Establishment of an ecosystem transect to address climate change policy questions for natural resource management

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Establishment of an ecosystem transect to address climate change policy questions for natural resource management

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Foreword

The Department of Environment, Water and Natural Resources (DEWNR) is responsible for the management of the State's natural resources, ranging from policy leadership to on-ground delivery in consultation with government, industry and communities.

High-quality science and effective monitoring provides the foundation for the successful management of our environment and natural resources. This is achieved through undertaking appropriate research, investigations, assessments, monitoring and evaluation.

DEWNR's strong partnerships with educational and research institutions, industries, government agencies, Natural Resources Management Boards and the community ensures that there is continual capacity building across the sector, and that the best skills and expertise are used to inform decision making.

Sandy Pitcher
CHIEF EXECUTIVE
DEPARTMENT OF ENVIRONMENT, WATER AND NATURAL RESOURCES

Acknowledgements

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Summary

- In this report we present a real world example from a research institution–government partnership in South Australia for climate change biodiversity conservation planning.
- Climate change is expected to be a significant driver of ecosystem change and, given a range of additional anthropogenic impacts (e.g. habitat clearance), evidence-based management is crucial to minimise biodiversity loss during this change. However, whether science can effectively guide biodiversity management through climate change has been a long-standing question, as individual ecological studies often lack immediate policy relevance or direct policy recipients.
- The program, Transects for Environmental Monitoring and Decision Making (TREND), which was completed in 2014, used a range of iterative processes starting with policy drivers and questions that informed the scientific program, two-way dialogue on the research and its relevance to policy, translation of peer-reviewed findings into policy relevant products, and the identification of gaps for future activities.
- Specifically the science–policy integration model involved a seven stage process:
    - Determine policy drivers
    - Develop scientific framework
    - Generate initial data
    - Review approach
    - Major research phase
    - Primary policy translation phase
    - Program review
- At the inception of TREND, environmental agencies in South Australia had high-level climate change policies but a perceived lack of specific data on ecosystem climate sensitivity. TREND provided these data via policy fora that ensured the project research was directed towards relevant policy imperatives and established research–policy connections at the time of the work. The project research, which was based on existing data and field measurements, suggested climate change may result in significant changes to the species composition of terrestrial ecosystems, and identified species and habitats that are climatically adaptable or that have limited tolerances.
- To help derive practical and useful evidence-based guidelines, specific policy relevant questions developed by the project team were answered using project results and associated knowledge. These questions included:
    - What drives species composition and how will this be affected by climate change?
        - What species or ecosystems could provide early indicators of stress?
        - What species and ecological communities are most and least at risk from climate change and what are the expected impacts?
        - How will climate change interact with other disturbance to influence ecosystem attributes?

    - What adaptation strategies could improve the resilience of key species and communities?
        - What shifts in distribution, species composition and ecological characteristics can we expect?
        - What are the implications for conservation planning and landscape design?

- TREND successfully established partnerships, generated policy-relevant data on climate sensitivity, effectively leveraged other research and scientific infrastructure funding (more than 10x the original project costs for TREND), formed the blueprint for a national climate change ecosystem monitoring network (the Australian Transect Network - part of the Terrestrial Ecosystem Research Network; http://www.tern.org.au), and produced excellent quality scientific knowledge and research results (published over 25 peer reviewed papers). In addition, an independent review of all science outputs relevant to climate change ecosystem resilience planning for the Adelaide & Mt Lofty Ranges NRM region found that the TREND project outputs were able to be directly applied to the region's on-ground management.
- A full breakdown of the project outputs and outcomes can be found http://www.trendsa.org.au
- This report has outlined some of the co-creation processes, iterative design feedback frameworks and science/policy translation communications that were used in an attempt to bridge the gap between science, policy, and implementation with respect to climate change adaptation. This report outlines the practical steps taken at each of these phases to achieve the outputs and outcomes of the TREND project. It is also important to acknowledge, however, that the challenges relating to science-policy translation are complex and multi-layered, and include a range of strategies, including improved general acknowledgement of the business drivers of academia and government; broad collaboration across all elements of knowledge development; and dedicated resourcing of knowledge brokers in government and research institutions. DEWNR have begun to develop some of these approaches in collaboration with the South Australia research sector, using mechanisms such as those developed with the NRM Research and Innovation Network (NRM RaIN). Continuing to acknowledge and develop these solutions will further improve the application of science into NRM policy and delivery, with benefits to both natural resource managers and researchers.

1 Introduction

There has been lively debate about how ecological science could better link to biodiversity policy to inform the management of natural systems and ecosystem services in the face of anthropogenic impacts (Jones *et al.* 1999; Watson 2005; Moser and Luers 2008; Perrings *et al.* 2011). Climate change is recognised as a significant concern for the management of biodiversity, and is already influencing the function of ecosystems (Moser and Luers 2008; Grimm *et al.* 2013; Stein *et al.* 2013; Svenning and Sandel 2013). Despite numerous research papers on climate change ecology, questions remain over the relevance of the science for managers, and whether existing policy processes can use new data (Jones *et al.* 1999; Moser and Luers 2008).

For scientific research to be useful to policy, it must be relevant (e.g. in terms of time scales), credible (e.g. peer reviewed) and assist decision-making in the presence of uncertainty, while not being policy prescriptive (Jones *et al.* 1999; Cash *et al.* 2003; Watson 2005). For policy processes to make use of science, policy makers must be aware of, and receptive to, the science, and have the capacity to translate it into policy and action (Moser and Luers 2008; Sutherland *et al.* 2013). For the science–policy interface to be realised, both sides must reach an adequate level of maturity (Jones *et al.* 1999) and integrate policy development with research, monitoring and assessment (Perrings *et al.* 2011).

At a strategic level, a lack of either relevant data, or political will to address climate change ecology concerns, could disrupt the process. A practical constraint may be that differences in cultural norms, drivers and reward systems limits the effectiveness of research-policy partnerships (Kinzig *et al.* 2003; Kueffer *et al.* 2012). Impediments to effective partnerships include the two sectors operating within different timeframes. For example, there is often an emphasis on quick solutions in government, and a variety of demands for policy development that vary over time, and may be inconsistent with the long-term focus of science (Briggs 2006). The sectors may also differ in which natural resource management questions are considered important or answerable (Cash *et al.* 2003), which suggests that the collaborative development of appropriate questions may be a good starting point. Targeted questions designed to inform evidence-based policy have been identified previously through researcher–government and non-government organisation partnerships. For example, representatives of 28 UK-based organisations identified 100 policy questions directly relating to climate warming to influence the ecological research agenda for informing policy development in the UK (Sutherland *et al.* 2006).

