, particularly as the temporal and spatial scales of man's impacts on the biosphere move beyond the local, to regional, national and with human-influenced climate change to a global scale.

With the intrinsic and extrinsic value of biodiversity linked not to one but to many species (and their attendant genetic diversity and supporting ecosystem) developed over long periods of time, effective conservation relies on integrating and focusing research effort across not one but a multitude of scientific disciplines (Dixon 1994). Such models that include levels of scientific integration have been promulgated for some time (Falk 1990); however, practical examples of multi-disciplinary approaches to conservation and restoration of species and ecosystem remain rare.

Just as the issues are complex and overlap as the scale of the impacts increase, so conservation scientists (from the spectrum of conservation-related disciplines) need to actively engage in collegiate approaches to problem-solving and do more to interact as part of functioning, interdisciplinary teams (Balmford and Cowling 2006). For example, understanding the interactions between threats at the landscape level, the amelioration of those threats and ecosystem restoration will require collaboration between landscape ecologists, conservation biologists and restoration ecologists. The level of engagement also needs to consider the socio-political context, including linkage with the community, traditional owners, land managers and decision makers, to ensure their research outputs deliver timely, contemporary and sustainable outcomes (Balmford *et al*. 2002).

Equally, the conservation sciences are beginning and need to continue to embrace a wider and more diverse range of scientific disciplines in pursuit of effective solutions for conservation. For example, molecular genetics is providing new and exciting opportunities at almost all levels in conservation sciences, from investigating patterns of gene flow, mating systems, population genetic structure, hybridisation and effective population size, to wildlife forensics and identification of conservation units. We also now see the application of genomics in conservation genetics through genome-sequence information and new technological and bioinformatics capabilities that have the potential to dramatically improve our understanding of genetic health and local adaptation in populations of threatened species and other key species of conservation interest (Kohn *et al*. 2006).

The broadening of information needs in the conservation sciences is also invigorating several traditional scientific disciplines. For example, to understand the impact of climate change on resilience and conservation of global species and ecosystems, scientists are looking to the past for solutions to the future. The emerging discipline of paleoecology (use of fossil pollen and seeds/fruits, tree rings, charcoal and 'ancient' DNA) provides useful medium to long-term perspectives on the dynamic underpinning contemporary ecosystems and species (Dodson and Macphail 2004; Dodson *et al*. 2005; Willis and Birks 2006). For example, by careful interrogation of paleoecological evidence it may be possible to improve definition of habitat naturalness (e.g. impact of biological invasions), increase understanding of the impacts of disturbance regimes (e.g. fire) or better define the natural variability and resilience of ecosystems. Paleoecology informs for the present and also templates scenarios for understanding how species and ecosystems might respond to change.

The conservation sciences and their collective disciplines represent challenges and opportunities for scientists. The foundations for conservation science have been well grounded and the next few decades will no doubt determine whether the integration and direction of conservation-biology research will lead to its successful application and the reversal in the decline of the world's biological diversity. In the words of Michael Soule '*The intellectual challenges are fascinating, the opportunities plentiful and the results can be personally satisfying*' (Soule 1985).

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