A synthesis of ecological research relevant to climate change adaptation for South Australia (AECOM 2013) only makesgeneric, high-level conclusions about promoting ecosystem resilience. Similarly, in an overview of a landscape assessment framework used by South Australia's Department of Environment, Water and Natural Resources (DEWNR), Rogers *et al.* (2012) stated that "... among those stressors that are impacting a landscape's biodiversity, climate change may be one that we can do the least about." In the absence of detailed data on the climate sensitivity of South Australian ecosystems, they concluded that climate change impacts on biodiversity were best addressed by increasing general resilience. While this is an important and low risk strategy for dealing with critical threats (Heller and Zavaleta 2009; Dawson *et al.* 2011), an important question for researchers and policy makers in South Australia became: Can we do better than a generic 'improve resilience' approach to climate change?

This paper presents a model for science–policy integration, with particular reference to climate change conservation planning, and to assess the implementation of this model. This partnership focused on the development of research objectives to inform existing government strategies, and implemented a research program designed to address key policy questions. Our case study in South Australia lies within the Mediterranean Biome, which is one of the most globally vulnerable systems to climate change due to limited geographic extent and high land-use impacts (Mouillot *et al.* 2002; Bardsley and Sweeney 2010). The need to integrate scientific research into climate change policy with practical management actions in such regions has been recognised previously (Moser and Luers 2008; Bardsley and Sweeney 2010).

2 The TREND transect as a framework for climate change science–policy partnership

The South Australian Transects for Environmental Monitoring and Decision Making (TREND) is a collaboration between university and government (The University of Adelaide, Primary Industries and Regions SA, South Australian Research and Development Institute, Department of Environment, Water and Natural Resources [DEWNR]). TREND was established with funding from the Government of South Australia and later expanded by the Australia-wide Terrestrial Ecosystem Research Network, which has integrated TREND into a national network of ecosystem transects (the Australian Transect Network). The broad aim and scope of TREND was determined at its inception: to establish baseline monitoring transects in South Australia to assess the impact of climate change on the composition of the state's natural systems, primarily through the concept that space can be used as a proxy for time. Data were collected to assist natural resource managers to better incorporate climate change into their planning.

The benefits partners hoped to achieve by participating in TREND included gaining a greater understanding of the influence of climate on ecosystems, but also to better integrate science and policy on a long-term basis. Baseline data from the project were expected to aid in the identification of systems and species most susceptible to climate change, and those already undergoing change. Information collected was therefore intended to improve climate change science, while supporting government policy and decision-making (Fig. 1).

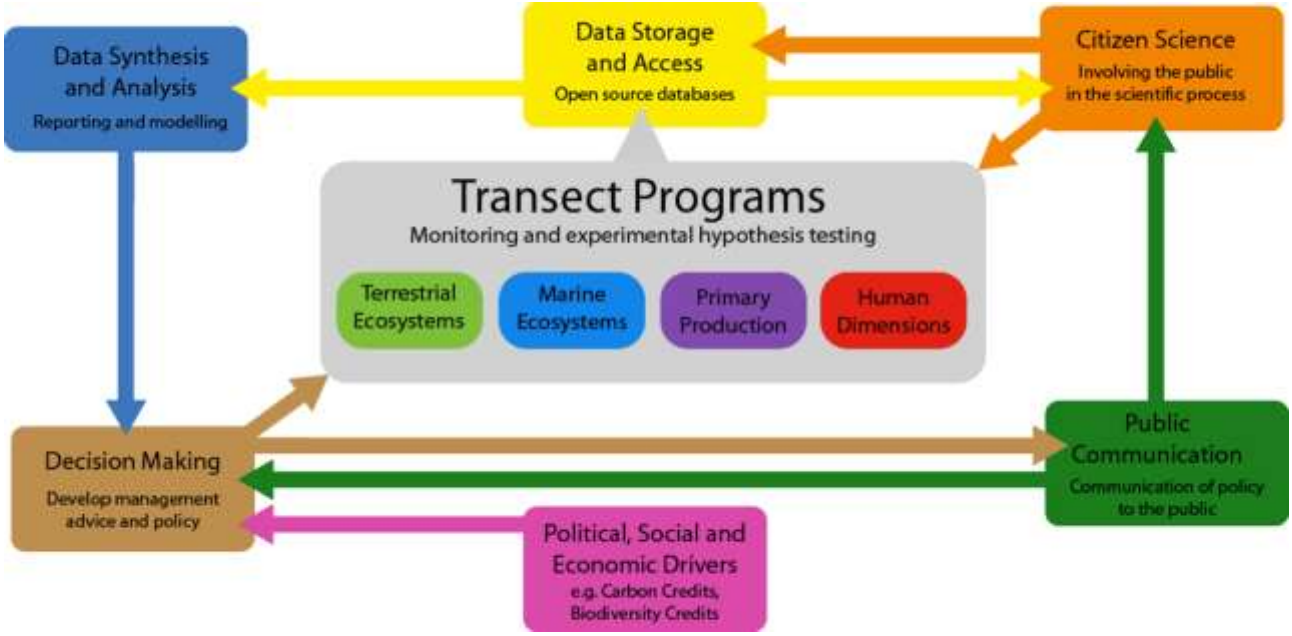

Fig. 1. Envisaged framework for climate change policy–science information flow for the TREND project, as devised at the inception of the project.
The framework involves an iterative cycle of scientific data generation via Transect Programs and implementation of monitoring and experimental stations (central box). These data are stored in open access databases for longevity and to maximise their use (yellow). Citizen Science programs (orange) allow members of the public to submit data (e.g. on selected species occurrences) to supplement those collected centrally. A range of collected and open access data undergo Synthesis and Analysis (blue) and results relevant to climate change adaptation inform Decision Making (brown), which includes the development of management recommendations, updates to policy and the opportunity to direct future research priorities. Policy is of course directed not only by science from the transect, but also by a range of Political, Social and Economic Drivers (pink). The final element of the framework is two-way communication with the wider public (green).

We focus here on the science–policy integration process undertaken for the terrestrial ecosystems transect of TREND (marine ecosystems, productive terrestrials systems and human dimensions were also considered in parallel but are not reported here), located in the Mount Lofty Ranges (south) to Flinders and Gammon Ranges (north) regions of South Australia (Fig. 2). A generalised model was developed to capture the main elements of the science–policy workflow (Fig. 3), which describes an iterative process whereby high level policy drivers and policy gaps lead to a set of specific, collaboratively developed, policy relevant questions. Researchers gather data to answer these questions during several stages, including initial gathering of available information and pilot data, a review of the approach and its relevance to the policy questions, followed by a major research phase. Results were then translated back onto policy needs and further gaps identified. The implementation of each of these phases for TREND is described in the following sections.

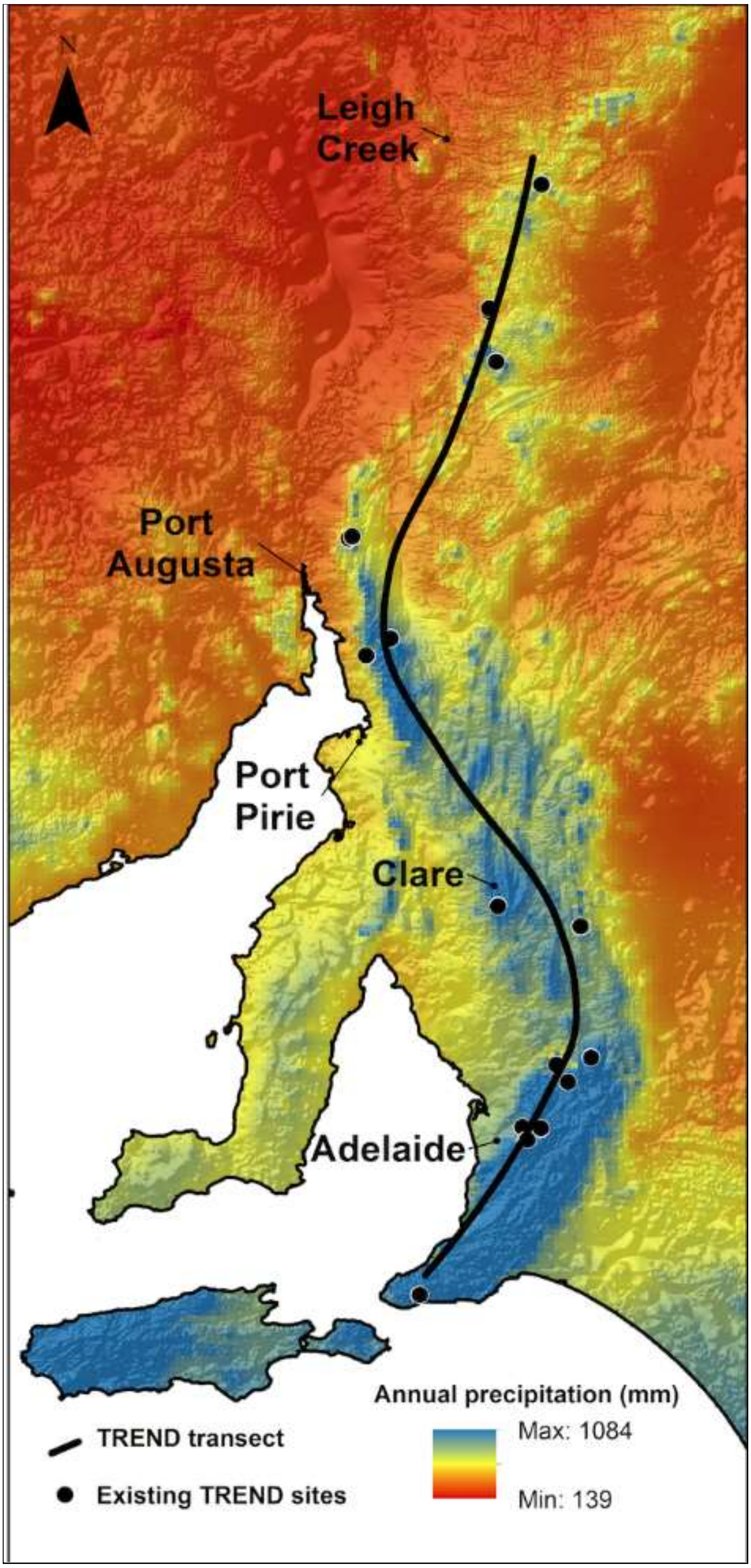

Fig. 2. Map of the case study region (in southern South Australia) with the TREND transect highlighted by the bold line and some key monitoring locations marked.

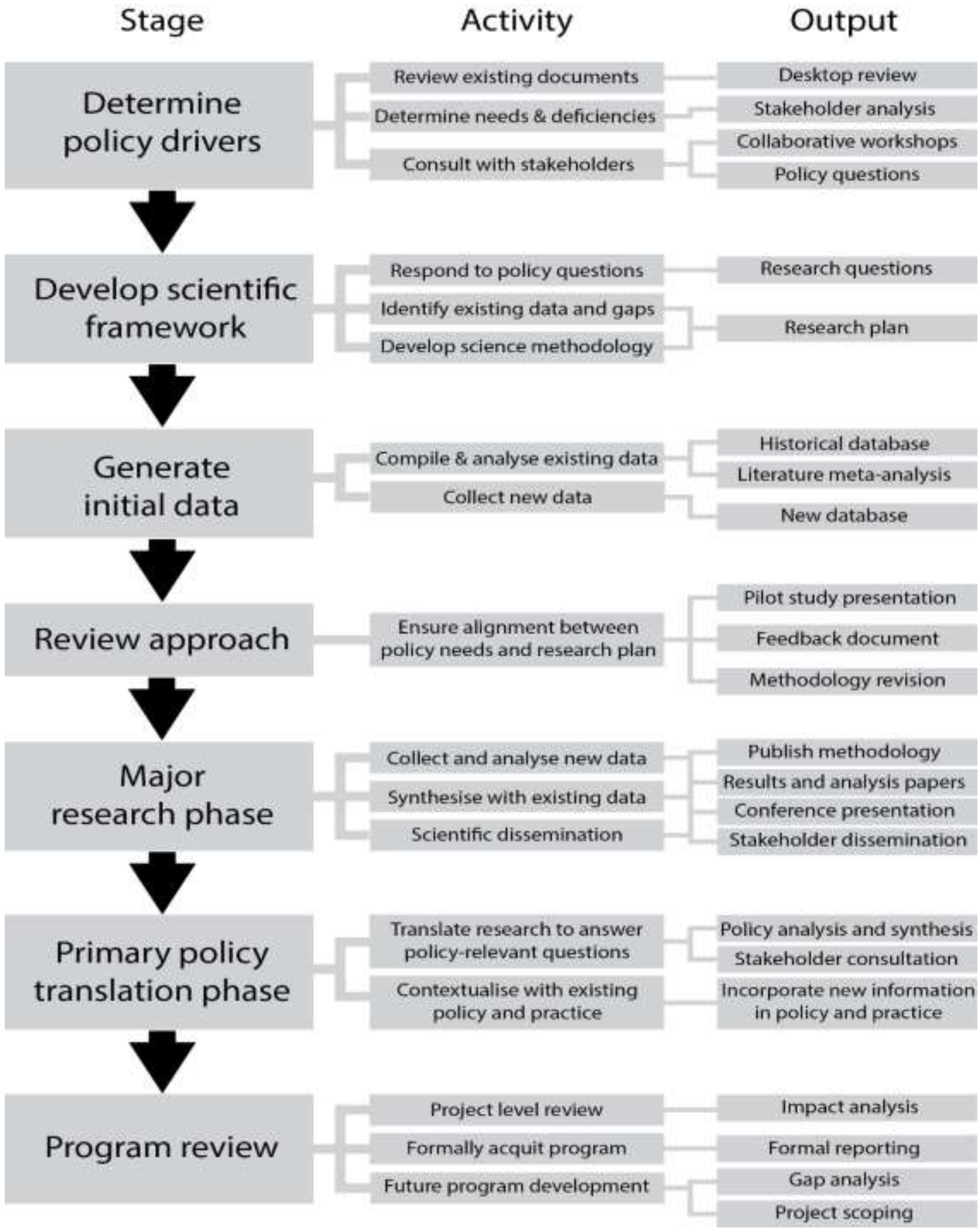

Fig. 3 A generalised model framework for maintaining the science–policy interface, which was applied to the TREND project.

The model is iterative and involves two-way communication between researchers and policy makers. The model is not intended to be linear or determinate, in that further gaps identified at the project review stage lead to new cycles. Summaries of actions taken at each step for TREND are given in the text.

3 Determine policy drivers

3.1 Climate change policy context in South Australia

The high-level policy background to TREND is multi-layered. Significant climate change policy drivers for natural resources management (NRM) planning in South Australia include the state's Strategic Plan, DEWNR Corporate Plan, the State Natural Resources Management Plan, as well as relevant Australian Government initiatives. While setting the broad objectives of climate change NRM policy, existing policies alone do not lead directly to specific management actions (Paton *et al.* 2010). As an example, the Climate Change Adaptation Framework for South Australia focuses on promoting generic strategies for increasing resilience of biodiversity, and on developing new policy for biodiversity conservation and sustainable use of land and water resources under climate change. A key emphasis in the climate change policies is the need to understand vulnerabilities within and across sectors and to identify or create knowledge to underpin management decisions. The TREND project therefore did not set out to supersede existing policy, but to fill data gaps at a practical level. In addition, information need to be in a form that it can be practically applied and is appropriate for on-ground delivery.

3.2 Development of policy questions

The policy translation work directed research within the scope of the established climate change transect towards policy questions relevant for evidence-based decision making by Government (Fig. 3; Box 1). The initial phase consisted of identifying the broad policy questions that government needed answered, to ensure the ensuing data collection was relevant. Policy makers, including a diverse group of government policy specialists, applied scientists and land managers, were also encouraged from the start to respond directly to new scientific information as it became available.

Box 1. Policy-relevant questions for 'TREND', terrestrial ecosystems, South Australia

1. What drives species composition and how will this be affected by climate change?
    - What species or ecosystems could provide early indicators of stress?
    - What species and ecological communities are most and least at risk from climate change and what are the expected impacts?
    - How will climate change interact with other disturbance to influence ecosystem attributes?
2. What adaptation strategies could improve the resilience of key species and communities?
    - What shifts in distribution, species composition and ecological characteristics can we expect?
    - What are the implications for conservation planning and landscape design?

Prior to an initial workshop, invitees were provided with information about TREND and the main policy drivers directing climate change adaptation research in South Australia. Invitees were asked to provide draft policy questions, which were compiled and synthesised. At the workshop, researchers provided a description of the aims and methodology of the proposed research and a policy officer delivered an overview of the policy translation expectations. Workshop participants discussed and prioritised the previously compiled draft policy questions, with guidance from researchers as to what was realistic. Therefore, policy issues were identified prior to the workshops and the workshops focussed on the synergies between the policy issues and the planned research.

4 Develop scientific framework and generate initial data

4.1 Scientific framework

In response to the policy questions, researchers developed a conceptual model highlighting where science can provide data, and management can influence outcomes, relating to climate change influences on ecosystem composition, and this became a context for specific data gathering and analysis (Fig. 4). Predicting the species composition of an ecosystem under climate change based on the responses of individual species is fraught with complexity (Shipley *et al.* 2006). One way to reduce complexity is to start with shifts in higher-level community constraints, such as potential biomass or functional properties, which are to some degree determined by the environment, and from this, determine the likely species composition (Shipley *et al.* 2006; Guerin *et al.* 2014a). The contributions of intrinsic (e.g. changes in species relative abundances in situ) versus extrinsic responses (e.g. changes in species composition) to a shifting community constraint determine the resilience of the community, and hence the magnitude of expected changes. Therefore, data on potential ecosystem responses inform decision-making to enhance resilience and adaptation. For example, intrinsic resilience is dependent upon maintenance of genetic variation within populations – a function of population size, historical factors (e.g. refugia during historical periods of climate flux) and the potential for gene flow between populations (Guerin *et al.* 2014a). Adaptive potential can be enhanced via landscape planning and appropriate seed selection for restoration (Breed *et al.* 2013). Adaptive potential also relates to concepts of ecological resilience that describe a system's capacity to be placed under stress, but still essentially retain its fundamental structure and function (Walker and Salt 2006, 2012)

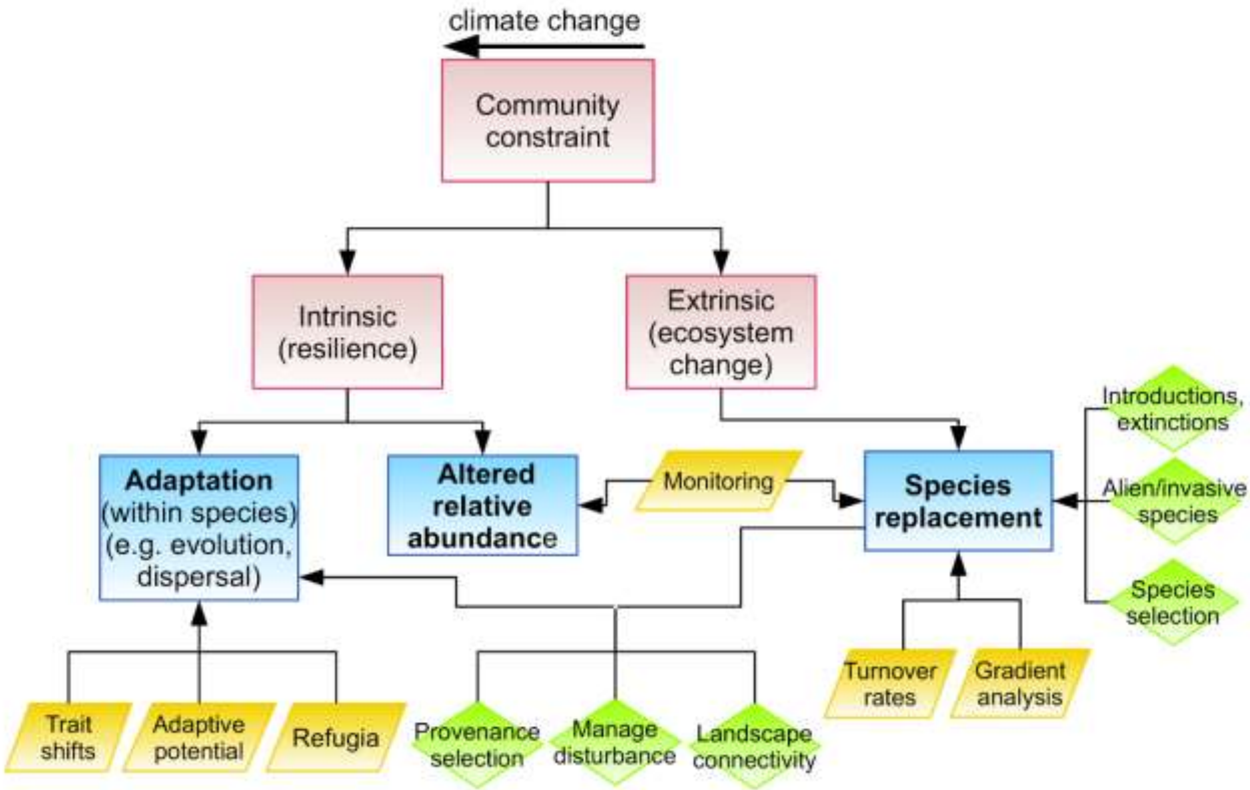

Fig. 4 The conceptual scientific framework for ecosystem adaptation to climate change that was developed as context for specific TREND research projects:
Where yellow boxes represent scientific information and green boxes management actions. An ecological community level constraint (such as functional properties within a patch of vegetation) shifts with climate change (top red box), driving changes at lower levels of organisation. The community level response can be intrinsic or extrinsic (blue boxes). Intrinsic resilience can include changes within species (e.g. evolution-adaptation, phenotypic plasticity) and changes in relative abundance, to match the new constraint. Resilience levels can be informed by studies identifying refugia and species adaptive potential (e.g. landscape genetics). Resilience can be manipulated in restoration via provenance selection and management of landscapes. Extrinsic responses involve changes in species composition. Gradient analysis can inform rates of species replacement across heterogeneous landscapes. Restoration can pre-empt species replacement via species selection and management of alien species. Managing at community level avoids the complexity of predicting responses among diverse species. However, information on individual species sensitivity and adaptive capacity is useful for understanding vulnerability

4.2 Generate initial data

In conjunction with the development of conceptual approaches, researchers accessed existing relevant ecological and environmental datasets. These included opportunistic records of target species, data from vegetation survey plots established for the Biological Survey of South Australia in the vicinity of the transect, herbarium collections from the transect and environmental data such as climate surfaces. Researchers subsequently conducted pilot field studies such as methodological trials and baseline survey at monitoring locations and population-based sampling of species along the transect, for various functional and genetic analyses. With these data, researchers developed approaches for desktop analysis that were informative of ecosystem resilience, including modelling the climatic distribution of individual species and changes between plant communities sampled at different points along climate gradients.

5 Review approach

Once researchers had implemented the first phase of fieldwork and desktop analysis, they presented early results and conclusions, plus an outline of planned approaches, to a follow-up workshop with a large gathering of scientific and policy officers, mainly from DEWNR. The session included discussion of results and their relevance to the policy questions and was an opportunity for a face-to-face question and answer session on the technical detail, but also for policy officers to give feedback and direct future work, advice which was subsequently incorporated into work programs.

6 Major research phase

With initial results and practical feedback from the formative review in hand (Section 5), researchers reviewed scientific approaches. A range of individual analyses were then completed and published in the scientific literature, ensuring that the evidence base intended to inform practical management outcomes had gone through peer review and was therefore more likely to be perceived as credible. Individual studies focused on areas such as vegetation monitoring methods, spatial modelling of existing plot-based data, exploratory analysis of empirical data from new field plots, analysis of historical herbarium collections and population genetics. Relevant literature on the region generated externally to TREND was also reviewed (e.g. Crossman *et al.* 2012).

At the core of the major research phase was the establishment of a field-based ecosystem transect over a distance of ~750 km, including 120 plots (Guerin and Lowe 2013c; Guerin *et al.* 2014b; Keith *et al.* 2014), covering strong latitudinal and altitudinal gradients in temperature and rainfall and a range of vegetation types. The field transect allowed for spatial analysis of abiotic drivers of community composition, while establishing a monitoring baseline (Guerin *et al.* 2014b).

Ecological climate sensitivity was determined through analyses of new and existing data, such as correlative species distribution modelling (supplemented in some cases with population genetic data) and modelling of community composition with respect to environmental and geographic differences (e.g. Guerin and Lowe 2013a; Guerin *et al.* 2013; Guerin *et al.* 2014b; McCallum *et al.* 2014). The recurrent conclusion from these studies was that climate is a significant driver of species occurrences and ecological community composition. However, these studies found ecological changes with climate are not uniform across the landscape: while suitable habitat for many species was predicted to persist with modest climate change in the Mount Lofty Ranges, south, and upwards shifts of suitable habitat may generate sharper species turnover in the Flinders Ranges.

In parallel to studies on variation in the species composition of ecosystems, researchers conducted studies on individual species along the transect, and detected significant associations between ecologically relevant traits and spatial and temporal changes in climate. For example, leaf width has ecophysiological significance because narrower leaves better tolerate heat in arid climates (Yates *et al.* 2010), and leaves were found to be narrower in populations of Dodonaea viscosa subsp. angustissima (DC.) J.G.West at warmer locations (more northern latitudes) but also to have become narrower over time, based on herbarium samples spanning a century, consistent with a physiologically relevant response to climate change (Guerin *et al.* 2012, but see also Duncan 2013 and Guerin and Lowe 2013b). Orchids of the genus Diuris Sm. were found to have flowered significantly earlier in spring since around 1972, in association with El Niño events and a strong warming trend, based on herbarium records (MacGillivray *et al.* 2010).

These and other individual peer-reviewed research projects became the scientific basis for answering the policy questions (Box 1; Section 7).

7 Primary policy translation phase

7.1 Overview and synthesis

Individual research projects were completed and published in the primary scientific literature. Specific results were disseminated to attendees of the previous workshops and a wider range of policy officers and conservation practitioners in the form of discussions, presentations, reports and journal articles. While specific studies initially focused on the transect, some have been extended statewide or have wider relevance, at least for the southern agricultural regions of South Australia. This is important, as relatively little has been reported on ecosystem sensitivity to climate across the state. Data from outside TREND were also considered during the translation phase, such as a study of the exposure of plant species in South Australia's Murray–Darling Basin (immediately east of the TREND transect) to climate change (Summers *et al.* 2012). Broad assessments of spatial conservation priorities are useful because data on the adaptive capacity of individual species are sparse and translation seeks to inform conservation planning across regions and ecosystems.

An example of the relevance of the science to conservation planning is that ecosystems in the transitional zone between mesic and arid biomes were found to be climate-sensitive (rapid changes with respect to prevailing temperatures, for example), whereas landscapes that are less fragmented, and contain refugia (or heterogeneous habitats), such as mountain ranges, are likely to be relatively resilient. The translation of this knowledge for policy is that landscape planning must balance attempts to increase adaptive capacity and resilience with predictive provenancing and species selection in climate-sensitive ecosystems (Breed *et al*. 2013). For example, in the absence of specific data on climate sensitivity and genetic diversity, it could be assumed that species with small, isolated populations, or with restricted climatic ranges, will be at greater risk than phenotypically variable and widespread species (McCallum *et al.* 2014; Christmas *et al*. 2015). In general, research provides guidance for the practical interpretation of climate responses of biodiversity, by highlighting the importance of combining current knowledge about resilience (or adaptive capacity) with data on climate exposure (Prober *et al.* 2012; Gillson *et al.* 2013).

7.2 Relevance to policy questions

Following dissemination of research results, studies were synthesised to provide answers to the policy questions. For illustrative purposes, we provide brief summaries of these answers below, based on research data and general principles developed within TREND and wider supporting literature.

1. **What drives species composition and how will this be affected by climate change?**

Composition is determined by a complex set of factors, including history, niche conservatism, abiotic environments, species interactions, disturbance regimes and ecological drift (Guerin *et al.* 2014a). Climate is a fundamental abiotic driver, determining biome boundaries and how species are sorted across landscapes, although history, chance, landscape change and increasing concentrations of atmospheric CO2, among others, remain important (Guerin *et al.* 2014a). Climate change is expected to drive changes in composition by directly influencing species potential distributions, altering fire regimes and compounding landscape change. Management responses need to focus on different levels of biological organisation and on ecological processes that drive change.

– **What species or ecosystems could provide early indicators of stress?**

Early ecosystem indicators include phenotypic responses, such as in flowering phenology. Early signs of stress, such as decreased population size, biomass or reproductive output, would be expected in populations of vulnerable species (defined based on climate sensitivity or resilience in terms of population demography) in ecotones. The earliest changes detectable at community level will be in species relative abundance, as species replacement involves longer time lags (Davis 1986; Svenning and Sandel 2013).

- **What species and ecological communities are most and least at risk from climate change, and what are the expected impacts?**

Species least at risk have wide climatic tolerances or high adaptive capacity or phenotypic plasticity (Guerin *et al.* 2012). Communities least at risk are those within their limit of intrinsic resilience, given their climate sensitivity. Species most at risk have small, isolated populations, narrow climatic preferences or low adaptive capacity (McCallum *et al.* 2014). Communities most at risk are those within ecotones or with poor resilience relative to their sensitivity, due to landscape modification (Guerin *et al.* 2013). Within the study region, ecosystems in the central Mount Lofty Ranges are the most stable with spatial changes in climate, but have undergone significant habitat fragmentation, reducing their resilience. Policy makers need to decide how to respond to early warning signs of stress, and to evidence of risk. For example, decisions need to be made about continued investment of management effort into the most vulnerable species and communities.

- **How will climate change interact with other disturbance to influence ecosystem attributes?**

Historical disturbance in the study region includes habitat clearance, which has resulted in just 13% of pre-European (1836) vegetation remaining in the Mount Lofty Ranges (Armstrong *et al.* 2003). Habitat fragmentation promotes inbreeding (Breed *et al.* 2012) and restricts dispersal (McConkey *et al.* 2012), which together inhibit adaptation to climate change (Fig. 4; Christmas *et al*. 2015) and may push populations under stress due to historical change further towards collapse. On-going disturbance (i.e. periodic destruction of biomass via fire, grazing) has complex synergies with climate (de Bello 2005), while multiple threats from habitat fragmentation, altered disturbance regimes and climate change decrease the likelihood of persistence of range-restricted species (Lawson *et al.* 2010). Climate change is increasing the frequency and severity of fires (Mouillot *et al.* 2002), which opens up resources such as space for native and alien colonisers and, in conjunction with other aspects of global change, modifies vegetation composition, which itself affects fuel dynamics (Thomson and Leishman 2005; Cary *et al.* 2012; Guerin *et al.* 2014a). Fire management can be controversial due to conflicting management objectives and the need to minimise the impacts of unplanned fires on human lives and built assets (Gill *et al.* 2013). The challenges for fire management are particularly acute in peri-urban settings such as the Adelaide–Mt Lofty Ranges, but also at the rural–wildland interface (Gill and Stephens 2009). Key challenges remain around how to manage fire to achieve conservation objectives under changing climate in historically altered landscapes.

2. **What adaptation strategies could improve the resilience of key species and communities?**

The sensitivity and resilience of ecosystems to climate change varies. For individual species, concerns for promoting resilience include maintaining population sizes and genetic diversity (Sgrò *et al.* 2011; Christmas *et al.* 2015) and the use of quality seed of appropriate provenance in restoration (Breed *et al.* 2013). Community level resilience can be supported through landscape restoration to improve habitat area and connectivity between isolated remnants (Christmas *et al*. 2015). Restored ecosystems in ecotones may be more resilient if species adapted to warming conditions are used, rather than strictly historical composition (Guerin *et al.* 2013). This suggests that NRM managers need to experiment with alternative designs for habitat restoration using an adaptive management approach (Sabine *et al.* 2004).

- **What shifts in distribution, species composition and ecological characteristics can we expect?**

Widespread species are expected to contract south and/or to higher altitude. Distribution shifts are predicted to be more pronounced in the Flinders Ranges and other parts of South Australia's Mediterranean–desert biome ecotone due to higher climate sensitivity (Guerin and Lowe 2013a; Guerin *et al.* 2013). In the Mediterranean–desert ecotone, there is expected to be pressure towards a major ecological shift from e.g. sclerophyllous woodland vegetation to more open vegetation dominated by arid-zone taxa. An unknown factor is the degree to which these shifts can occur without management interventions such as corridor creation and assisted translocations.

– **What are the implications for conservation planning and landscape design?**

Landscape connectivity can promote gene flow and maintenance of metapopulations (Sgrò *et al.* 2011; Christmas *et al*. 2015). Species and seed sources for restoration can be selected to enhance adaptive capacity or pre-empt which genotypes and species will prosper (Breed *et al.* 2013; Guerin *et al.* 2013). In areas likely to undergo species turnover, selection of species for habitat restoration could include a higher proportion of provenances or even species from warmer habitats, whereas refugia could be restored using historical composition (Guerin *et al.* 2013). Strict adherence to historical composition in conservation objectives is likely to be counter-productive. However, we recognise that the issue of whether to implement restoration of novel ecosystems in the face of climate change remains a subject of debate in the literature and that there are unknowns about practical application (Hobbs and Suding 2009;).

8 Program review

The first cycle of TREND was completed in terms of finalising studies and acquitting funding. Participants considered how the research had addressed policy and research gaps and a range of associated research projects were initiated that would be further informative of ecological resilience and the functional consequences of climate change. For example, it was identified that basic information on the spatial location of biodiversity (e.g. in terms of levels of species diversity and endemism) within South Australia could be overlayed with climate sensitivity and habitat fragmentation data to provide an insightful resource relevant to landscape planning. Consequently, a research project has been initiated that seeks to answer basic questions such as: What kind of biodiversity does South Australia have, where is it, and how does it interact with areas of high climate sensitivity and landscape modification?

There is an emerging opportunity for uptake of research, with recent Australian Government investment in improving the climate change content of NRM plans, which places emphasis on identifying spatially explicit targets for investment in adaptation actions. This highlights the multi-layered nature of policy: a range of climate change NRM adaptation actions are not delivered by high-level strategic policy, but by operational policies embedded in planning documents, such as regional NRM plans, which take the extra step of developing practical approaches following the synthesis and interpretation of data.

9 Assessment of model implementation

The aim of this report was to assess the usefulness of our model (Fig. 3) in bridging the gap between ecological research and policy in the context of climate change. The envisaged framework for the TREND project (Fig. 1) was successfully implemented in terms of the flow of information, and NRM practitioners are starting to take up this information within practical programs. The project successfully established these partnerships and generated policy-relevant data on climate sensitivity. In addition, these partnerships facilitated the effective leveraging of additional research and scientific infrastructure funding (more than 10x the original project costs for TREND), and produced excellent quality scientific knowledge and research results (over 25 peer reviewed papers). The project has also formed the blueprint for a national climate change ecosystem monitoring network, the Australian Transect Network, part of the Terrestrial Ecosystem Research Network (http://www.tern.org.au).

The process highlighted research gaps as a foundation for developing evidence-based policy, which could otherwise remain generic. One of the biggest challenges for land managers is to determine where to take action, and TREND provided spatial analysis to highlight vulnerable systems and pointed land managers towards options for building landscape resilience. In fact an independent review of all science outputs relevant to climate change ecosystem resilience planning for South Australia, undertaken by the Adelaide and Mount Lofty Ranges region Natural Resources Management Board in 2015, found that the TREND project outputs used the best data, appropriate scientific methods and presented information at an understandable and relevant scale to make policy and management relevant decisions.

Importantly, two-way dialogue between researchers and decision-makers – a key aspect of the model – is on-going, allowing new research to feed policy development and changing policy priorities to inform the research agenda. Individual research projects can form part of the evidence base for sustainability, but one-way communication from researchers to government on perceived important questions may not lead to the best practical outcomes (Cash *et al.* 2003). For this reason, while the research component of TREND produced peer-review publications on the climate sensitivity of local ecosystems, it is useful to consider which factors influence the integration of specific research findings with policy objectives. A summary of such an analysis is given in Table 1.

Table 1. Examples of factors that influence the success of the science–policy integration model (see Fig. 3), with example outcomes from the TREND project

Project phase (Fig. 3)	Factor	Possible response	Actual TREND outcome
Determine policy drivers	Scale of policy needs compared to individual research projects	Researchers up front about limitations of what can realistically be achieved, and set research priorities	Set of precise and answerable policy questions developed
Determine policy drivers	Limitations of funded research scope and researcher expertise	Relevant match between research options (e.g. scope of funding and area of expertise) and policy recipients	Initial research scope limited to plant community composition along a pre-defined transect
Determine policy drivers	Breadth of developed policy relevant questions	Develop questions collaboratively with practical objectives to ensure breadth is neither too general, nor trivial	Developed questions were broad enough to be useful for policy but detailed enough to seed research projects
Develop scientific framework	Short-term research funding cycles	Focus on spatial analysis, historical data and establishing ecological baselines	Took advantage of retrospective data for temporal analysis and focused on modelling spatial climate change proxies
Major research phase	Scientific credibility of research findings	Research published in peer-reviewed journals and explained to decision-makers	A number of journal articles resulted from TREND, providing a sound basis for supporting policy change
Primary policy translation phase	Informing landscape-scale planning via research projects on specific species or sites	Develop general principles from specific research projects and wider literature. Implement research at a range of scales, e.g. population to region	TREND research framed within a model of climate change ecology based on literature and filled-in with local empirical data. Results synthesised and placed in context of wider literature
Primary policy translation phase	Integrating specific science into practical management regimes	Treat as iterative process. More realistic if earlier phases provided realistic policy questions and directed research towards applicable outcomes	On-going process via NRM planning. Other avenues being explored include trials of predictive species composition and provenancing for restoration
Program review	Availability of funding to address further policy needs identified	Use track record of practical science–policy links plus established ecological monitoring infrastructure as a platform	TREND was extended through a range of additional funding sources to build on initial gains

Limitations to the success of science–policy translation were evident. For example, the goals of the project had pre-defined boundaries, and the time and resources available were modest, leaving unanswered questions. Some relevant components of research will develop over a longer timeframe than the initial three-year funding cycle, requiring a long-term commitment to the partnership for these data to be integrated into policy. While information flow between TREND partners was useful, implementing a specific research project within a practical planning framework remains complex. Challenges remain in making primary scientific research truly policy relevant, i.e. exchanging and interpreting results in a useful format. For example, while scientific papers are useful for a technically knowledgeable audience, we also found that less formal reports with information presented spatially was accessible to a wider policy audience. The individual research studies – and ecology generally – tend to focus on specific components of ecosystem function, whereas managers need to make decisions across entire landscapes (McConkey *et al.* 2012) and to consider regional and local processes (Paton *et al.* 2010), which requires synthesis. In addition managers and scientists increasingly need to understand the limitations of the scientific data in the context of the social and economic systems within which they work, particularly the highly complex, and sometime conflicting priority, environment of natural resource management.

While no model is perfect, or simple to implement in the real world, the TREND model provided real potential for on-going research to be directed towards specific policy needs and opened up direct communication between researchers and policy makers. There are, of course, inherent limitations to the policy questions that science can credibly answer (Cash *et al.* 2003; especially on a short-term basis) and to the potential for science to become directly useful for conservation planning and on-ground implementation.

10 Conclusions

We have proposed a practical model for climate change science–policy integration, populated with real world examples from a transect through terrestrial ecosystems from the TREND project in South Australia. TREND was successful in its stated goals of: 1) establishing baseline monitoring transects to assess the influence of climate on ecosystem composition and; 2) collecting policy-relevant data on climate change ecology specific to the region. The process was centred on research but brought researchers, policy makers and natural resource managers into a collaborative environment. We conclude that the model contributed to bridging the gap between research and policy in that two-way dialogue guided research and provided NRM practitioners with guiding principles, based on local examples, and spatial information on climate sensitivity. Limitations of the process included practical constraints on what could be achieved and the on-going challenge of translating specific science into on-ground action. NRM planners now have some basic local information on the some likely impacts of climate change and their spatial and taxonomic idiosyncrasies.

The inherent difficulties in implementing evidence-based biodiversity management under climate change have been discussed at length (Jones *et al.* 1999; Moser and Luers 2008; Bardsley and Sweeney 2010; Stein *et al.* 2013). Climate change in coming decades is considered inevitable, regardless of action taken to limit greenhouse emissions (Stein *et al.* 2013) and therefore adaptation is required, because climate change, combined with impacts such as habitat fragmentation and invasive species, may exceed ecosystem resilience (Grimm *et al.* 2013; Stein *et al.* 2013). These changes may cross the threshold between ecosystems persisting in their present-day form, or entering transitional states (Grimm *et al.* 2013; Guerin *et al.* 2013; Stein *et al.* 2013), in fact, ecosystem shifts linked to climate change have already been documented (Peñuelas and Boada 2003; Grimm *et al.* 2013).

Adapting biodiversity management to climate change could involve promoting resilience to protect important biodiversity, or actively promoting change to enhance adaptation (Stein *et al.* 2013). The broadest policy-relevant conclusion of climate change ecology is that ecosystems are dynamic so that changes in climate will likely be reflected in changes to ecosystem composition and function. This suggests attempting to maintain ecosystem fidelity to historical states as a default may be unrealistic and counter-productive (Harris *et al.* 2006; Guerin *et al.* 2013; Stein *et al.* 2013). Policy makers can take advantage of insights from research if there is a long-term commitment to fostering and maintaining the type of partnership demonstrated by the TREND project.

Bridging the gap between scientific research and NRM decision-making continues to pose a challenge for the application of evidence in natural resource management, and remains a barrier to the effective application of scientific evidence in decision making. Here we have presented a case study of how scientific questions regarding climate change were designed by bringing together scientists and policymakers. Since this work was undertaken, DEWNR has been working with research organisations to actively develop mechanisms to improve the relationship between science generation and NRM decision making. The NRM Research and Innovation Network (www.nrmrain.org.au), a partnership between the three South Australian universities, SA Water, the regional NRM Boards, PIRSA and DEWNR, has been specifically designed to address the challenge of bridging the science-policy interface. The Network facilitates genuine collaborative partnerships between researchers and research institutions, and NRM policymakers and practitioners, such that scientific questions are designed and implemented in a way that the information can be most effectively applied to natural resource management issues. More broadly, DEWNR is increasingly placing emphasis on the importance of science translation into policy, and the need to actively engage with the research sector to achieve this.

11 Glossary

Abiotic driver — Non-biological/ecological factor that influences ecosystem function, such as landscape properties and climate

Adaptive management — A management approach often used in natural resource management where there is little information and/or a lot of complexity, and there is a need to implement some management changes sooner rather than later. The approach is to use the best available information for the first actions, implement the changes, monitor the outcomes, investigate the assumptions, and regularly evaluate and review the actions required. Consideration must be given to the temporal and spatial scale of monitoring and the evaluation processes appropriate to the ecosystem being managed.

Biodiversity — (1) The number and variety of organisms found within a specified geographic region. (2) The variability among living organisms on the earth, including the variability within and between species and within and between ecosystems

Biome — Major ecological regions defined by their climatic and ecological properties

Composition — The make-up of ecological communities, particularly the species that are present

Demography — The nature/make-up of populations of species

DEWNR — Department of Environment, Water and Natural Resources (Government of South Australia)

Ecological community — The set of species, generally within a particular taxonomic or trophic group (such as plants) that occur together within a habitat location

Ecological processes — All biological, physical or chemical processes that maintain an ecosystem

Ecology — The study of the relationships between living organisms and their environment

Ecosystem — Any system in which there is an interdependence upon, and interaction between, living organisms and their immediate physical, chemical and biological environment

Ecosystem services — All biological, physical or chemical processes that maintain ecosystems and biodiversity and provide inputs and waste treatment services that support human activities

Ecotone — A boundary between different ecological regions or habitats

Endemism — The restriction of species to a certain locality or region

Habitat fragmentation — Loss of habitat resulting in smaller, more isolated remnants

Metapopulation — A set of populations that interact with each other

Phenology — The timing of biological events such as flowering in plants

Phenotypic — Relating to species morphology/traits or observable characteristics

Phenotypic plasticity — Short-term phenotypic changes, for example in response to environmental conditions

Provenance — The region of origin, for example of seed

Relative abundance — The number of individuals or amount of biomass of species in a habitat in relation to other species

Species replacement — Ecological change involving the loss of some species from an ecological community and the appearance of additional species

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